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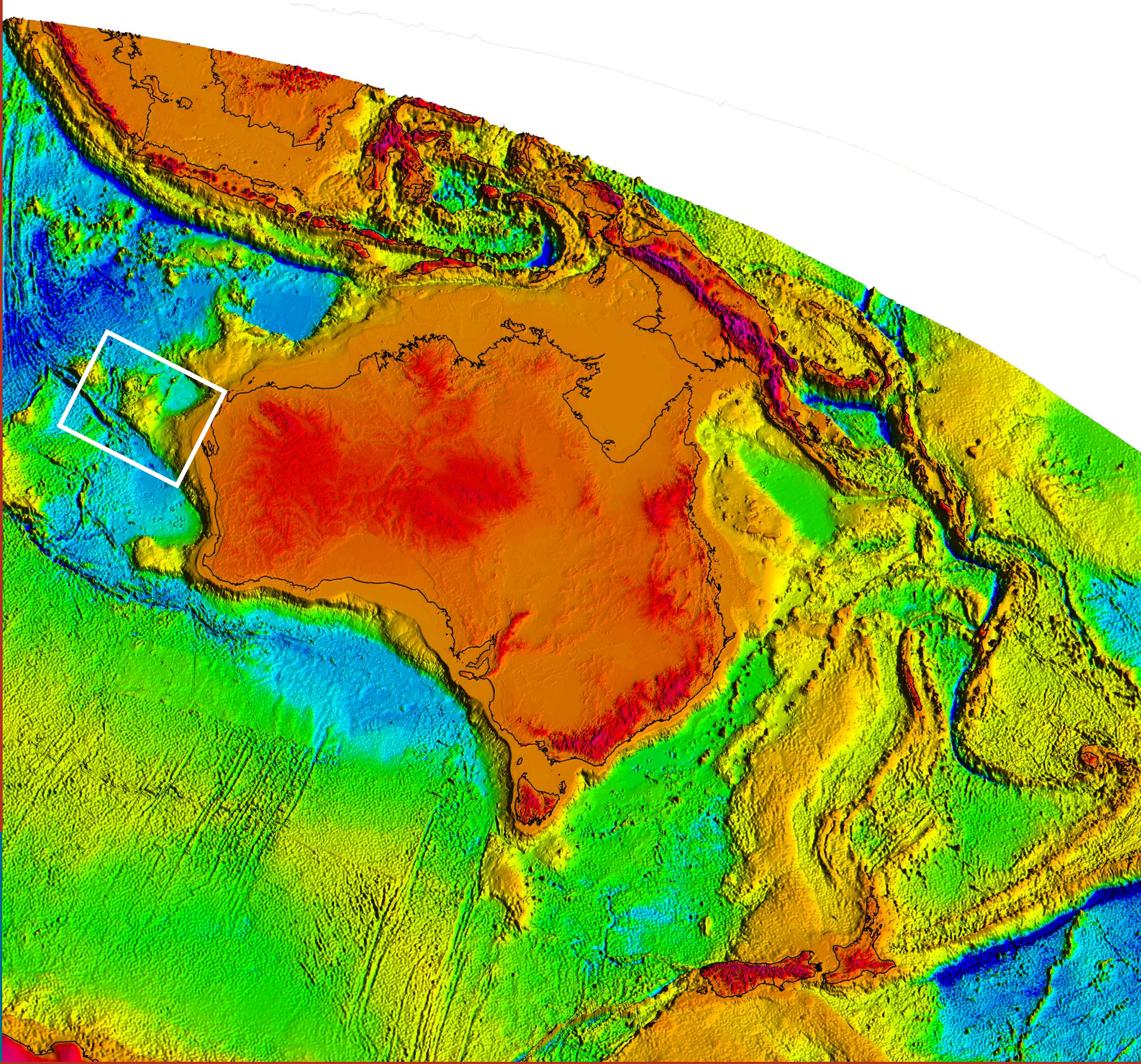

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GEOLOGICAL FRAMEWORK OF THE WALLABY PLATEAU AND ADJACENT AREAS

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The data, and the interpretations based on that data, contained in this report are not necessarily indicative or representative of the final information that might be used by Australia to support the location of the outer limit of the continental shelf beyond 200 nautical miles.

EXECUTIVE SUMMARY

The study which led to this report formed part of Geoscience Australia's Law of the Sea Project. The aims of the study were to provide an assessment of the geological framework of the Wallaby Plateau and adjacent areas, and so assist with the definition of the outer limit of Australia's continental shelf under the terms of the 1982 United Nations Convention of the Law of the Sea.

This study is the most comprehensive geo-scientific review to date of the Wallaby Plateau region. Approximately 13 000 km of seismic data were interpreted as part of the study resulting in a map detailing the volcano-tectonic provinces and features of the area. The study also utilised satellite gravity, ship-derived bathymetric data and satellite-derived predicted bathymetry, as well as geological data obtained from sparse scientific drilling, dredging and coring.

The main physiographic features of the study area are: (1) the Wallaby Plateau, previously described as an oceanic plateau, but of uncertain nature and origin; (2) the Cuvier Abyssal Plain; (3) the Wallaby Saddle, underlain by seaward dipping reflector sequences; (4) the Quokka Rise, a volcanic feature north of the Wallaby Plateau; (5) two transform-fault zones (i.e. Wallaby-Zenith Fracture zone & Cape Range Fracture Zone) that have associated volcanic ridges and build-ups; (6) the Zenith Seamount of volcanogenic origin located adjacent to the Wallaby-Zenith Fracture Zone; (7) the Sonne and Sonja Ridges formed during sea-floor spreading; and (8) the western Australian margin.

The nature and origin of the Wallaby Plateau will probably remain somewhat speculative until proven up from drilling. However, results from this study support the view that a core of extended continental crust underlies the plateau. Evidence for this conclusion comes mainly from crustal layering observed on seismic data, as well as seismic reflection configurations that have look-a-likes with, for example, the Mesozoic section of the adjacent Houtman Sub-basin. The existence of oceanic ridge jumps within the Wallaby-Cuvier area is based on interpreted magnetic lineations and provides a mechanism by which continental fragments under the Wallaby Plateau may have been left stranded, in an otherwise oceanic setting. The presence of a continental core underlying the Wallaby Plateau would imply that it formed part of the western Australian margin extensional terrane, prior to break-up in the Valanginian.

Petroleum prospectivity of the study area is limited to isolated depocentres in the Exmouth, Gascoyne and Houtman Sub-basins, all located on the continental shelf. A localised trough forming part of the northern Houtman Sub-basin may contain up to 5 km of preserved Triassic–Jurassic sediments. The trough lies in water depths ranging from 800–1200 m and is on trend with the northern Perth Basin where hydrocarbons are known to exist. Petroleum discoveries also exist in the Exmouth Sub-basin to the north. Polymetallic manganese nodules and crusts have been dredged in the study area, although they are unlikely to be of any economic interest in the foreseeable future.

1. INTRODUCTION

The 1982 United Nations Convention on the Law of the Sea (UNCLOS, United Nations, 1983) defines a nation's legal seabed and subsoil jurisdiction as extending throughout its Continental Shelf (Appendix 1). Where the continental margin of a nation extends beyond 200 nautical miles, the outer limit of the "legal" Continental Shelf[1] is defined by a series of rules contained within Article 76 of UNCLOS. The rules require definition of the foot of the continental slope, knowledge of sediment thickness and good bathymetric information defining the 2500 m bathymetric contour. In areas of complex bathymetry, geological considerations, such as structure and crustal characteristics, may be used to support the definition of the outer limit.

The Wallaby Plateau, together with the Exmouth Plateau to the north, form one of nine areas around Australia and its island territories, that could be claimed under the terms of UNCLOS as areas of extended Continental Shelf; one of several such areas that lie off Australia's western margin (Fig. 1). The total area of extended Continental Shelf in the Wallaby/Exmouth Plateau region has been estimated at 550,000 km^2 (Symonds & Willcox, 1989; Symonds et al., 1998).

The continental margin of Western Australia includes broad plateaus and terraces that are either: (i) underlain by extended continental crust, such as the Exmouth Plateau, or (ii) have a likely composite continental/magmatic origin, such as the Scott and Naturaliste Plateaus, and probably the Wallaby Plateau. It is these features that form the bulk of the extensions to Australia's Continental Shelf in this region.

As well as collecting, analysing and preparing data to support the submission that Australia will make to the UN Commission on the Limits of the Continental Shelf, Geoscience Australia's Law of the Sea Project has undertaken a geological framework study of each area of potential "extended" Continental Shelf. In this report, we present the results of the geological framework study of the Wallaby Plateau and adjacent areas of margin and ocean basin (Fig. 2). This reports complements a study of the Exmouth Plateau and adjacent ocean basins which was conducted in parallel with this study by Stagg *et al*. (2003).

The western Australia margin (Fig. 2) has been formed over a period of more than 400 million years, as a result of multiple rifting and basin-forming events that culminated in margin break-up (Hocking *et al*. 1994). The break-up propagated south in an anti-clockwise direction starting at ~156 Ma in the Argo Abyssal Plain, ~136 Ma in the Gascoyne and Cuvier Abyssal Plains, and ~131 Ma in the Perth Abyssal Plain (Müller *et al*., 1998). The break-up was

1 The "legal" Continental Shelf (LCS), defined by a complex series of rules or formulae, is quite distinct from the geomorphic continental shelf as understood by a marine scientist. The LCS includes the geomorphic continental shelf, the continental slope, marginal plateaus and sometimes the continental rise and the inboard edge of deep ocean basins.

associated with voluminous transient volcanism that modified the physiography of the margin (Planke *et al*., 1996; Symonds *et al*., 1996; Symonds *et al*., 1998). Ultimately, the locus of initiation of normal sea-floor spreading and interpretation of volcano-tectonic provinces and features define the position of the continent/volcanic margin-ocean boundary (Plate 1 and Fig. 9).

Analysis of recent multichannel seismic data, collected for the Law of the Sea Project, in combination with a reassessment of older seismic data have produced an improved understanding of the tectono-magmatic evolution of the area. Until now, the Wallaby Plateau has not been studied in great detail because of its relative remoteness and the general perception that the feature is non-prospective for petroleum.

In addition to examining the tectono-magmatic evolution of the region, this report also provides information on datasets, regional setting, stratigraphy and resource potential. The chapters on seismic interpretation and mapping of provinces and features form the core of the study, and provide the basis for much of the discussion chapter. In particular, the nature and origin of the Wallaby Plateau and adjacent ocean basins form a major component of this discussion.

2. DATASETS

2.1 Introduction

The scientific assessments which form the basis of this report have been made using a wide range of geophysical and geological datasets, including: (1) seismic reflection data; (2) ship-derived bathymetry; (3) satellite–derived predicted bathymetry; (4) satellite-derived Free-Air Anomaly gravity data; (5) data acquired from scientific and petroleum exploration drilling; (6) magnetic anomaly data; and (7) core and dredge samples. Much of the raw data has been included in the appendices, figures and plates of this report.

2.2 Study Area

The Wallaby Plateau study area is bounded by latitudes 19° and 29°S and longitudes 104° and 114°E, and is centred between the Cape Range Fracture Zone, Wallaby-Zenith Fracture Zone, and by the western Australian margin (Figs 2, 3 and 4). The main physiographic features within the study area include: (1) the Wallaby Plateau; (2) Cuvier Abyssal Plain; (3) Wallaby-Zenith Fracture Zone; (4) Cape Range Fracture Zone; (5) Zenith Seamount; (6) Wallaby Saddle; and (7) the continental margin east (Carnarvon Terrace) and north (Exmouth Plateau) of the Cuvier Abyssal Plain (Fig. 3). The Zenith Seamount is not discussed at length in this report as no seismic data exists over the feature. Secondary physiographic features within the study area include: (1) the Quokka Rise; (2) Sonne and Sonja Ridges, and physiographic features of the shelf (i.e. Carnarvon Terrace, Bernier Platform).

Water depth varies from approximately 2100 m at the crest of the Wallaby Plateau to about 4000 m at the base of the bounding slopes, with an areal extent of ~70,000 km² within the 4000 m isobath. Veevers *et al*. (1985b) subdivided the Wallaby Plateau into two features: a northwestern high referred to as 'Quokka Rise', and a larger southeastern high, referred to as 'Wallaby Plateau'. In this report we use the term Wallaby Plateau when referring to the southeastern high (Fig. 3). We will also use 'Wallaby-Cuvier area' when referring to an area that includes the Wallaby Plateau and Cuvier Abyssal Plain.

2.3 Bathymetric Data

Bathymetric data have been routinely acquired on all research cruises and surveys in the Wallaby–Cuvier area; the density of coverage ranges from high on the shelf, to moderate on the crest and margins of the plateau, to sparse on the Cuvier and Perth Abyssal Plains. Bathymetric data presented in this report have been integrated from all available sources: conventional ship bathymetry profiling, multi-beam swath mapping, and satellite predicted bathymetry where ship-board data are effectively non-existent. The data set used is an early version of the gridded bathymetric data set of Petkovic & Buchanan (2002).

In this data set, data were re-gridded from a 30 arc-sec gridded bathymetric model (Personal communication – C. Buchanan) and the predicted bathymetry (Smith & Sandwell, 1994; Smith et al., 1997). The 30 arc-sec gridded bathymetric model is based on all available ship-track data, whereas the predicted bathymetry has been derived from satellite gravity data (see also section '2.6 Potential Field Data'). The satellite gravity field accurately reflects sea-floor topography in the 15–160 km wavelength band, except for areas with large sediment thickness. Large-scale bathymetric features are generally isostatically compensated and are not correlated with the gravity field. Sandwell & Smith (1997) developed an algorithm to predict water depth from the satellite gravity, and ground-truthed their model with the ship-track data. The predicted bathymetry does not have sufficient accuracy or resolution to be used for navigational purposes, but can be helpful in studies of remote areas, where bathymetric charts derived from ship tracks lack detail. In the gridded data set, areas without real gridded data were filled with predicted bathymetry. The resulting bathymetry is represented by the background image in Figure 4 and by the 3D perspective view displayed in Figure 5.

Isobaths superimposed on backdrop images in Figures 4, 6, 8 and 9, and Plate 2, originate from a digital version of the General Bathymetric Chart of the Oceans (GEBCO) (Jones *et al.*, 1997), and from Geoscience Australia's Offshore Resource Map Series (ORMS). 'ORMS' is a set of bathymetric maps covering the western and southern parts of the Australian margin, and depicts sea-floor morphology at a 100 m interval and at a scale of 1:1,000,000. 'ORMS' maps were compiled predominantly for the shallower areas of the margin and, thus, do not cover the full extent of the study area (i.e. 19–29 °S; 104–114 °E). GEBCO contours were used in the deeper water areas of the study area and were merged with the shallower water 'ORMS' contours.

2.4 Seismic Reflection Data

AGSO Survey 135, Shell *'Petrel'* roving reconnaissance survey (N), BMR Surveys 17 and 18 are all located in the Wallaby Plateau study area (Fig. 6 & Plate 1), and are listed below in decreasing order of importance to this study. Details of seismic survey parameters can be found in Appendix 2. 'AGSO' refers to the Australian Geological Survey Organisation and 'BMR' refers to the Bureau of Mineral Resources, both previous names for the organisation now called Geoscience Australia.

- **AGSO Survey 135**, carried out in 1994, included the acquisition of 4243 km of seismic data along 21 lines. These lines cover the Wallaby Plateau, Cuvier Abyssal Plain and SW Exmouth Plateau, and include tie-lines between the Exmouth Plateau and Wallaby Plateau study areas. The data is of good quality and permitted detailed imaging of various features within the study area.

- **Shell-*Petrel* Survey,** carried out in 1971, included seismic lines that zigzag across the continental slope and extend across the Wallaby Plateau, Wallaby Saddle and Cuvier Abyssal Plain. Nopec Inc. reprocessed the survey for Geoscience Australia in 1998, and produced a good quality dataset, in many ways as useful as AGSO Survey 135. As with the AGSO Survey 135 data, the quality of the Shell dataset permitted detailed imaging of volcanostratigraphic features.

- **BMR Surveys 17 & 18**, carried out in 1972, formed part of a major program covering Australia's continental margins. Most lines in the Wallaby Plateau study area cross the continental shelf and slope, with about 70% of lines orientated E–W; 20 % of lines orientated NW–SE, and the remaining 10% are orientated N–S. Seismic data were recorded using a sparker system and are only available in analogue form. The data are of inferior quality compared to that of AGSO Survey 135 and the Shell-*Petrel* survey and were used only to map the major geological features.

Note 1: Seismic lines from AGSO Survey 136 are located on the eastern fringe of the Wallaby Plateau study area (Plate 1). These lines were not interpreted but were used to correlate seismic horizons from wells outside the study area (i.e. south Exmouth Sub-basin and Pendock-1) with seismic lines within the project area. Likewise, lines from AGSO Survey 162 in the far north of the study area (Plate 1) were not interpreted as part of this study.

Note 2: The research vessel 'Maurice Ewing' recorded two seismic reflection lines in the Cuvier Abyssal Plain and outer Exmouth Plateau, as well as acquiring refraction and wide-angle seismic data using ocean bottom seismometers. These data were acquired from October to December 2001 and are yet to be interpreted. The Lamont-Doherty Earth Observatory of the Columbia University operates the 'Maurice-Ewing' and named the cruise EW0113; Geoscience Australia collaborated on this cruise and refers to it as Survey 235. Line locations are shown on Plates 1 and 2, but the profiles were not used in this study.

2.5 Seismic Velocity Data

Seismic velocity data are available from a number of sources including: (1) expanding seismic profiles (Francis & Raitt, 1967; Appendix 5); (2) stacking velocity analyses from AGSO Survey 135; and (3) ocean bottom seismometers deployed by Lamont-Doherty Geological Observatory using the research vessel "Maurice Ewing" in October to December 2001. These data were not used in the present study.

2.6 Potential Field Data

Potential field data are available from two sources:

(1) Gravity and magnetic profiles from ship surveys, for example BMR Surveys 17–18, Shell-*Petrel* survey, and AGSO Survey 135. Profiles of total magnetic intensity provide the dataset that permits magnetic anomalies to be identified from which magnetic lineations are interpreted;

(2) High-resolution satellite gravity datasets such as those of of Sandwell & Smith (1997). In recent years, ship-derived gravity data have largely been

supplanted by high-resolution satellite gravity data, which have assisted in a better understanding of continent margin structure, particularly the interpretation of basement structure; more so in conjunction with seismic data.

Satellite-based gravity data originate from satellites carrying radar altimeters that measure the shape of the ocean surface along tracks 3–4 km apart. Variations in the ocean surface are caused by very small changes in the Earth's gravitational field. For instance, a typical undersea volcano 2000 m high with a radius of about 20 km will produce a 2 m elevation of the ocean surface. The accuracy of modern satellite radar is very high: 10–15 km in horizontal resolution, and 0.03 m in vertical resolution. Data collected by the European Space Agency ERS-1 (Exact Repeat Mission), and recently declassified data from the US Navy Geosat altimeter provide detailed measurements of ocean surface height (Sandwell & Smith, 1997). Continuous profiles of geoid height calculated using multiple satellite passes, collected over many years, can be combined to produce high resolution maps of the marine gravity field. Sandwell & Smith (1992) used a method for converting geoid height measurements into images of gravity anomaly. The authors have also tested the accuracy of this method through comparisons with shipboard gravity measurements, and its values agree with the ship data at a level of 50 $\mu m.s^{-2}$. Gravity datasets produced with this method are now available from the National Geophysical Data Center (NGDC), in the USA.

For this study, the 2-min satellite gravity dataset (Sandwell & Smith, 1992; Smith et al., 1997) was downloaded from the NGDC web site, and processed in ERMapper[2] to produce a gravity image (Fig. 7) that was used to underpin the geological interpretation.

2.7 Geological Sample Data

Geological samples within the Wallaby-Cuvier area include material from scientific drilling and seabed sampling (i.e. dredging and coring). In addition, data from petroleum exploration wells located outside the Wallaby-Cuvier area were used in the present study to provide control for seismic interpretation. Aspects of scientific drilling, seabed sampling and the petroleum exploration wells are discussed below.

Scientific drilling carried out by the Deep Sea Drilling Project (DSDP Site 263) and the Ocean Drilling Program (ODP Site 766) provided stratigraphic information for Cretaceous and Cainozoic sequences at the SW edge of the Exmouth Plateau and in the Cuvier Abyssal Plain, respectively (Fig. 8). Results of the Ocean Drilling Program are summarised in the post-cruise reports of Haq *et al*. (1990) and Haq *et al*. (1992), while results of the Deep Sea Drilling Project are summarised in Gradstein, Ludden *et al*. (1990).

In the past 25 years, a number of seabed samples have been taken in the Wallaby Plateau region by a variety of research institutes and vessels (Fig. 8). These samples range from shallow sediment cores, taken from the seabed to

[2] Vizulisation software by Earth Resource Mapping Inc..

provide the physical property measurements required to compute heat-flow data, to dredges used to identify consolidated sedimentary and volcanic rocks. The latter sample type is of most value to this report and provides essential information that complements the exploration and scientific drilling. The location of seabed sample stations and seabed sample descriptions are summarised in Plate 2 and Appendix 3, respectively.

Petroleum exploration wells Edel-1, Houtman-1 and Wittecarra-1 are located on the outer fringes of the study area, to the south (Plate 1), and were of limited use to this study. Log data and lithology information for Edel-1, Houtman-1 and Wittecarra-1 (Plate 3) are, however, deemed relevant as the wells lie on trend to depocentres of the northern Houtman Sub-basin. Petroleum exploration wells Vinck-1, Resolution-1 and Pendock-1 are located at the very outer fringes of the study area, (Plate 1) and were of only limited use to this study.

3. PREVIOUS WORK

3.1 Western Australian Continental Margin

Our present understanding of the regional geology of the continental margin of Western Australia and the eastern Indian Ocean comes from a number of sources.

- Several papers deal with the break-up history of the margin, based largely on sea-floor spreading magnetic lineations. Some of the key papers are Markl (1974), Larson (1975, 1977), Heirtzler *et al*. (1978), Veevers *et al*. (1985a), Veevers *et al*. (1985b) and Fullerton *et al*. (1989). Recently, Mihut & Müller (1998a,b) and Müller *et al*. (1998) have re-interpreted all the magnetic lineation data available in the region and refined the plate kinematics of the region. Some important revisions to these studies that are critical to the Wallaby-Cuvier area are contained in Brown *et al*. (in press). We discuss the more recent studies in detail later in this report.

- Several papers deal with the western Australian continental margin and its evolution, based largely on seismic reflection profiling and seabed sampling data. Key papers include Willcox & Exon (1976), Symonds & Cameron (1977), Hinz *et al*. (1978), Exon & Willcox (1978, 1980), von Stackelberg *et al*. (1980), Stagg & Exon (1981), Exon *et al*. (1982), von Rad & Exon (1983), Exon, Williamson *et al*. (1988), Mutter *et al*. (1989), Williamson *et al*. (1990), Exon & Ramsay (1990), Colwell, Graham *et al*. (1990), and von Rad *et al*. (1990). A thematic issue of the *AGSO Journal* (Exon, 1994) discusses the geology of the outer North West Shelf in a selection of papers that summarise much of the current state of knowledge of the geology of the region. One of these papers (Colwell *et al*. 1994) deals specifically with the Wallaby Plateau. The most recent papers dealing with the regional geology include those of AGSO North West Shelf Study Group (1994) and Stagg *et al*. (1999). A number of other recent papers examine the volcanic aspects of the evolution of the west Australian margin (Symonds *et al*., 1998; Frey, 1998; Mihut & Müller, 1998b). A recent volume (Veevers 2000) summarises many of the aspects of the history on Gondwanaland which impacted on the evolution of the western Australian continental margin.

- Several papers detail the results of scientific drilling by the Deep Sea Drilling Project (DSDP) and its successor, the Ocean Drilling Program (ODP). Veevers & Heirtzler (1974) describe results of DSDP Leg 27, which drilled holes on the Argo, Gascoyne and Cuvier Abyssal Plains. Gradstein, Ludden *et al*. (1990) and Gradstein, Ludden *et al*. (1992) discuss the proceedings of ODP Leg 123, which drilled ODP Site 766 immediately west of the Exmouth Plateau. See also Williamson *et al.* (1990), Haq *et al.* (1990), Exon *et al.* (1991), Haq *et al.* (1992), von Rad, Haq *et al*. (1992), and Exon & von Rad (1994).

3.2 Wallaby Plateau

The nature of the Wallaby Plateau has been debated over the years and is still not resolved. Symonds & Cameron (1977) interpreted the plateau as mainly continental in origin, while Veevers & Cotterill (1978) suggested that it was a volcanic build-up or epilith formed on oceanic crust. Dredging on the continental margin, Wallaby Plateau and Sonne Ridge recovered only volcanic material (von Stackelberg *et al*., 1980; Colwell, Graham *et al*., 1990). A re-interpretation of seismic data in the region (Colwell *et al*., 1994) suggested that the basement structure under the plateau was similar to that of other large oceanic plateaus (e.g. the Kerguelen Plateau). Recently, Mihut & Müller (1998b) reinterpreted magnetic data in the Wallaby Plateau region and invoked a mantle plume model to explain the development of the continental margin and Wallaby-Cuvier area. The model presented the Bernier Platform – Wallaby Plateau – Zenith Seamount as resulting from a hotspot trail. Planke *et al*. (1996) compared the tectonic evolution of the western Australian margin to the well-studied volcanic margins of the Atlantic, and proposed an alternative model for the formation of the Wallaby Plateau. According to that model, the plateau has a core of extended continental crust mixed with magmatic material, and is blanketed by basaltic extrusive bodies. Symonds *et al*. (1998) suggested that the Wallaby Plateau complex, with its variable seismic character, trace element indications of sub-continental lithosphere (Colwell *et al*., 1994), and rift-transform corner setting, is likely to have a complex development history. Like Planke *et al*. (1996, 1997), Symonds *et al*. (1998) interpreted the Wallaby Plateau complex to be a composite feature cored by some extended continental blocks that have been modified and blanketed by voluminous magmatism associated with breakup and transform development along its southern margin.

The continental margin bordering the Wallaby-Cuvier area is one of the most poorly-known segments of the western Australian margin, although restricted sampling along the continental slope and on the Wallaby Plateau has revealed the presence of basaltic volcanic rocks. All seabed sampling results in the region are summarised in papers in Exon (1994). Our understanding of the margin's volcanic nature is largely based on seismic data. Hopper *et al*. (1992) and Colwell *et al*. (1994) have described seaward dipping reflectors at the base of the continental slope, and have interpreted them as volcanic wedges emplaced during break-up. Frey (1998) and Symonds *et al*. (1998) have analysed volcanic features of the margin and identified several seismic volcanic facies described on other typical volcanic margins. Among them are seaward dipping reflector sequences (SDRS), hyaloclastic build-ups, sills and landward flows, indicating voluminous magmatism around, or just following continental break-up.

Other significant igneous features in the region include the Sonne and Sonja Ridges, located to the north of the Wallaby Plateau, which are known, from dredging, to be composed of basalt, volcanic breccias and tuff (von Stackelberg *et al*., 1980). The volcanic facies are interpreted to have formed during periods of intense volcanism associated with rift propagation during sea-floor spreading in the Cuvier Abyssal Plain (Müller *et al*., 1998b). According to that model, the

Sonne Ridge formed in the place of an extinct spreading ridge whilst the Sonja Ridge, at least in its southern part, formed along a pseudo-fault associated with this propagating rift. In this report, the term 'pseudo fault' is used for such features as identified from magnetic anomalies and magnetic lineations, rather than being interpreted from seismic data.

4. REGIONAL SETTING

4.1 Physiography

Wallaby Plateau and Volcanic Ridges

The physiography of the Wallaby Plateau was initially described by Falvey & Veevers (1974). Veevers *et al*. (1985b) described the region as consisting of two main bathymetric highs: (1) a large bathymetric high located to the SE, called the Wallaby Plateau; and (2) a smaller bathymetric high to the north called the Quokka Rise (Figs 3, 4 and 5). The Wallaby Plateau lies in water depths ranging from ~2100 m to about 4000 m while the Quokka Rise lies in water depths ranging from slightly over 2500 m to about 4000 m (Plate 2). The Wallaby Plateau is bounded to the north by the Cuvier Abyssal Plain and to the south by the Perth Abyssal Plain and the steep scarp of the Wallaby-Zenith Fracture Zone. The latter rises 2000 m above the deep ocean-floor and trends NW (Figs 4 and 5). The northern slope of the Wallaby Plateau is shallow-dipping, gradually merging with the Cuvier Abyssal Plain. In the west, the Wallaby Plateau is separated from the Zenith Seamount (Figs 3 and 4) by a bathymetric trough, which is sometimes referred to as the Wallaby-Zenith Basin (Mihut & Müller,1998b). This trough is 100–150 km wide, trends NNE, and is characterised by unusually rough topography. In the east, the Wallaby Plateau is separated from the upper part of the continental margin by the NE-trending Wallaby Saddle.

Two ridges trend NNE across the Cuvier Abyssal Plain from the northern margin of the Wallaby Plateau (Fig. 3). To the east, the Sonne Ridge is composed of several highs where water depths range from 3800 m in the north to 3000 m at the point where it merges with the eastern flank of the Wallaby Plateau. The Sonne Ridge is narrow and asymmetric feature in the north, and broader and flat-topped with up to 1 km of sediment cover in the south. It is generally considered to be an abandoned spreading ridge formed between magnetic anomalies M9 (i.e. 129 Ma) to M4–5 (i.e. 126.5 Ma) (Veevers *et al*., 1985b; Mihut & Müller, 1998b).

In the west, the Sonja Ridge is shorter and more continuous, with water depths ranging from 2700 m in the south, to 3500 m in the north. Mihut & Müller (1998b) have interpreted the ridge as originating from a pseudo-fault that developed as a result of ridge-propagation in the Cuvier Abyssal Plain, between magnetic anomalies M9 (i.e.129 Ma) and M5 (i.e. 126.5 Ma).

Oceanic Basins

Oceanic basins within the Wallaby-Cuvier area include the Cuvier Abyssal Plain, the Wallaby-Zenith Basin - a poorly known, roughly triangular feature bounded by the Wallaby Plateau, Zenith Seamount and Wallaby-Zenith Fracture Zone – and the Perth Abyssal Plain to the south (Figs 3 and 4). The Cuvier Abyssal Plain lies in water depths in excess of 5000 m and is exceptionally flat. Its smooth seafloor is disrupted by the Sonne and Sonja

Ridges and by less prominent volcanic build-ups and mounds. The seafloor of the Wallaby-Zenith Basin is unusually rough (Fig. 4), with volcanic mounds rising 1000 m above base-level. This oceanic basin is also imaged by the satellite gravity that shows a linear gravity low trending N–S down the middle of the feature (Fig. 7). A possible interpretation of this triangular basin could be that it relates to rift propagation processes (Mihut & Müller, 1998b). Müller *et al*. (1998b) interpret a pseudo-fault along the western edge of the Wallaby-Zenith Basin, roughly parallel to eastern margin of the Zenith Seamount, and the linear gravity low as being associated with an extinct spreading ridge. The proposed rift propagation model is, however, not very well constrained by the exisiting data indicating that further work is required to better understand the origin of this triangular-shaped feature.

Western Australian Shelf and Slope

The western Australian continental shelf and slope to the east of the Wallaby-Cuvier area can be split up into a number of elements based on structural trends and bathymetric gradients (Fig. 3). These include:

- an area about 300 km in extent, trending NW–SE along the inboard part of the Wallaby-Zenith Fracture Zone. The bathymetric gradient is relatively steep over this part of the continental slope (i.e. ~ 3 deg.) but levels out in the area of the fracture zone;
- an area about 250 km in extent, trending N–S, and bordering the Wallaby Saddle;
- an area about 400 km in extent, trending broadly NE–SW, bordering the Cuvier Abyssal Plain and extending to the Cape Range Fracture Zone;
- an area with relatively steep bathymetric gradients (~ 2–3 deg.) coincident with the Cape Range Fracture Zone; and
- an area known as the Wallaby Saddle, about 250 km in extent, trending N–S.

The shallow area of the continental slope is comprised of the 500-1500 m deep Carnarvon Terrace (Fig. 3), initially described by Symonds & Cameron (1977) and later studied by Baillie & Jacobson (1995). Adjacent to the Wallaby Saddle, the Carnarvon Terrace is underlain by (the Bernier Platform (Fig. 9), a basement high area decribed by Megallaa (1980). The continental shelf is mainly underpinned by the Gascoyne Platform structural element, as described by Lasky & Mory (1999), and this element also extends onshore.

4.2 Plate Kinematics

Regional Synopsis

Continental break-up on the northern Australian margin was initiated during the Oxfordian (155–158 Ma) in the location of the Argo Abyssal Plain (Veevers & Li, 1991). Ludden (1992) further refined the break-up age as Callovian–Oxfordian (i.e. 150–155 Ma). A later stage of break-up during the Valanginian (i.e. 131–136 Ma) formed the Gascoyne, Cuvier and Perth Abyssal Plains (Fullerton *et al*., 1989; Veevers *et al*., 1991; Müller *et al*., 1998). Magnetic anomaly patterns trending NE and encompassing anomalies M11–M5 have been identified in the Cuvier Abyssal Plain and adjacent

Gascoyne Abyssal Plain (Larson, 1977; Larson *et al*., 1979; Johnson *et al*., 1980; Veevers *et al*., 1985a; Fullerton *et al*., 1989). Müller *et al*. (1998) further identified magnetic anomaly anomaly patterns as old as M14 over the Wallaby Saddle. At that location, sea-floor spreading is interpreted to be continuous to anomaly M4–5 (~127 Ma, Hauterivian), when a westward 'jump' in the Cuvier and northern Gascoyne Abyssal Plains left behind abandoned spreading ridges and associated symmetric magnetic anomaly patterns (Fig. 9).

Cuvier Abyssal Plain and Wallaby Plateau

Müller *et al*. (1998) propose a plate kinematic model of the western Australian margin based on the interpretation of magnetic anomalies and high-resolution satellite altimeter data (Sandwell & Smith, 1997). The model includes:

- an explanation of the evolution for the northern part of the Cuvier Abyssal Plain encompassing the location of the continent–ocean boundary and origin of fracture zones, extinct spreading ridges, and pseudo-faults related to rift propagation events;
- a revision of the orientation of sea-floor spreading magnetic anomalies in the Gascoyne, Cuvier and Perth Abyssal Plains;
- a view that magnetic lineaments in the Argo Abyssal Plain trend NE–SW now parallel magnetic lineaments in the Cuvier Abyssal Plain, thus indicating that sea-floor spreading on the northern Australian margin occurred on a similar azimuth; and
- two large-scale rift propagation events, although these were initially interpreted as a single rift jump (Larson, 1977; Larson *et al*., 1979; Johnson *et al*., 1980; Veevers *et al*., 1985b; Fullerton *et al*., 1989). The first propagating rift is contemporaneous with the initial break-up in the area and coincides with chron M11 (i.e. ~133 Ma) and ending before chron M4 (i.e. ~126 Ma). The second propagating rift coincided with chron M4 and ended at chron M0 (i.e. ~120.4 Ma). Major volcano-tectonic features left by propagating ridges are represented by the Sonne and Sonja Ridges.

Although this model appears to explain the complex pattern of magnetic lineations that has been interpreted in the Wallaby Plateau region, it is based on the assumption of an oceanic origin for many of the region's major tectonic features. Mihut & Müller (1998b) and Müller *et al*. (1998) interpret a complex arrangement of magnetic anomalies and related extinct ridges and pseudo-faults throughout the Wallaby-Cuvier area based on a relatively sparse data set. In particular, they map magnetic anomalies M11-M14 over the Wallaby Saddle to the east of the Wallaby Plateau (Fig. 9), and anomalies M4-M10N over the western part of the Wallaby Plateau and the Quokka Rise. The complex and variable seismic characteristics of these areas, varying from SDRSs beneath the Wallaby Saddle to layered crust beneath parts of the Quokka Rise, are quite different to that of the oceanic, seafloor-spreading crust of the Cuvier Abyssal Plain. Given this, it is difficult to envisage how these features could have been formed by normal systematic seafloor spreading. Great care needs to be taken in mapping and interpreting seafloor-spreading magnetic anomalies in complex volcanic margin environments in which lineated magnetic anomalies could potentially arise from a variety of processes that are not necessarily associated with systematic spreading. This is particularly true for areas with relatively sparse data.

If future seismic or drilling data confirms the presence of continental fragments anywhere within the Wallaby Plateau complex or Wallaby Saddle area, then the reconstructions of Mihut & Müller (1998b) and Müller *et al*. (1998) will have to be revised. Some seismic evidence suggests that there is a continental component to the Wallaby Plateau (see Section 7.2), similar to that of other large plateaus related to evolution of the western Australian margin, such as the Exmouth, Naturaliste and Kerguelen Plateaus (Stagg *et al*., 2003, Borissova *et al*., 2002; Borissova, 2002). Recently, Brown et al. (in press) re-assessed the magnetic lineations in the Wallaby-Cuvier area and concluded anomalies M11-M14 over the Wallaby Saddle are probably the result of processes related to volcanic margin formation rather than normal seafloor spreading. They suggested that the oldest oceanic crust in the area is represented by anomaly M10 (~ 130 Ma), and supported the view of Symonds *et al*. (1998) that the Wallaby Plateau complex is a composite feature of extended continental blocks covered by volcanics and modfied by magmatism.

At about 99 Ma (i.e. Cenomanian), a major change in spreading direction occurred when Greater India, now a separate plate, began its rapid northward drift (Müller *et al*., 1998). The authors also noted, from an analysis of more than a hundred exploration wells, that this event coincided with anomalous tectonic subsidence of up to 550 m on the North West Shelf. The impact of sea-floor spreading then reduces dramatically with the onset of the rapid northward drift of Greater India.

The next major plate movement on the North West Shelf involved plate convergence between SE Asia and Australia during the Oligocene. The plate convergence initiated compressional structures on the North West Shelf although the effect in the Wallaby-Cuvier area appears to have been minimal.

4.3 Regional Basin Evolution

Introduction

The term “Southern Carnarvon Basin” as used by Lasky & Mory (1999), covers most of the continental shelf bordering the Wallaby-Cuvier area (Fig. 4), and underlies the Gascoyne Platform, Carnarvon Terrace and Bernier Platform. The basal section of the Southern Carnarvon Basin contains Silurian–Early Carboniferous and Late Carboniferous–Permian sediments, separated by a major North West Shelf-wide unconformity in the mid-Carboniferous (Hocking *et al*., 1994). The upper section of the basin contains a westward-thickening veneer of Mesozoic and Cainozoic rocks (i.e. > 4 km) with only a very thin cover to the east (Hocking *et al*., 1987 and this study). The Northern Carnarvon Basin (e.g. Hocking *et al.,* 1994) incorporates the Exmouth Sub-basin, whereas the Southern Carnarvon Basin incorporates the Gascoyne Sub-basin, the boundaries of which have recently been redefined by Geoscience Australia (i.e. personal communication – Barry Bradshaw).

The Perth Basin incorporates the Houtman Sub-basin that contains Mesozoic sediments. The Houtman Sub-basin is not discussed at length in this report as it lies at the SE extremity of the Wallaby Plateau study area. The northern part of the Houtman Sub-basin contains substantial Paleozoic and Mesozoic-aged depocentres, in excess of 5 km thick (Seggie, 1990).

The volcano-tectonic provinces and features of the Wallaby-Cuvier area have formed since the Valanginian around the time of initiation of sea-floor spreading. Although older sediments and crust may be present beneath the Wallaby Plateau (discussed later),this study has not focussed on pre-Valanginian geology and rifting events. For example, AGSO North West Shelf Study Group (1994) identified a mid-Carboniferous tectonic event, Early Triassic and Late Triassic–Early Jurassic events. Ludden (1992) dated initiation of sea-floor spreading in the Argo Abyssal Plain as Callovian–Oxfordian (i.e. 150–155 Ma) and this break-up event is now recognised regionally across the North West Shelf (AGSO North West Shelf Study Group, 1994).

An overview of the tectonic, and sedimentary history, palaeogeography, and interpretation of regional deep seismic transects of the western Australian margin is given by the following authors: Gradstein & von Rad (1991), Exon & Colwell (1994), Etheridge & O'Brien (1994), AGSO North West Shelf Study Group (1994), Baillie *et al*. (1994), Bradshaw *et al*. (1994), and Stagg *et al*. (2002).

Paleozoic

The early stage of basin development in both the Perth and Southern Carnarvon Basins dates back to the Late Devonian–Early Carboniferous, when NE–SW-oriented upper and lower crustal extension occurred throughout the region resulting in NW–SE-trending depocentres. A series of NE-trending depocentres developed from the mid-Carboniferous onwards constituting the Westralian Superbasin of Yeates *et al*. (1987). The Bernier Platform was formed during the tectonic rifting episode initiated in the Late Carboniferous and uplifted during the Late Jurassic–Early Cretaceous rifting (Yeates *et al*., 1987; Cockbain, 1989).

Early Triassic to Mid-Jurassic

Much of what is known about the Southern Carnarvon Basin originates from the Northern Carnarvon Basin where petroleum activity has been focussed. For example, onset of rifting in the Northern Carnarvon Basin is tied to the near base Triassic unconformity (Jablonski, 1997). Rift-derived subsidence resulted in a thick section of Triassic marine to fluvio-deltaic sediments being deposited along the western Australian margin until a regional transgression in the latest Triassic. Further subsidence and rifting in the latest Triassic or earliest Jurassic (Forman & Wales, 1981) led to the development of major tectonic elements including the Barrow-Dampier Rift and Exmouth Sub-basin (AGSO North West Shelf Study Group, 1994). Further extension in the Early to Mid-Jurassic produced significant depocentres and hydrocarbon traps, many petroleum-bearing. Mid- to Late Jurassic marine shales and siltstones (i.e. Dingo Claystone) were then deposited in the Exmouth Sub-basin (Thomas & Smith, 1974), and possibly also, the Gascoyne Sub-basin.

Mid-Jurassic to Valanginian

Late Mid-Jurassic thermal uplift and erosion occurred prior to break-up on the North West Shelf and sea-floor spreading in the Argo Abyssal Plain during the Callovian–Oxfordian. In the Valanginian, Greater India broke off resulting in post-break-up Early Cretaceous shallow marine claystones and siltstones of the Winning Group being deposited (i.e. Aptian-Cenomanian), and unconformably overlying older rocks in the Carnarvon and northern part of the Perth Basin (Thomas & Smith, 1974).

Valanginian–Barremian

Initiation of sea-floor spreading between Greater India and Australia has been investigated by a number of authors, including Johnson *et al*. (1976), Larson (1977), Larson *et al*. (1979), Johnson *et al*. (1980), Falvey & Mutter (1981), Powell *et al*. (1988), and Fullerton *et al*. (1989). The above authors suggested that break-up south of the Argo Abyssal Plain had occurred in the Early Cretaceous around 125 Ma (i.e. magnetic anomaly M10). The Early Cretaceous date for sea-floor spreading has since been refined as Valanginian. As mentioned previously, Müller *et al*. (1998) interpreted the oldest anomaly as M14 (135.8 Ma) located over the Wallaby Saddle and overlying an area mapped in the present study as being characterised by SDRSs (Figs 9 and 10). Chron M14 would pre-date sea-floor spreading in the Cuvier Abyssal Plain by ~5 Ma where the oldest chron is M11 (i.e. 132.1 Ma). Recently Brown *et al*. (in press) re-assessed magnetic anomalies in the area and suggested anomaly M10 (130.2 Ma) represents the oldest oceanic crust. The mineralogical study of ashfalls by von Rad & Thurow (1992) that are intercalated with silty claystones at three ODP Sites suggests that they are Berriasian–Valanginian. The above evidence points to the oldest oceanic crust in the Wallaby-Cuvier area as being Valanginian (~130-132 Ma) in age. Marine conditions prevailed following break-up.

Late Cretaceous

During the Late Cretaceous, there was a rapid change from terrigenous sedimentation to shelf carbonate sedimentation (Exon & Colwell, 1994). In the Northern Carnarvon Basin, a late Santonian–Campanian-aged calcilutite unconformably overlies the Early Cretaceous sequence, itself overlain by a Late Maastrichtian calcareous sandstone and the Miria Marl (Patrick Quilty in Appendix 6 of Colwell, Graham *et al*., 1990). In the Perth Basin, an equivalent carbonate sequence, the Gingin Chalk, was deposited (Jones & Pearson, 1972). Lastly, the Turonian gamma-ray spike is recognised as being representative of an oceanic anoxic event present at a global scale, including on the North West Shelf (AGSO North West Shelf Study Group, 1994).

Cainozoic

By the Oligocene, the region had subsided considerably and deep-water pelagic carbonates were deposited, forming carbonate wedges that extend into deeper water (Ramsay & Exon, 1994). A mid-Oligocene unconformity is widely recognised on the North West Shelf (AGSO North West Shelf Study Group, 1994) and more locally on the Exmouth Plateau (Spencer *et al*., 1995). The event is synchronous with the collision of the northern margin of the Australian plate with the SE Asian plate. It also corresponds with the clearing of Antartica off Tasmania.

Collision of the Australian plate with the SE Asian plate continued throughout the Late Miocene–Pliocene. Compressional structures are widely recognised on the North West Shelf (AGSO North West Shelf Study Group, 1994), and more locally on the Exmouth Plateau (Spencer *et al*., 1995). It is represented, in the Wallaby-Cuvier area, by faults terminating in Late Miocene–Pliocene sediments. Compression tectonics also resulted in tilting of the continental margin, resulting in deepening palaeo-water depths (Bradshaw *et al*. 1998).

5. STRATIGRAPHY

5.1 Introduction

The stratigraphy of the inner shelf areas of the North West Shelf has been well documented from petroleum exploration activity over the last fifty years, since petroleum was first discovered at Rough Range in the onshore Carnarvon Basin in 1953 (Purcell & Purcell, 1988; 1994; 1998). A number of petroleum wells, located on the outer fringes of the study area, are reviewed below. The 'outer' shelf areas of the North West Shelf comprising the deeper water areas are, however, less well known. Two wells (DSDP Site 263 and ODP Site 766), drilled in the deep ocean areas of the Wallaby-Cuvier area, are reviewed in this report. The raw data for the relevant wells are summarised as composite well-logs in Plate 3 and the stratigraphy is summarised in Plate 4.

5.2 Regional Stratigraphy

The regional stratigraphy has been broken up to reflect the region's tectonic/structural elements, including: (1) the Cuvier Abyssal Plain (represented by DSDP Site 263); (2) Gascoyne Platform; (3) Exmouth Sub-basin; and (4) outer Exmouth Plateau (represented by ODP Site 766). Columns showing the stratigraphy of the Exmouth Sub-basin and Exmouth Plateau are based on the biozonation and stratigraphic chart of Shafik *et al*. (1998) while the stratigraphy of the Gascoyne Platform is based on the biozonation and stratigraphic chart of Nicoll *et al*. (1998). The stratigraphy at DSDP Site 263 and ODP Site 766 is based on the work of Veevers & Johnstone (1974) and Buffler *et al*. (1992), respectively. Sediments from these deep-water sites are dominantly pelagic with a volcanogenic component, and do not have formal stratigraphic names assigned to them (see Plate 4).

5.3 Stratigraphic Control in the Wallaby-Cuvier Area

Only DSDP Site 263, located in the Wallaby-Cuvier area, provides direct bio-stratigraphic control to tie the seismic data. Bio-stratigraphic control from distant locations (see Plates 1–2) is provided by wells in the Exmouth Sub-basin (Resolution-1), Gascoyne Sub-basin/Carnarvon Terrace (Pendock-1, Edel-1, Wittecarra-1), Houtman Sub-basin (Houtman-1), and outer Exmouth Plateau (ODP Site 766, Vinck-1).

DSDP Site 263

DSDP Site 263 formed part of Deep Sea Drilling Project Leg 27, and is located on the southeastern part of the Cuvier Abyssal Plain in water depths of 5048m (Fig. 8). The well drilled through 746 m of sediment before reaching total depth in sediments that may be Albian in age. It did not reach basement. Veevers & Heirtzler (1974) did, however, calculate depth to acoustic basement at 750 m, below the total depth reached. This prediction was based on onboard velocity measurements, where values were increased empirically by 5% to fit other velocity measurements from Leg 27. The horizons interpreted by Veevers & Heirtzler (1974) are top of acoustic basement (i.e. oceanic crust at 0.78 s TWT (two-way time) below seabed), and the base of a well-stratified 'Unit 1' (i.e. 0.90 s TWT below seabed).

Altogether, 271 m of section was cored with 163.5 m of core recovered (Veevers & Heirtzler, 1974). The sparsity of core material (i.e. only 22% of the total 746 m section was recovered), and differences in the ages determined by micropalaeontologists working on palynomorphs and nannofossils, mean that much of the dating is equivocal. The results are summarised in Table 1.

Table 1: Major stratigraphic units identified by Veevers & Heirtzler (1974) in DSDP Site 263

Unit	**Interval (mbsf)**	**Age**	**Description**	**Cores**	**Thickness (Recovered)**
1	0–100	Quaternary to Late Pliocene	Greenish-grey detrital foram ooze with minor clay and quartz. Graded in place. Sharp lower boundary.	1–3	100 m (20%)
2	100–195	Early Paleocene (or younger?) to Late Albian	Greenish-grey to olive black, stiff, clayey nanno ooze and nanno-bearing clay, with nanno proportion increasing upward.	4–7	95 m (22%)
3	195–470	Early Cretaceous (Late Albian nannos; Aptian dinos)	Greenish black semi-lithified claystone, with minor pyrite and traces of quartz, feldspar, zeolites, nannos, fish fragments and kaolinite.	8–19	275 m (24%)
4	470–746	Early Cretaceous (mid- to Late Albian nannos; Barremian dinos)	Olive-black semi-lithified silty quartz-bearing to quartz-rich kaolinitic claystone. Common pyrite and calcite nodules and veins. Common burrows, mottles and shell fragments.	20–29	276 m (20%)

Note: 'Dinoflagellate cysts' are abbreviated to 'dinos', 'Nannofossils' are abbreviated to 'nannos', 'Foraminefera' is abbreviated to 'foram'. Nannoplankton are poorly preserved throughout and radiolarians are rare. Benthonic and calcareous foraminifera are fairly frequent and diverse below 385 m (lower Unit 3 and Unit 4). Palynomorphs are useful throughout. mbsf – meters below sea-floor.

The Lower Cretaceous claystones in the core samples of Unit 4 are dominantly of continental origin, and contain shallow-marine indicators and little evidence of carbonate dissolution in deep water. The initial DSDP report (Veevers & Heirtzler, 1974) assumed that the claystones were deposited in deep water, but Veevers & Cotterill (1978) suggest that they were probably reworked from shallow into deeper water. This remains an open question. In the sediments of Unit 3 (Table 1), the calcareous microfossils are poorly preserved, suggesting that deposition may have been below the lysocline. The gradual increase in the percentage of nannofossils toward the top of Unit 2 suggests further changes in water-depth or water chemistry. Unit 1 contains reworked shallow-water benthonic foraminifera and calcareous turbidites, and has a significant component of material probably derived from the shelf by gravitational processes (i.e. turbidity currents, slumping, grain flow).

The difference in apparent ages in the Lower Cretaceous sediments could be caused by the reworking of Barremian and Aptian dinoflagellates, spores and pollen, from shelf sediments into a rapidly subsiding Albian marine basin. The older sediments could have been eroded subaerially on the shelf and by canyoning, transported by gravitational processes possibly down canyon systems, and redeposited. The Barremian–Aptian deposits were probably largely muddy, like those preserved on much of the North West Shelf and dredged from this margin (see below), and could have been mixed with the calcareous pelagic rain to form poorly bedded claystones. The presence of reworked Barremian–Aptian sediments would mean a time lag of 20–25 Ma after Valanginian break-up, before much sediment was deposited on the abyssal plain in the Albian. Just such a time-lag of 20 Ma has been demonstrated in the Argo Abyssal Plain, where break-up is dated as Oxfordian (155 ± 3 Ma; Ludden, 1992), although the oldest dated sediments are Tithonian (~135 Ma; Duboulin & Bown, 1992). What causes such a lag is uncertain, but it is possible that when the oceanic crust first formed it was subaerial and not subject to sedimentation. Another possibility is that heating associated with the initial break-up formed cuestas draining landward, and almost no sediment was carried into the ocean.

ODP Site 766

A total of 458 m of sediments were cored above volcanic basement in a water depth of 4535 m at ODP Site 766 west of the Exmouth Plateau (Fig. 8). The hole reached total depth in basalts and diabasic sills/dykes contained within lower Cretaceous sediments (Gradstein, Ludden *et al*., 1990). Most of the sedimentary column is Cretaceous in age, with a fairly continuous section from the latest Valanginian to the Campanian (Plate 3).

Buffler *et al*. (1992) suggest that the 150 m of Hauterivian–Barremian glauconitic sandstone/siltstone could have been derived from shallow-water shelves and volcanic landmasses located further to the east. These sediments would have originated from a source area that would have been probably above sea-level immediately after Greater India broke away, and possibly transported down canyon systems. Subsidence modelling suggests an initial water depth of about 800 m at ODP Site 766 into which the shallow water sediments were transported. The Barremian sequence consists of about 50 m of dark hemipelagic claystone, and was deposited while the source and depositional areas were subsiding rapidly as the crust cooled.

The Aptian–Cenomanian sediments consist of about 110 m of open-marine chalk deposited in deep water. The lithology changes in the Upper Cretaceous when 55 m of clays and oozes were deposited under sediment-starved open-marine conditions, with clay finally disappearing in the Campanian. The Cainozoic-aged sequence of nannofossil ooze is only 95 m thick. Buffler *et al*. (1992) suggest that strong deep-sea currents swept through the area periodically throughout the Cretaceous and Cainozoic, as interpreted on the basis of numerous unconformities visible on the seismic reflection profiles.

Pendock-1

At Pendock-1 (Fig. 8), there is reliable biostratigraphic control of the Paleozoic basement whilst dating of the Mesozoic section is poor (Genoa Oil NL, 1970). This well was, however, of only limited use to this study as no well logs were available to tie the seismic data. In addition, the well does not tie Cretaceous-aged horizons that cover the Wallaby-Cuvier area.

Vinck-1/ODP Site 762/Resolution-1

Well constrained biostratigraphy in Vinck-1, ODP Site 762 and Resolution-1 provided excellent age-control to seismic horizons on the Exmouth Plateau (Stagg *et al*., 2002). However, interpreted horizons on the Exmouth Plateau could not be correlated unambiguously into the Cuvier Abyssal Plain across the Cape Range Fracture Zone. These wells were, therefore, of limited use to this study.

Edel-1, Houtman-1, Wittecarra-1 and Livet-1

Seismic horizons in the Wallaby-Cuvier area were not tied to wells Edel-1, Houtman-1, Wittecarra-1 and Livet-1 due to time constraints and the poor biostratigraphy of the Mesozoic section. The wells do, however, contribute to the assessment of the region's petroleum prospectivity.

Core Samples

The results of seabed coring operations in the region are summarised in Table 2. The Quaternary cores were, however, of limited use in this study. The cores show that ooze and chalk predominate in bathyal depths, and red clay predominates in the abyssal plain. One core from the central Cuvier Abyssal Plain (i.e. S08-156KL) differs in that it contains a trace of white chalk of Palaeocene–Eocene age.

Table 2: Core stations (after Colwell, Graham *et al*., 1980; Exon, 1979; Lamont-Doherty Geological Observatory of Columbia University, 1976a & 1976b); refer to Plate 2 for location, further details of the core sites can be found in Appendix 3

Site	**Water depth (m)**	**Description**	**Location**
RC11-145PC	3869	339 cm foram chalk	Wallaby Saddle
RC11-146PC	2371	388 cm foram chalk	Carnarvon Terrace
RC14-59PC	5550	1078 cm brown clay and volcanic clay, with Mn micro-nodules	Cuvier AP
V18-214PC	5147	660 cm clay (lutite), red-brown, with Mn micro-nodules	Perth AP
054BC057	5060	33 cm Quaternary clay	Central Cuvier AP
054GC019	5060	400 cm Quaternary clay	Central Cuvier AP
054PC015	4780	792 cm Quaternary clay	Western Cuvier AP
S08-156KL	4780	Trace of Early Paleocene–Eocene white chalk	Western Cuvier AP
054PC017	4845	336 cm Quaternary clay	Western Cuvier AP
054PC018	4060	88 cm ooze & volcaniclastic sandstone	NE Wallaby Plateau
096GC021	2100	~200 cm Pleistocene mudstone	Wallaby Plateau
096GC022	2106	~200 cm Pleistocene mudstone	Wallaby Plateau

Note: 'Central Cuvier AP' is the abbreviation for central Cuvier Abyssal Plain located NE of the Sonne Ridge. 'Western Cuvier AP' is the abbreviation for western Cuvier Abyssal Plain located on the gentle NNE-facing slope of the Wallaby Plateau between the Sonne and Sonja Ridges.

Dredge Samples: Volcanogenic Rocks of the Wallaby Plateau and Adjacent Areas

Dredging (Fig. 8) recovered rocks of ?Early Cretaceous age that were interpreted as being part of a volcanic sequence post-dating the Valanginian-aged break-up of the margin (von Stackelberg *et al*., 1980; Colwell *et al*., 1994; Symonds *et al*., 1998). Key dredges pertinent to this section are shown in Table 3 and originate from Colwell, Graham *et al*. (1990) and Exon (1979). Two identifiers are used for the Sonne S08 samples – the originals and those used in Geoscience Australia's database (see Appendix 3/Table 3).

von Stackelberg *et al*. (1980) reported on the volcanogenic rocks dredged at stations prefixed with 'S08-' (Table 3), basing the reports on petrographic and geochemical analyses by R. Emmermann, and initial cruise results from Exon (1979). Only volcanic and volcaniclastic rocks were dredged from the Sonne Ridge and Wallaby Plateau at that time, providing no evidence of a continental origin for the plateau. Variably altered tholeiitic basalts were recovered from the Sonne Ridge and the southern flank of the Wallaby Plateau. They have an intersertal to intergranular texture and are often amygdaloidal. For sample S08-170KD, dating gave a questionable K/Ar age of 89 Ma (Turonian); this sample's high loss on ignition indicates that this is a minimum age, not contradicting the assumed Neocomian age of all the volcanics. Volcanic breccias containing basalt fragments, probably tholeiitic, were sampled along the southern flank of the Wallaby Plateau. Altered, slightly differentiated alkali basalts, possibly hawaiites, were also recovered from the Sonne Ridge. Widespread, more-or-less altered tuff and lapillistone, and poorly sorted tuffaceous sandstone to siltstone were also recovered at various stations and contain various admixtures of non-volcanic (epiclastic) components. Multicoloured, poorly sorted volcaniclastic sandstone and breccia are also widespread. White, phosphatised pyroclastic claystone is common along the Sonne Ridge and NE of the Wallaby Plateau.

Dredge hauls 096DR036 and 096DR038 (Table 3) originate from the central part of the Wallaby Plateau (Colwell, Graham *et al*., 1990). The dredge hauls set out to sample the only known exposure of dipping basement reflections within the Plateau itself. Dredge haul 096DR036 contained mainly basaltic conglomerate with moderately well rounded clasts. Highly weathered basalt/ trachyandesite and amygdaloidal basalt were also recovered. Dredge haul 096DR038 also recovered basaltic conglomerate containing subrounded bimodal clasts, and highly weathered basalt. Geochemical analysis of the least weathered samples suggests that basalt samples are very similar to basaltic lavas dredged from the Naturaliste Plateau to the south (Colwell *et al*., 1994).

Table 3: Dredge stations (after Colwell, Graham *et al*., 1990; von Stackelberg *et al*., 1980). Refer to Plate 2 for location of dredge stations, further details of the dredge stations can be found in Appendix 3

Site original number	Site (database)	Water depth (m)	Description	Location
S08-147KD	054DR045	5060–5000	Cainozoic–Quaternary marl	Cuvier AP
S08-148KD	054DR046	4875–4540	Mid Cretaceous basalt, volcanic sandstone & mudstone, Mn noduless & crusts	Sonne Ridge
S08-149KD	054DR047	4930–4920	Mid Cretaceous volcaniclastic breccia	Sonne Ridge
S08-155KD	054DR051	5060–4830	Mid Cretaceous basalt, volcaniclastic breccia & claystone	NE Wallaby Plateau
S08-159KL	054DR053	4470–4130	Mid Cretaceous volcanic sandstone with clasts	NE Wallaby Plateau
S08-161KD	054DR055	4470–4230	Mid Cretaceous volcanic sandstone	NE Wallaby Plateau
S08-165KD	054DR058	4415–4240	Mid Cretaceous pebbly volcaniclastic sandstone, with Mn nodules	NE Wallaby Plateau
S08-167KD	054DR060	5340–4750	Mid Cretaceous volcanic claystone and siltstone, tuff, breccia, basalt, with Mn nodules	S Wallaby Plateau
S08-168KD	054DR061	5100–4050	Mid Cretaceous basalt, volcanic claystone and siltstone, tuff	S Wallaby Plateau
S08-170KD	054DR063	4620–3970	Mid Cretaceous basalt, breccia, volcanic sandstone and mudstone, with Mn nodules	S Wallaby Plateau
S08-173KD	054DR066	4980–3885	Mid Cretaceous chert, volcanic mudstone (?Altered tuff)	S Wallaby Plateau
	096DR001	4125–3700	Aptian & Early Albian siltstone; Early Paleocene & Early Miocene chalk	Continental slope
	096DR002	4994–4720	Early Albian mudstone	Continental slope
	096DR003	3890–3700	Early Albian mudstone	Continental slope
	096DR004	4200–3540	?Early Cretaceous sandstone and Quaternary ooze	Exmouth Sub-basin
	096DR005	4200–3150	Valanginian sandstone, siltstone, Quaternary mud	Exmouth Sub-basin
	096DR006	4100–3340	?Early Cretaceous siliceous mudstone, shale, Quaternary mud/ooze	Exmouth Sub-basin
	096DR007	3700–3150	Hauterivian siltstone and sandstone, Late Paleocene chalk	Exmouth Sub-basin
	096DR008	3550–3180	Barremian siltstone, sandstone, igneous rocks, Late Oligocene–Early Miocene chalk	Exmouth Sub-basin
	096DR009	2650–2200	Maastrichtian, Late Paleocene, Eocene, Oligocene mudstone, marl, limestone	Exmouth Sub-basin
	096DR010	2410–2100	Late Eocene mudstone, Quaternary mud	Exmouth Sub-basin
	096DR011	3700–3070	Early Albian, Late Campanian, Oligocene marl and chalk	Exmouth Sub-basin
	096DR034	3950–3410	?Early Cretaceous amygdaloidal basalt/ andesite, porphyry	SW Exmouth Plateau
	096DR035	5025–4050	?Early Cretaceous siliceous mudstone, sandstone, basalt/gabbro, ?fault breccia,	SW Exmouth Plateau

	096DR036	3120–2850	?Early Cretaceous basaltic conglomerate, basalt & Mn crusts	C Wallaby Plateau
	096DR037	3200–3010	Pleistocene ooze	C Wallaby Plateau
	096DR038	3120–2980	?Early Cretaceous basaltic conglomerate, basalt & Mn crusts	C Wallaby Plateau

Note: 'C Wallaby Plateau' is the abbreviation for central Wallaby Plateau; 'AP' is the abbreviation for abyssal plain; 'FZ' is the abbreviation for fault zone.

Dredge Samples: Cretaceous Siliciclastic Sediments and older rocks of the Continental Slope

Sandstone, siltstone and mudstone have been dredged from sites on the continental slope of the Exmouth Sub-basin (Table 3). A palynological study by Burger (1994) provided seven Neocomian ages for sediments in dredge hauls 096DR005, 096DR007, 096DR008, and one Aptian age for sediments in dredge haul 096DR001. Sediments are interpreted to be equivalents of the Barrow or Lower Winning Groups and were deposited in open and restricted marine and continental shelf environments. Samir Shafik dated marine siltstone and mudstone samples as Early Albian using nannofossils in dredge hauls 096DR001–096DR003 (Appendix 5 in Colwell, Graham *et al*., 1990). A marl in dredge haul 096DR011 and mudstone in dredge haul 096DR009 were also dated as Maastrichtian and originated from the same location in the Exmouth Sub-basin. Patrick Quilty, using planktonic foraminera (Appendix 6 in Colwell, Graham *et al*., 1990), obtained three Early Cretaceous dates for sediments in dredge hauls 096DR001, 096DR003 & 096DR011, and one Late Cretaceous date for sediments in dredge haul 096DR009.

The older, Neocomian samples from the continental slope (i.e. 096DR001–096DR003, Table 3) are dominantly all greenish grey or olive coloured siliceous mudstones to fine sandstones, with a few calcareous samples. The fabric includes carbonaceous flecks, glauconite, burrowing and mottling. The younger, Aptian–Albian samples from the continental slope overlying the Exmouth Sub-basin (i.e. 096DR004–096DR011, Table 3) are mostly fine siliceous sandstones, siltstones and mudstones that range from shaly, when fresh, to soft and muddy when altered. They are olive brown or brown when reasonably fresh. Their components can include glauconite, carbonaceous grains, mica, and rarely calcareous cement. They are massive to flaggy, and burrowed in places. Dredge haul 096DR011 contains a predominantly olive grey marl dated as Late Campanian, and an olive grey calcareous mudstone 096DR009 dated as Maastrichtian. Intrusive igneous rocks and metamorphosed mudstones were dredged along with younger sediments at dredge station 096DR008. A preliminary assessment suggested that the igneous rocks include granite and gabbro (Colwell, Graham *et al*., 1990).

Dredge Samples: Cainozoic Calcareous Sediments of the Continental Slope

Cainozoic sediments have been dredged on the continental slope of the Exmouth Sub-basin, but are rare on the Wallaby Plateau (Table 3) where the only recovery to date is on the NE side of the Plateau (i.e. S08-156KL, Table

2). This one sample is a white nannofossil marl of Late Paleocene to Eocene age (von Stackelberg *et al*., 1980).

Cainozoic calcareous sediments were recovered in dredge samples 096DR001, 096DR007–096DR011. These have been briefly described by Colwell, Graham *et al*. (1990), and they have been dated by Samir Shafik using nannofossils (Appendix 5 in Colwell, Graham *et al*., 1990), and by Patrick Quilty using foraminera (Appendix 6 in Colwell, Graham *et al*., 1990).

Dredge sample 096DR001 contains yellowish grey, burrowed chalk. An Early Paleocene sample contains minute globigerinid foraminifera and a Middle Miocene sample contains planktonic foraminifera. The same samples are dated as Early Paleocene and Early Miocene using nannofossils. Dredge sample 096DR007 contains yellowish grey to white, burrowed chalk with Late Paleocene, Eocene and Oligocene microfossils. Dredge sample 096DR008 contains orange to grey chalk with Late Oligocene to Early Miocene, and Mid-Miocene microfossils. Dredge sample 096DR009 contains light grey marl and calcareous mudstone with Late Paleocene, Oligocene and Mid-Eocene microfossils. Dredge sample 096DR010 contains light grey calcareous mudstone with Late Eocene microfossils. Dredge sample 096DR011 contains yellowish grey marl with Mid-Oligocene microfossils.

5.4 Summary

The overall stratigraphy of the Wallaby-Cuvier area is poorly known due to only one well (DSDP hole 263) having been drilled in the area. Core and dredge samples and distant wells located on the continental slope, Carnarvon Terrace, Gascoyne Platform and Exmouth Plateau do, however, provide some additional constraint. Plate 4 summarises what is known of the lithostratigraphy in the Cuvier Abyssal Plain, outer Exmouth Plateau, Exmouth Plateau, Exmouth Sub-basin and Gascoyne Platform. This study does, however, provide additional constraints to the stratigraphy using seismic-based volcano-stratigraphic concepts of Planke & Symonds (1995), Planke *et al*. (1996), Planke *et al*. (1997), Planke *et al*. (1998) and Planke *et al*. (2000). These additional constraints are discussed in the following chapter.

6. SEISMIC INTERPRETATION

6.1 Introduction

Interpretation of the Wallaby Plateau and adjacent ocean basins was carried out in parallel with the interpretation of the Exmouth Plateau and adjacent ocean basins of Stagg *et al*. (2003). Consequently, a similar horizon nomenclature was used in both areas with the exception of a few horizons that were identified in only one of the areas. The regional unconformities within the sedimentary section were, on average, easier to pick than the volcanic crustal types/facies that required considerable subjectivity. Appendix 4 lists all horizons used and relevant type seismic sections. Plates 5 and 6 display seismic sections that were interpreted and only available in digital format (i.e. AGSO Survey 135 and Shell-*Petrel* survey). Other seismic data were used to create the map of volcano-tectonic provinces and features, but these data were only available in analog form (i.e. BMR Surveys 17 & 18), and were not reproduced here.

6.2 'Non-volcanic' Seismic Horizons

Paleozoic (*Pz*)

Seismic horizon *Pz* was interpreted on the continental shelf and slope and represents top of basement, presumed to be Paleozoic in age, and possibly similar to sequences of Early Paleozoic age identified by Seggie (1990) and Marshall *et al*. (1989) in the Perth Basin. Seismic character underlying horizon *Pz* shows a relatively bland section containing some isolated high-amplitude reflections (Fig. 11). Figure 12 shows another example in the Houtman Sub-basin where high-amplitude reflections are visible and parallel *Pz*. In the later case, high amplitude reflectors at depth may be indicative of Permian coals identified elsewhere on the North West Shelf (AGSO North West Shelf Study Group, 1994).

Triassic (*tr*)

Seismic horizon *tr* has been interpreted on the Exmouth Plateau (Plate 6) where it is distinguished from the overlying *val* horizon (see below) by erosional truncation of rotated fault blocks. It is possible that the Triassic section is present on the Wallaby Plateau itself, but horizon *tr* was not interpreted there because of the high level of uncertainty.

Valanginian (*val*)

Seismic horizon *val* has been interpreted on the western Australian continental shelf and slope including the Exmouth Plateau where it is defined by a erosionaly truncated surface (Fig. 11, Plates 5–6). The age of the horizon pre-dates the formation of the Cuvier Abyssal Plain and Wallaby Plateau, so that it is interpreted only on the edges of the Wallaby-Cuvier area.

Top Turonian (*tur*)

Seismic horizon *tur* has been interpreted on the continental shelf and slope and Wallaby Saddle (Figs 11–12). The horizon was not interpreted in the Wallaby-Cuvier area due to poor resolution. The Turonian is characterised by a global anoxic event, and has also been interpreted on the North West Shelf (AGSO North West Shelf Study Group, 1994) as a high amplitude reflector, showing some discordance with underlying and overlying reflectors.

Top Cretaceous (*cret*)

Seismic horizon *cret* is relatively well controlled from biostratigraphy as well as seismic character of underlying and overlying units. For example, the seismic character of the Cretaceous section in the Cuvier Abyssal Plain is bland while the top Cretaceous to Oligocene interval is characterised by higher amplitude seismic reflectors (Fig. 13). Robinson *et al*. (1974) suggested that this is due to an upwards change from clastic to carbonate lithology. Horizon *cret* has been interpreted throughout the Wallaby-Cuvier area.

The top Cretaceous unconformity is widely recognised on the North West Shelf (AGSO North West Shelf Study Group, 1994) and more locally on the Exmouth Plateau (Spencer *et al*., 1995). The top Cretaceous unconformity is synchronous with the opening of the Coral Sea and also corresponds to a drop in relative sea-level.

Oligocene (*olig*)

Seismic horizon *olig* has been interpreted at the base of a downlapping sequence on the western Australian margin (Fig. 11), and tied to wells on the Exmouth Plateau. Horizon *olig* cannot be interpreted with confidence in the Wallaby-Cuvier area due to lack of well-control and diminished reflectivity. Horizon *olig* also merges with the top Cretaceous horizon *cret* on the western Australian continental slope, possibly suggesting that the Palaeocene–Oligocene interval is condensed or absent in the Wallaby-Cuvier area, as is the case at ODP Site 263 (Plate 3).

Intruded Continental Crust (*icc*)

Seismic horizon *icc* has been interpreted as the top of a relatively featureless to poorly-resolved section that is presumed to be continental crust and contains evidence in part of intrusive bodies, volcanic flows, dipping reflectors (Fig. 14), faulting and folding. Horizon *icc* spatially coincides with the continental slope and probably corresponds to top of a thinned magmatically modified continental crust of uncertain affinity.

Form Lines (*mz, pz*)

Form lines have been used to help highlight the general form of the sedimentary section (Figs 11–12 & 14) as well as localised unconformities. Form lines include *mz* where Mesozoic section is interpreted and *pz* where Paleozoic section is interpreted.

6.3 'Volcanic' Seismic Horizons/Volcanic Crustal Types

Seismic volcanostratigraphy is a relatively new branch of seismic stratigraphy, which uses seismic sequence and facies analysis for describing volcanic margin complexes. This approach was first applied in the Columbian Basin by Bowland & Rosencratz (1988) for describing volcanic constructions, and developed further for volcanic margins by Planke *et al*. (1997, 1998, 2000) and Symonds *et al*. (1998). Planke *et al*. (1997, 1998, 2000) and Symonds *et al*. (1998) based their work on seismic data from the Voring margin off Norway as well as the western Australian margin. A typical extrusive break-up sequence on a rifted margin is sub-divided into four main seismic facies, including: (1) landward flows; (2) inner seaward dipping reflector sequences (SDRS); (3) outer high; and (4) outer SDRS (Fig. 15).

Knowledge of volcanic rifted margins has improved dramatically over the last 10 years. Eldholm *et al*. (1995) defined five crustal provinces that are commonly observed on volcanic margins:

(1) "normal" continental crust;
(2) continental crust thinning seaward with a moderate amount of intrusions;
(3) strongly extended and intruded continental crust underlain by a high-velocity (7.1-7.7 km/s) lower crustal body (LCB);
(4) "volcanic margin" crust (Eldholm and Grue, 1994), also with a LCB; and
(5) "normal" oceanic crust.

There are normally no sharp lateral boundaries between the various provinces.

The definition of a continent-ocean boundary (COB) on volcanic margins is quite difficult, and is commonly thought to mark the change from the intruded, thinned continental crust of province 3, to crust composed entirely of igneous rock emplaced during breakup in province 4; that is, somewhere beneath the main SDRS. Symonds *et al*. (2000) argues that the COB is a relatively meaningless concept on volcanic margins, and the use of the term "continent-ocean transition" (COT) is probably more appropriate. One way of viewing the COT on a volcanic margin is that it lies between 'normal' oceanic crust (province 5) and 'normal' rift zone crust (province 2). It would therefore include all provinces associated with significant volumes of breakup extrusives and intrusives and the LCB, as well as abnormal 'oceanic'/magmatic crust and highly altered continental crust (Symonds *et al*., 2000). Such an interpretation fits well with volcanic margins such as the western Australian margin, where multiple SDRSs, volcanic buildups, outer highs and thicker then normal 'oceanic' crust can all occur over a 300 km wide zone west of extended continental crust (e.g. the western Exmouth Plateau; Symonds *et al*., 2000).

Thus, in the case of volcanic margins, excess melt production prior to and during breakup, will result in intrusions and lava flows (SDRSs) altering and covering pre-existing crust, and can produce a complex transitional volcanic margin crust that is distinctly different in character, composition and thickness from 'normal' continental and oceanic crust. The tectono-magmatic processes that form this type of crust are margin-building processes largely unrelated to 'normal' systematic seafloor spreading that forms the deep ocean basins.

In the past, evidence for highly extended and modified continental crust lying beneath lava flows in the volcanic margin transition zone has been difficult to come by. Recently, Berndt *et al*. (2001a) suggested that fragments of continental crust have controlled the geometry of multiple SDRSs beneath the central Vøring margin off Norway, and Tsikalas *et* al. (2001) have located 'windows' in the lava cover on the Lofoten-Vesterålen volcanic margin off Norway in which they have been able to image deformed Mesozoic sequences below. Such interpretations reinforce the notion of a volcanic margin transition zone which can be considered to have its own discrete crustal type incorporating modified continental crust and pure magmatic crust. We will refer to the crust within the transition zone as volcanic margin crust. High-quality seismic data and the detailed nature of the study have allowed us to map the distribution of various crustal types, including volcanic margin crust, and to interpret the various volcanic facies mentioned above and previously described by Symonds *et al*. (1998). We have also interpreted additional volcanic seismic facies and mapped them as volcano-tectonic provinces and features (Fig. 10).

Top Composite Volcanics on Volcanic Margin Crust (*cvvm*)

Seismic horizon *cvvm* is defined as the top of a composite volcanogenic complex made up of multiple volcanic build-ups and/or large volcanogenic mounds. Horizon *cvvm* has been used exclusively for the Quokka Rise and Zenith Seamount (Fig. 10). The seismic character underlying *cvvm* is generally bland but can include downlapping events (Fig. 16) that are interpreted as ?volcanic deltas.

Top Composite Volcanics on ?Continental Crust (*cvcc*)

Seismic horizon *cvcc* is defined as the top of a ?composite volcanogenic complex made up of multiple volcanic build-ups and/or volcanogenic mounds, and/or ?continental blocks and crust (Fig. 17). Horizon *cvcc* has also been used to designate the ?collapsed volcanic complex or caldera identified on the Wallaby Plateau, where reflections dip towards a ?vent on adjoining lines (Fig. 18). In the latter case, individual volcanic flows have been interpreted over the ?collapsed volcanic complex. Horizon *cvcc* has been interpreted exclusively over the southern Wallaby Plateau (Fig. 10).

Top Composite Volcanics on Layered Volcanic Margin Crust (*cvlc*)

Seismic horizon *cvlc* is defined as the top of a composite volcanogenic complex made up of multiple volcanic build-ups and/or volcanogenic mounds with evidence of ?crustal layers being present (Fig. 19). Horizon *cvlc* has been interpreted beneath the northern part of the Wallaby Plateau (Fig. 10).

Top of Rough ?Oceanic and Volcanic Margin Basement (*tobr*)

Seismic horizon *tobr* defines the top of rough ?oceanic/volcanic margin basement (Fig. 20). It is generally a high-amplitude event that is readily mappable, although shallow sills in the overlying sedimentary section may obscure it. The seismic character underlying horizon *tobr* is often bland. The horizon has been interpreted on the fringes of the Wallaby Plateau, Quokka Rise and Wallaby Saddle, and beneath the Wallaby-Zenith Basin between the Zenith Seamount and Wallaby Plateau (Fig. 10).

Top of Smooth Oceanic Basement (*tobs*)

Seismic horizon *tobs* defines the top of smooth oceanic basement underlying the abyssal plain (Fig. 13), and is interpreted in both the Perth and Cuvier Abyssal Plains. The horizon is generally a high-amplitude event that is readily interpretable, although shallow sills in the overlying sedimentary section may occasionally obscure it.

Top of Layered Oceanic Basement (*tobl*)

Seismic horizon *tobl* defines the top of smooth oceanic basement underlying the abyssal plain (Fig. 21), but differs from horizon *tobs* in that it has up to 0.5 s of flat-lying low-frequency reflectors underlying it. Horizon *tobl* is defined as a high-amplitude event and is readily mappable. Horizon *tobl* has been interpreted immediately west of the Cape Range Fracture Zone but cannot be clearly defined geographically due to poor seismic coverage in the area. Horizon *tobl* has, as a consequence, been merged with horizon *tobs* in Figure 10.

Top Lower Slope Volcanics (*slop*)

Seismic horizon *slop* defines the top of ?volcanic basement on the lower continental slope where the dominantly continental crust is interpreted to have been magmatically modified (Plate 5). Horizon *slop* is a high-amplitude event that is readily mappable, although shallow sills in the overlying sedimentary section may obscure it. Horizon *slop* has been interpreted along the eastern margin of the Cuvier Abyssal Plain.

Intrusions (*intr*)

Seismic horizon *intr* defines top of individual intrusions in continental crust.

Top Volcanics Extruded Along Transform Faults (*tiv*)

Seismic horizon *tiv* defines top of volcanic build-ups and other volcanic features extruded along transform faults, including both the Cape Range Fracture Zone and Wallaby-Zenithy Fracture Zone. These volcanic build-ups form extensive elongate ridges that have a vertical relief ranging from several hundred metres to more than 1000 m (Fig. 22).

Top Build-ups (*buil*)

Seismic horizon *buil* defines top of volcanic build-ups located within the Wallaby-Cuvier area. The relief of individual build-ups may vary from a few tens of metres to hundreds of metres. No internal reflection character is evident (Fig. 20).

Top of Seaward Dipping Reflector Sequence (*tsdr*)

Seismic horizon *tsdr* defines the top of seaward dipping reflector sequences (SDRSs). SDRSs are wedge-shaped and have a divergent seismic reflection configuration (Fig. 23). SDRSs vary in length from 10–50 km, and their thickness varies up to about 8 km. The oceanwards boundary of an SDRS often appears to be a landward-dipping extensional fault. Alternatively, this apparent fault may consist of feeder dykes that have subsequently been rotated from the vertical as the SDRS has subsided and tilted. The base of an SDRS is not prominent. In the Wallaby Saddle, the outer SDRS is smaller than the inner SDRS and the reflection configuration is less divergent (see Fig. 15).

Mutiple stacked SDRSs have been interpreted beneath the Wallaby Saddle and individual SDRSs have been interpreted beneath the outer southwestern Exmouth Plateau, and margins of the Cuvier Abyssal Plain (Fig. 10). SDRSs beneath the deep margin of the Exmouth Plateau (Stagg *et al*., 2003) and adjacent to the Cuvier Abyssal Plain are generally not as well defined as those beneath the Wallaby Saddle. No clear SDRSs have, as yet, been interpreted on the flanks of the Wallaby Plateau.

Top of Landward Lava Flows Over SDRSs and Rifted Crust (*flow*)

Seismic horizon *flow* is interpreted as the top of lava flows that have been extruded landwards over the top of SDRSs and continental fault blocks. Horizon *flow* is characterised by high-amplitude irregular reflections while the section underlying it may be masked. Horizon *flow* has been interpreted on the eastern edge of the Wallaby Saddle adjacent to the zone of SDRS.

Top of Undifferentiated Volcanic Build-up Between SDRSs (*udif*)

Adjacent SDRSs are typically separated by volcanic build-ups that are defined by the seismic horizon *udif*. These volcanic build-ups may have relief ranging from a few tens of metres to several hundred metres. No internal reflection character is evident (Fig. 24).

Top Debris Flows (*tdeb*)

Debris flows have been interpreted at the base of steep slopes such as those near volcanic ridges and volcanic build-ups, and are represented by the seismic horizon *tdeb* (Fig. 25).

Top Flows/sills on Volcanic Basement (*vflo*)

Seismic horizon *vflo* defines the top of late-stage lava flows over magmatically modified ?continental crust or onto sediments overlying such crust (Fig. 18).

Moho (*moho*)

Seismic horizon *moho* defines the top of Moho and has only been interpreted in the Cuvier Abyssal Plain (e.g. Plate 6, line 135/11).

Form Lines (*sd*, *vo*, *sill*)

Form lines in volcanic units, similar to form lines in sedimentary units, have been used to highlight: (1) SDRSs (i.e. *sd*; Figures 23–24); (2) volcanic units as yet unidentified (i.e. *vo*; Figures 13, 16, 19, 21 & 25); and (3) high-amplitude reflectors that cross-cut the dominant reflector trends (i.e. *sill*; Figures 17 & 22). Horizon *vo* in Figure 26 outlines what is interpreted as an intrusive-like body on the Wallaby Plateau overlain by packages of sub-parallel reflectors that may have both a continental and/or magmatic origin.

7. VOLCANO-TECTONIC PROVINCE MAPPING

7.1 Introduction

A large quantity of seismic data (totaling 13 000 km) was interpreted in the six month period available to this study. The resulting volcano-tectonic provinces and features map is shown in Figure 10. This chapter describes the volcano-tectonic provinces and features, and builds in aspects of structural elements and events pertinent to the North West Shelf region.

The following broad volcano-tectonic provinces have been differentiated in this work: (1) Cuvier Abyssal Plain; (2) Cape Range Fracture Zone; (3) Perth Abyssal Plain; (4) Wallaby-Zenith Fracture Zone; (5) Wallaby Plateau; (6) Quokka Rise and Zenith Seamount; (7) Other transitional areas that includes the Wallaby Saddle; and (8) western Australian margin.

7.2 Volcano-tectonic Provinces and Features

Cuvier Abyssal Plain

The Cuvier Abyssal Plain covers the northern part of the Wallaby-Cuvier area (Fig. 10). Basement topography is very smooth and is represented both on seismic sections and in map-form as *tobs*. The smoothness of the Cuvier Abyssal Plain is broken up by volcanic ridges (i.e. *vo* in Fig. 10), and is intruded in places by volcanic build-ups (i.e. *buil* in Fig. 10). These volcanic build-ups are in the order of 1–20 km across. The abyssal plain has also been affected by the Late Miocene reactivation, and faults can be seen within the sedimentary section in the northern part of the abyssal plain, particularly around volcanic build-ups (Fig. 27), and adjacent to the Cape Range Fracture Zone (Plate 1).

Cape Range Fracture Zone

The Cape Range Fracture Zone is of the order of 20–30 km wide and is a major transform that bounds the southern edge of the Exmouth Plateau and the northern edge of the Cuvier Abyssal Plain. It is linked to the volcano-tectonic feature 'transform volcanics' that defines a zone of volcanics extruded along the transform (i.e. *tiv* in Fig. 10). Detailed fault patterns around the Cape Range Fracture Zone have not been interpreted although, as mentioned above, Late Miocene reactivation faults are present in the Cuvier Abyssal Plain region, adjacent to the transform.

Perth Abyssal Plain

The Perth Abyssal Plain has not been extensively studied as it lies on the fringe of the study area. Where it has been examined on its northern margin, it is characterised by smooth oceanic basement (i.e. *tobs* in Fig. 10).

Wallaby-Zenith Fracture Zone

The Wallaby-Zenith Fracture Zone is of the order of 100–150 km wide and is a major transform that bounds the souther edge of the Wallaby-Cuvier area and the northern edge of the Perth Abyssal Plain. The northern part of the transform is flanked by a zone 20–40 km wide made up of large volcanic ridges and build-ups (i.e. *tiv* in Fig. 10). The largest of these volcanic build-ups are represented by the volcano-tectonic feature *buil*. The fracture zone is cross-cut west of the Wallaby Plateau by a volcanic ridge, about 30–40 km wide, and at least 500 km in extent (i.e. *vo* in Fig. 10). Both the fracture zone and volcanic ridge have been identified from the regional gravity image. The width of the fracture zone is significant as it may indicate an oblique component of movement during breakup in the region, and thus the potential for significant volcanism along the transform.

Wallaby Plateau

The Wallaby Plateau shows evidence of 'sedimentary-style' layering and faulting (Fig. 17), as well as magmatism both in the form of intrusive bodies and lava flows. The plateau has been differentiated in this study into: (1) a southern area made up of composite volcanics on possible continental crust (i.e. *cvcc* in Fig. 10); and (2) a northern area made up of composite layered volcanics on crust of uncertain origin or affinity that has been classified as volcanic margin crust (i.e. *cvlc* in Fig. 10).

The possibility of continental material within the core of the Wallaby Plateau comes from four observations:

(1) Packages of parallel seismic reflections underlying parts of the plateau that appear to be indicative of sedimentary layering (e.g. Figure 17 and Line 135/11, Plate 6), similar to that observed in sedimentary basins on adjacent parts of the continental margin, rather than volcanic sequences typical of Large Igneous Provinces (LIPs) and volcanic margins. As discussed by Symonds *et al*. (1998) the seismic character of parts of the Wallaby Plateau (e.g. Fig. 17) is similar to that of the Triassic blocks beneath the Exmouth Plateau, and to parts of the Mesozoic and Paleozoic sedimentary section of the Houtman Sub-basin beneath the adjacent Carnarvon Terrace (Fig. 12).

(2) Faulting and folding (Figs 17 & 26) within the possible sedimentary section is similar to that within sedimentary basins on the adjacent margin (e.g. Fig. 12).;

(3) Differences in seismic character between areas of non-reflective known/sampled volcanics (e.g. Fig. 22) and adjacent areas of thick reflector sequences (e.g. Fig. 17).

(4) Analogies to other Indian Ocean plateaus which have been shown by drilling or dredging to contain continental fragments within an otherwise "oceanic" or magmatic setting. Particular examples of the latter line of evidence are the Naturaliste Plateau, where Cambrian gneisses where dredged from its southern flank in 1998 (Beslier *et al*., 2001; Borissova, 2002); and the Kerguelen Plateau where ODP Site 1137 on Elan Bank recovered clasts of garnet-biotitie gneiss (Nicolaysen *et al*., 2001; Borissova *et al*. 2002). However, it should be noted that to date no pre-

break-up sedimentary rocks have been recovered from limited sampling of the Wallaby Plateau.

Volcanic build-ups have been mapped on the Wallaby Plateau within the volcano-tectonic province element 'composite volcanics on ?continental crust' (i.e. *cvcc* in Fig. 10). These build-ups range in size from several kilometres up to 50 km across. They are not ridge-like nor uniformly smooth in shape and appear to differ in origin from volcanic build-ups identified over oceanic basement areas (i.e. *tobs* & *tobr* in Fig. 10). Their origin will be discussed in Chapter 9.

Quokka Rise and Zenith Seamount

The Quokka Rise is relatively unstructured and is characterised by a complex of mound features. Sigmoidal downlapping pattern typical of volcanogenic deltas and flows are evident in the top 0.3 sec.

We have classified the Quokka Rise as 'composite volcanics on volcanic margin crust' (i.e. *cvvm* in Fig. 10). The classification *cvvm* differs from the classifications *cvcc* & *cvlc* present on the Wallaby Plateau by having a generally bland internal character.

The Zenith Seamount has not been studied in any detail but, based on satellite gravity data (Fig. 7), may be similar to the Quokka Rise.

Transitional Areas

The Cuvier Abyssal Plain merges with the volcano-tectonic province element 'slope volcanics' (i.e. *slop* in Fig. 10), present at the base of continental slope. Further to the south, in the Wallaby Saddle, the 'slope volcanics' feature (*slop)* merges with a large area of seaward dipping reflector sequences (i.e. *SDRS* in Fig. 10). The change in character between the two areas may indicate that different extensional and/or volcanogenic processes were operating (see Chapter 9).

Areas NW, W and E of the Wallaby Plateau, as well as N of the Quokka Rise, are characterised by a rough ?oceanic/volcanic margin basement topography (i.e. *tobr* in Fig. 10). These areas contrast significantly with the smooth topography of the Cuvier Abyssal Plain, which is probably underlain by "normal' oceanic crust. The 'tobr' province that coincides with the Wallaby-Zenith Basin (e.g. seismic line 135/08, Plate 5) may relate to an epsiode of Barremian (M4-M0) spreading and rift propagation between the Wallaby Plateau and Zenith Seamount.

Western Australian Margin

The volcano-tectonic feature 'slope volcanics' (i.e. *slop* in Fig. 10) grades landward into 'intruded continental crust' (i.e. *icc* in Fig. 10) along the eastern edge of the Cuvier Abyssal Plain. In this area, possible intrusive bodies and compressional structures have been interpreted within Mesozoic sediments. The compressional structures present on the continental slope south and west of the Bernier Platform (Plates 5–6) are faulted and folded and may have been formed contemporaneously with the Wallaby-Zenith Fracture Zone during Valanginian break-up, resulting in en-echelon structures. Late-stage, near-top Miocene–Pliocene faulting is recorded in Cretaceous to probable late Miocene–Pliocene sediments overlying the Bernier Platform (e.g. seismic line 135/10, Plate 6), although it appears to be localised.

In the area immediately NNE of the Wallaby-Zenith Fracture Zone, 'basement' blocks form terraces. Normal faulting prevails and folding of probable Paleozoic sediments occurs across a zone at least 60 km wide. The seismic data are, however, too sparse to accurately ascertain the faulting patterns.

7.3 Magnetic Anomalies

As part of this study, the magnetic anomalies, pseudo-faults and transforms of Müller *et al*. (1998) and Mihut & Müller (1998b) were checked against features and the volcano-tectonic provinces mapped from seismic data. This comparison allowed an assessment of the robustness of both interpretations. For example, magnetic lineaments (Fig. 9) overlying the Cuvier Abyssal Plain and smooth oceanic basement (i.e. *tobs* in Figure 10) are deemed reliable. However, seafloor spreading magnetic lineaments interpreted over the Wallaby Saddle (i.e. associated with *tobr* and *SDRS* in Figure 10) are unreliable as the seismic data does not indicate oceanic crust. Linear magnetic anomalies in this area may relate to the SDRSs themselves or to other volcanic/magmatic features (e.g. elongate intrusions) associated with volcanic margin development.

8. RESOURCE POTENTIAL

The study area is made up of a number of sub-basins and other structural elements with a diversity of geology and, hence, resource potential. These elements and those exploration wells discussed below are shown in Figure 8.

8.1 Gascoyne and Houtman Sub-basins

Introduction

The Gascoyne Sub-basin (of the Southern Carnarvon Basin) and Houtman Sub-basin (of the Perth Basin) are located on the western Australian margin bordering the Wallaby-Cuvier area (Fig. 4). The sub-basins are located on the fringe of the study area and so haven't been studied intensively as part of the present study.

Reprocessing of the Shell-*Petrel* survey seismic data in recent years has provided an upgraded dataset with which to review the Gascoyne Sub-basin and northern margin of the Houtman Sub-basin. Preliminary interpretation of lines N305, N306 and 135/10 was made, and a depocentre of limited extent has been interpreted. The depocentre is located on the outer shelf/ slope, in water depths ranging from 800–900 m, and may contain up to 5 km of sediments (Fig. 12). The Mesozoic section seen on line N306 and underlying horizon *val* is seismically bland, which is consistent with the regional character of the basal Triassic Locker Shale or its equivalent. The presence or absence of either Triassic or Jurassic sediments can, however, not be confirmed until the section is drilled.

The presence in the adjacent Houtman Sub-basin of a thick Triassic section overlain by a thin Jurassic section or alternatively thick Jurassic section, possibly in excess of 3 km, has been described by Marshall *et al*. (1989) and Seggie (1990). Pendock-1, located in the Gascoyne Sub-basin and drilled by Genoa Oil NL (1970), intersected 250 m of Upper Cretaceous sediments that overlie Upper Silurian–Lower Carboniferous sediments.

Hydrocarbon Shows

Wells Houtman-1 and Wittecarra-1 in the Houtman Sub-basin have recorded hydrocarbon shows. Galloway (1978) described results from the Houtman-1 well as follows:

> 'Fluorescence, cut and brown oil staining in core, a gas anomaly on the density/neutron log, high carbon number hydrocarbons (liquid) on the gas detector and gas and oil scum from Formation Interval Tests indicate a gas saturated sandstone with considerable liquids, some in the liquid state in the reservoir. Production testing yielded no hydrocarbons, only mud filtrate, indicating deep invasion by the mud and the potential for significant formation damage. This is supported by the fact that the formation was open to high weight drilling mud (11.5 lb/gal. equating to a 34% or 1600 psi pressure differential at depth) for one month prior to casing and testing and the fact that the sandstones contain substantial kaolinite. The clogging of pore throats is believed to be the result. The core analysis

> and production testing indicate that the sand lacked any permeability but this is contradicted by the SP log and calliper log responses.'

The above well tested the basal Cadda Formation of Jurassic age.

BHP Petroleum Pty Ltd (1986) summarised shows recorded in the Wittecarra-1 well as follows:

> 'Wittecarra-1 recorded minor fluorescence with moderate cut encountered with increased gas readings between 1850–1950 metres. A small, faulted, four way dip closure is apparent in seismic TWT but closure is less obvious once the effect of the sloping water bottom is removed.'

That well tested the top Woodada Formation of Triassic age.

No shows have been recorded in Pendock-1 located in the Gascoyne Sub-basin, and no shows have been recorded elsewhere in the offshore part of the sub-basin.

Prospectivity

In the north Houtman Sub-basin, the marine Kockatea Shale of the Lower Triassic may be an oil-prone source whilst the Lower Permian Cattamarra Coal Measures may provide a gas-prone source (Marshall *et al*., 1989).

Potential reservoirs may include the Upper Jurassic non-marine sandstones of the Yarragadee Formation, Lower Jurassic non-marine sandstone, marginal marine sandstones of the Cockleshell Gully, and Upper Triassic non-marine sandstones of the Lesueur Formation (Marshall *et al*., 1989).

The mid-Jurassic volcanic Cadda Formation and Lower Jurassic marginal marine Cockleshell Gully Formation may provide local seals. The Valanginian to Quaternary post-break-up section may contain sediments up to 1.5 km thick with probably immature source rocks, but may act as a regional seal where it thickens offshore. Inshore, updip wells Edel-1, Wittecarra-1 and Houtman-1 intersected condensed to thin Cretaceous sequences less than 100 m thick.

No information is readily available to assess maturation, timing and migration.

Summary

The localised ?Mesozoic depocentre identified in the Houtman Sub-basin is up to 5 km thick, and may contain elements favourable to hydrocarbon generation and entrapment. Water depths vary from 800–1200 m, which is a range accessible to current drilling technology. Structural/stratigraphic traps with ?Triassic/Jurassic reservoirs sealed by post-Valanginian sediments exist (Fig. 12). Structural traps may exist within positive flower structures associated with the Wallaby-Zenith Fracture Zone. Rollovers involving sediments juxtoposed against basement may also be present. A more-detailed study is needed to ascertain and rank the prospectivity elements within both the Gascoyne and Houtman Sub-basins.

8.2 Exmouth Sub-basin

Introduction

The Exmouth Sub-basin is located NE of the Wallaby-Cuvier area and cuts across the Cape Range Fracture Zone (Fig. 4). The architecture of the southern extremity of the sub-basin has been briefly studied using seismic lines from BMR Surveys 17–18, AGSO Survey 136 and Shell-*Petrel* survey. The sedimentary section is up to 3 km thick (2 s TWT) but thins to the south. Sub-parallel seismic reflectors suggest Triassic and/or Berriasian–Valanginian sediments. Discordant reflectors cross-cutting sediments are assumed to be sills, and thus reflect a component of igneous activity within these sediments.

Hydrocarbon Shows

Resolution-1 (Fig. 8) intersected a gas-saturated interval interpreted from electrical logs. Crush cut fluorescence was also observed in Triassic cuttings. Ten formation tests were run in the Triassic section; of these, one test recovered 11.33 L of gas and 23.3 L of filtrate (Esso, 1980) Weak shows were also recorded in the Upper Jurassic Dingo Claystone where a very dull, slow blue crush cut fluorescence was logged. No shows were recorded in the Cretaceous Barrow Group equivalents.

In recent years, a number of significant hydrocarbon discoveries have been made in the Exmouth Sub-basin to the E and SE of Resolution-1. These include Vincent-1 and Enfield-1 (oil and gas discoveries), Coniston-1 (oil discovery) and Laverda-1 (oil discovery).

Prospectivity

Both Jurassic and Triassic source rocks were intersected in Resolution-1 (Fig. 8). The Upper Jurassic Dingo Claystone, for example, is considered a rich source rock with an excellent oil-prone rating and is ranked as the most prospective source rock in the Exmouth Sub-basin. For example, values of 2.36% for total organic carbon (TOC) were measured between 3345 –3745 m. In contrast, coals in the Triassic section are considered as fair-to-good gas- and oil-prone source rock with an average TOC of 2.53% in the interval 3758–3883.8 m. The Cretaceous shales contain less than 1% TOC and are rated as poor potential source rocks (Esso, 1980).

Resolution-1 intersected 104 m of Triassic sandstones and 845 m of massive and interbedded sands belonging to the Barrow Group and the Mardie Greensand, thus establishing the presence of clastic reservoirs (Esso, 1980).

The Cretaceous and Upper Jurassic sections are considered to be excellent regional seals in the main depocentre but thin towards the edges of the basin and to the south (Esso, 1980).

Triassic–Jurassic source rocks in the southern Exmouth Sub-basin may be immature to sub-mature at best, based on thickness of sediment. However, increased heatflows from episodic volcanic events around time of break-up may have contributed to the maturation of potential source rocks.

Summary

The Exmouth Sub-basin is prospective to the north while the prospectivity in the southern part of the basin is unknown. A thinner sedimentary section may downgrade the prospectivity of the southern Exmouth Sub-basin although drilling would be required to confirm this as well as the age of the sediment. The sedimentary section could, for example, be an equivalent of Barrow Delta sediments intersected elsewhere in the Exmouth Sub-basin. Further work will be required to assess the southern Exmouth Sub-basin more fully. The existence of traps cannot be ascertained from our work but may include fault, horst and stratigraphic types.

8.3 Cuvier Abyssal Plain

Introduction

The thickest depocentre in the Cuvier Abyssal Plain is located to the NE with sediment thickness ranging up to 3 km. These sediments form a wedge at the base of the continental slope and are bounded to the north by the Cape Range Fracture Zone. Thickness of sediment elsewhere on the Cuvier Abyssal Plain is generally in the order of 2 km or less. All sediments are post-Valanginian in age.

Hydrocarbon Shows

No petroleum wells have been drilled in close vicinity to the Cuvier Abyssal Plain, and only one well, DSDP Site 263, penetrated sediments of the Cuvier Abyssal Plain.

Prospectivity

No source rock data are available from which to make a reliable interpretation on the likelihood of source rocks.

Sediments deposited during or immediately after initiation of sea-floor spreading, in the Valanginian, may contain coarse clastic sediments intermixed with volcanoclastics. Any potential reservoirs in volcanoclastic sediments can be expected to be highly variable laterally.

Sediments deposited on the Cuvier Abyssal Plain should consist predominantly of marine shales and deep water carbonates, so that the presence of seal units is likely, at least in the upper part of the sediment section. A good regional seal at the base of the sediment section is unlikely although multiple local seals are likely to be present.

It is probable that any potential source rocks deposited on the Cuvier Abyssal Plain are immature to sub-mature at best, based on thickness of sediment encountered (i.e. <3 km).

Summary

Potential petroleum traps in this area may include rollovers over basement highs or stratigraphic traps. As any potential source rocks are likely to be sub-mature at best, prospectivity of this area must be rated as low.

8.4 Wallaby Plateau

The petroleum prospectivity of the Wallaby Plateau has been investigated in this study solely from interpretation of seismic data, as no petroleum wells have been drilled. Although one area of the Wallaby Plateau may contain possible Mesozoic sediments, most of the Wallaby Plateau probably consists of volcanogenic sequences with negligible hydrocarbon potential. No petroleum wells have been drilled on the plateau and no geochemical data exists. Overall, the prospectivity of the Wallaby Plateau is rated as low to very low in view of the dominant volcanogenic nature of the province and the excessive water depths, generally greater then 2100 m.

8.5 Non-petroleum Resources

Manganese nodules and crusts have been recovered as part of dredge hauls in the Wallaby-Cuvier area (Appendix 3). In particular, manganese nodules and crusts are common on current-swept areas of the Sonne Ridge and Wallaby Plateau (e.g. dredge hauls S08-148KD (054DR046), S08-161KD (054DR055), S08-165KD (054DR058), S08-167KD (054DR060), S08-170KD (054DR063), S08-148KD (096DR036) & S08-161KD (096DR038), see Appendix 3). von Stackelberg *et al*. (1980) noted that almost all the deep-sea dredged rocks have blackish-brown coatings of iron–manganese oxides of relatively young age. The crusts vary in thickness from less than a millimetre to about a centimetre. The nodules commonly have volcanic cores and both nodules and crusts may have a rough botryoidal surface. In many crusts, rock fragments have been incorporated, giving the crusts the appearance of polynodules.

The presence of manganese nodules and crusts raises the possibility that resource potential may exist in the form of deep-sea metals (Table 4). Table 4 lists atomic absorption analyses obtained by von Stackelberg *et al*. (1980). Both nodules and crusts are of low grade, and of no commercial interest. Given the low grades and the worldwide lack of commercialisation of even high (> 2% Ni + Cu + Co) grade nodules, the manganese nodules and crusts of the Wallaby-Cuvier area are unlikely to have any economic value, even in the long term.

Table 4: Manganese nodules and crusts (after von Stackelberg *et al*., 1980)

Area (station)	**Water depth (m)**	**Fe%**	**Mn%**	**Ni%**	**Cu%**	**Co%**	**Ni+Cu+ Co %**	**Analyst (no.)**
Sonne Ridge nodules S08-148KD (054DR046)	4800	12.00 13.40	15.63 18.40	0.39 0.28	0.28 0.28	0.19 0.20	0.86 1.02	BGR (1) BMR (1)
Wallaby Plateau nodules S08-	4800–4600	13.82 13.70	15.63 11.30	0.33 0.24	0.19 0.16	0.28 0.20	0.80 0.60	BGR (2) BMR (1)

165KD (054DR058 & S08-170KD 054DR063)								
Wallaby Plateau nodules S08-167KD (054DR060)	5300	13.45 13.60	15.38 16.70	0.25 0.31	0.13 0.15	0.22 0.23	0.60 0.69	BGR (1) BMR (1)
Average all nodules	4400–5300	13.09 13.57	15.55 15.47	0.32 0.36	0.20 0.20	0.23 0.21	0.75 0.77	BGR (4) BMR (3)
Average all crusts	2500–5300	12.71 18.15	12.23 15.93	0.28 0.32	0.09 0.14	0.16 0.20	0.53 0.66	BGR(26) BMR (6)

9. DISCUSSION

9.1 Introduction

The continental margin in the vicinity of the Wallaby Plateau has a number of significant characteristics. Firstly, the margin is largely dominated by volcanics, as is also the case on other parts of the western Australian margin (see e.g. Symonds *et al*., 1998). Secondly, transform-faults influence major portions of the margin. Thirdly, sedimentary basins are poorly defined and appear restricted in size.

The present study includes the interpretation of volcano-tectonic provinces and features based on recently acquired and newly reprocessed multi-channel seismic data (i.e. AGSO Survey 135, Shell-*Petrel* survey). This chapter assesses the origin of the various volcano-tectonic provinces and features identified in the Wallaby-Cuvier area, makes comparisons with other volcanic margins around the world, and examines the evolution of this complex region.

9.2 Case for the Volcanic Origin of the Wallaby-Cuvier Area

Large Igneous Provinces

The world's rifted continental margins may be differentiated as either non-volcanic or volcanic (Symonds *et al*. 1998). Volcanic rifted continental margins underwent excessive transient volcanic activity during continental break-up and the initial period of sea-floor spreading, and are commonly associated with Large Igneous Provinces (LIPs). LIPs are characterised by voluminous emplacements of predominantly mafic rocks that do not originate at normal sea-floor spreading centres, and may include continental flood basalts, oceanic plateaus and ocean basin flood basalts (Eldholm *et al*., 1995). LIPs usually contain enormous volumes of lava that settled in place very rapidly, and they have similarities in their temporal, spatial and compositional characteristics.

The volcanic nature of the western Australian margin has been described by Crawford & von Rad (1994), Planke *et al*. (1996), Symonds *et al*. (1996), and Symonds *et al*. (1998). These studies have confirmed the presence of an extensive magmatic province bordering the western Australian margin. However, the moderate level of break-up related volcanism in this region, compared to areas such as the North Atlantic, has led to classification of the margin as a transitional or intermediate-type volcanic margin (Symonds *et al*. 1998).

The magmatic province bordering the western Australian margin includes:

(1) volcanic plateaus, multiple seaward dipping reflector sequences (SDRS) and hyaloclastic build-ups in the Wallaby-Cuvier area (Symonds *et al*. 1998). The volcanic plateaus include the Wallaby Plateau and Quokka

Rise, and the Zenith Seamount, and these have been referred to as LIPs by White & McKenzie (1989) and Coffin & Eldholm (1992);

(2) sills, dykes and magmatic underplating interpreted beneath the SW Exmouth Plateau (Frey, 1998); and

(3) flood basalts on the Rowley Terrace and Scott Plateau and subaerial basalt flows in the adjacent Browse Basin (Symonds *et al*., 1998).

All these volcanic features are thought to result from transient voluminous magmatism at about, or just following, the time of continental break-up. The nature and significance of volcanic plateaus, and detailed timing of volcanism in the Wallaby-Cuvier area are poorly understood, and are discussed further below.

Seaward Dipping Reflector Sequences

General description

The presence of SDRSs near a continent/volcanic margin–ocean boundary is one criteria used to classify margins as volcanic (Symonds *et al*., 1998). SDRSs were first defined from Ocean Drilling Program Leg 104, which drilled 800 m through the entire inner part of an SDRS (Eldholm, Tiede, Taylor *et al*., 1987; Planke, 1994) at ODP Site 642, on the Voring margin off Norway. The drilling results confirmed that the inner part of the SDRS consists of subaerially emplaced flood basalts intercalated with sediments (Fig. 15). Flow thicknesses vary from 0.6–18.5 m, while most sediment layers are less than 1 m thick (Planke, 1994). An outer volcanic high occurs near the seaward termination of the inner part of the SDRS. Further seaward, a smooth, top-basement reflector, commonly underlain by an outer SDRS, is interpreted as the top of a sequence of flood basalts and shallow sills emplaced in a deep marine environment. No outer SDRS has yet been drilled.

The identification of facies units within a volcanic margin complex (i.e. from the shallow to deeper water - inner flow, lava delta, landward flow, inner SDRS, outer volcanic high, and outer SDRS, respectively; Figure 15), formed the basis for the development of volcanostratigraphy concepts (Planke *et al*., 1997, 1998; Planke *et al*. 2000). The characteristics of the major volcanic margin facies are described below. Such volcanic facies have been interpreted in the Wallaby-Cuvier area including well-preserved SDRSs beneath the Wallaby Saddle (Symonds et al.1998; Figure 23).

Landward Flows

Typically, this volcanic facies is imaged on seismic data as an irregular sheet-like body of sub-parallel, horizontal or seaward-dipping reflectors that pinch-out landward. They are commonly identified landward of and above the inner SDRS (Planke *et al*. 1998). The internal reflector configuration is typically chaotic and/or hummocky.

Inner Seaward Dipping Reflector Sequence

The top of the inner SDRS is defined by a high-amplitude reflector, but reflectivity within the SDRS is typically weaker and discontinuous, and forms a divergent-arcuate or divergent-planar pattern. Intra-SDRS reflector terminations and boundaries define each SDRS unit. The inner SDRS is commonly distinguished from the next SDRS by a ?landward dipping fault, and occasionally by an outer volcanic high - a mounded feature characterised by a strong reflector at the water-bottom, and chaotic internal reflector patterns (Planke *et al*. 2000).

Outer Volcanic High

The outer volcanic high of Planke *et al*. (2000) is thought to represent a volcanic build-up of hyaloclastic flows emplaced when the eruptive centre initially subsided into submarine conditions. Where the outer volcanic high is present in the Wallaby-Cuvier area it is less pronounced than similar features described from other volcanic margins (Eldholm, Thiede, Taylor *et al*. 1987; Eldholm *et al*. 1989). A typical outer high has a relief of several hundred metres, whereas outer volcanic highs in the Wallaby-Cuvier area have a relief less than 200 m. The extent of the outer volcanic high in the Wallaby-Cuvier area is unknown because of the relatively wide seismic line spacing.

Outer Seaward Dipping Reflector Sequence

The outer SDRS has a less-prominent reflection configuration and reflectors are shorter in extent than those of the inner SDRS. This may reflect deposition in deeper water resulting in less extensive lava flows.

Formation of SDRSs

The mechanism of SDRS formation has been widely debated in the literature over the past decade (Mutter *et al*., 1982; Gibson & Gibbs, 1987; Eldholm *et al*., 1995). Mutter *et al*. (1982) proposed a simple emplacement model in which the SDRS is formed by subsidence of the lava pile around the eruption centre due to loading and thermal contraction. This model invokes construction of an SDRS on both flanks of the incipient oceanic ridge axis, with subsequent ocean-floor separating SDRSs on opposing margins. SDRSs facing each other on one margin have, as yet, not been described which suggests the need for an oceanic ridge axis, or an asymmetric formation process. The Mutter *et al*. (1982) model also fails to explain the presence of multiple SDRS, as is the case beneath the Wallaby Saddle,

The abrupt seaward termination of each SDRS unit has been interpreted as occurring at a steep, slightly concave fault (Gibson & Gibbs, 1987), which developed as syn-constructional listric faults during fissure eruptions. In this scenario, the SDRS would infill a narrow, asymmetric rift basin. The subsequent seaward-dipping nature of the SDRS is explained by the continuing rotation of stacked landward flows down landward-dipping syn-constructional listric faults (Eldholm *et al*., 1995). However, normal extensional faults are rarely clearly imaged within the SDRSs, as is the case beneath the Wallaby Saddle (Fig. 23). Some good examples of such faults occur on the west Exmouth Plateau margin (Stagg et al., 2003) and have been interpreted on Gulf of Aden margin off Yemen (Tard et al., 1991). Eldholm *et al*. (1989) suggested that the symmetry of SDRSs on conjugate margins could be explained by simple shear extension during formation.

The presence of multiple SDRSs under the Wallaby Saddle may support the concept of normal faults associated with their formation. The faults themselves, could have acted as magma conduits, although it is possible that the eruption centres could have been located some distance away from the faults. Palaeo-relief combined with fault geometry probably determined the location of the SDRS.

The stacked nature of SDRSs under the Wallaby Saddle (Fig. 23) suggests that the inner SDRS is older. Consequently, the locus of extension and magma supply suggest a progressive migration of the eruptive centre to the NW. Seafloor spreading magnetic lineations interpreted by Müeller *et al*. (1998) over the Wallaby Saddle would indicate that these SDRSs were formed on oceanic crust; however, the complexity of basement seen on the seismic data indicates that the Wallaby Saddle is unlikely to have formed by 'normal' systematic seafloor spreading. Thus, crust of ?continental and/or transitional origin may occur beneath the Wallaby Saddle (Plate 5), and has likely been highly modified by magmatism. Such crust is probably best thought of as unique volcanic margin crust as it is modified and created by the specialised magmatic/volcanic processes that construct a volcanic margin.

Several explanations for the distribution of SDRSs in the Wallaby-Cuvier area (Fig. 10) are possible, as follows:

- Transform faults interpreted by Müeller *et al*. (1998) separate the Wallaby Saddle from the Cuvier Abyssal Plain (Fig. 9). These faults may separate two margin segments (i.e. Wallaby Saddle & Cuvier Abyssal Plain) that have differing spreading regimes and/or polarity.
- Alternatively, the Wallaby Saddle may be underlain by highly extended continental and/or transitional crust, while oceanic crust underlies the Cuvier Abyssal Plain. This is supported by gravity modelling along line 135/08 (R. Parums, pers. comm., 2002).The magma generation and extensional regimes may have differed significantly for both areas, resulting in SDRSs forming on volcanic margin crust in one area, and an abyssal plain being generated on oceanic crust in the other area. Eruptive and spreading centres may also be offset between both areas.
- Analogues of sea-floor spreading that are characterised by a system of propagating rifts and isolated volcanic centres, have been described in areas of back-arc spreading (Barker & Austin, 1998). The existence of several spatially disconnected magma chambers with multiple eruptive phases may have contributed to the complexity of the distribution and structural characteristics of the volcanic features observed in the Wallaby-Cuvier area.

Igneous Bodies of the Wallaby-Cuvier Area

Introduction

Igneous bodies mapped in the Wallaby-Cuvier area (Fig. 10) vary in their morphology, leading us to speculate that their modes of emplacement, and therefore possibly age and petrology, may differ. Examples include intrusive bodies beneath the Wallaby Plateau and continental margin; ?lava deltas on the Quokka Rise and Sonne Ridge; a ?caldera complex beneath the Wallaby Plateau; and bodies adjacent to transform-faults.

Lava Deltas

Lava deltas are interpreted on the eastern edge of the Sonne Ridge (Fig. 25) and on the Quokka Rise (Fig. 16). These volcanic facies are usually recognised by downlapping sequences associated with abrupt escarpments.

Caldera Complex

Wedge-shaped bodies have been interpreted beneath the Wallaby Plateau where reflections are seen to dip inwards on adjoining seismic lines (Fig. 18). The overall structure is interpreted as a collapsed volcanic complex or caldera. An evolutionary model for the Rotorua Caldera in New Zealand was proposed by Bailey & Carr (1994) (see Figure 28). Although this caldera formed in a quite different tectonic setting to the Wallaby Plateau, the inward-dipping blocks and wedges on the edge of the caldera, and secondary flows within the caldera, are similar to features seen on the Wallaby Plateau (Fig. 18). The evolutionary model for the Rotorua Caldera shows eruptive events and a drop of the magma level in the chamber (Fig. 28a & b). As the magma level drops and support is removed, the overlying chamber roof starts to collapse (Fig. 28c), eventually leading to full collapse and partial blowout of the chamber roof. Secondary magma pulses intrude up zones of weakness and lavas flow across the floor of the caldera, that may also be partially filled with water (Fig. 28d & e) and sediments.

Transform faults

The Cape Range Fracture Zone is estimated to be up to 50 km wide and is defined mainly from the physiography of the southern edge of the Exmouth Plateau (Fig. 3). Large-scale volcanic build-ups are also present in the outer Exmouth Plateau (Fig. 10), where discordant reflectors cut across sediments and indicate the presence of sills. In contrast, the Wallaby-Zenith Fracture Zone is defined from a satellite gravity-based low that is over 100 km wide, as well as from flanking volcanic ridges and build-ups. Müeller *et al*. (1998) interpreted the width of the latter transform to indicate partial rotation of the Greater India Plate during the drift stage. It is also probable that oblique drift of the Greater India Plate would have been conducive to excessive magmatism adjacent to the transform.

Mantle Plume Models

Considerable evidence from around the world suggests a link between volcanic rifted margin formation and the presence of mantle plumes that account for increased melt production. Both plume (e.g. White & McKenzie, 1989; Mihut & Müller, 1998b) and non-plume models (e.g. Mutter *et al*., 1988; Hopper *et al*., 1992; Planke *et al*., 1996; Planke *et al*., 1997) have been proposed to explain the arrangement of volcanic features along the western Australian margin. The model of Planke *et al*. (1997) is discussed below under the heading 'Continental Fragmentation in a Warm Mantle Model'. Other workers have proposed hybrid models incorporating non-plume rift and break-up-related volcanism, and plume-related (hot-spot) post-break-up volcanism (e.g. Colwell *et al*., 1994; Symonds *et al*., 1996).

Mihut & Müller (1998a, b) proposed that the Bernier Platform, Wallaby Plateau and Zenith Seamount resulted from a short-lived hotspot track, thus endorsing the mantle plume model. Arguments used by Mihut & Müller (1998a, b) are based on the following factors:

- the high standing nature of the Bernier Platform prior to break-up;
- the crustal thicknesses beneath the Wallaby Plateau and Zenith Seamount;
- the interpretation of magnetic data;
- an interpreted synthetic hotspot track of a 'Bernier hotspot'. The hotspot track fits the geometry of the Wallaby Plateau and Zenith Seamount, and shows that the features formed at about 130–125 Ma and 125–120 Ma, respectively, but mostly on the Indian plate; and
- the abrupt end is explained by the fact that the spreading ridge propagated away from the hotspot after 115 Ma, due to the fast ESE motion of the Australian plate relative to a nearly stationary Indian plate, using a mantle reference frame.

There are two interesting implications of this model. Firstly, it implies that most of the volcanism documented by the presence of the Wallaby Plateau and Zenith Seamount occurred on the Indian Plate. Secondly, the 100–150 km width of the Wallaby-Zenith Fracture Zone would be the consequence of a mantle plume, which was originally centred on the rift, but migrated west of the rift immediately following the start of sea-floor spreading.

9.3 Case for a Continental Fragment within the Wallaby Plateau

Although as yet only volcanic rocks, have been recovered from the Wallaby Plateau, it is possible that it contains continental fragments.

Layering in ?Intermediate Crust

Both AGSO North West Shelf Study Group (1994) and Frey (1998) have summarised the crustal architecture and tectonic events of the region. The work of Frey (1998), in particular, focuses on volcanic terranes and crustal layering interpreted beneath the Exmouth Plateau - a plateau of continental origin. Frey (1998) incorporates rheological considerations within models that include both underplating and non-underplating scenarios. This work is relevant to the Wallaby-Cuvier area, because of its geographical proximity. Possible layering interpreted beneath the Wallaby Plateau may be evidence of a core of intermediate crust underlying the plateau.

Distinct, repeated seismic reflection patterns indicating the presence of three crustal layers has been observed in the Cuvier Abyssal Plain, NE Wallaby Plateau, outer Exmouth Plateau and Wallaby Saddle (Fig. 29). The uppermost layer is identified by its relatively bland seismic character; the middle layer is characterised by either inclined reflectors, possibly truncated, shingled patterns or SDRS in the case of the Wallaby Saddle; and the lower layer is characterised by diffraction-like events within a relatively bland section. Areas where no layering is interpreted may be more igneous in nature with a crust of different origin.

Although the layering identified beneath both the Cuvier Abyssal Plain and outer Exmouth Plateau (Fig. 29a & b) may indicative of oceanic crust, the quite different style of layering present beneath the NE Wallaby Plateau (Fig. 19 & 29c) and Wallaby Saddle (Fig. 29d) does not unambiguously indicate the presence of either oceanic or magmatic crust. In particular, it is possible that the middle and lower layers identified beneath the NE Wallaby Plateau may represent intermediate ?continental or volcanic margin crust overlain by volcanics (i.e. upper layer). This observation is, however, highly interpretive and speculative.

Continental Features

The possible presence of a continental core beneath the Wallaby Plateau is based on:

- the similarity between well-stratified ?sedimentary sequences that occur beneath parts of the Wallaby Plateau (e.g. Figure 17) and sedimentary section interpreted in the Houtman Sub-basin to the east (Fig. 12) and beneath the Exmouth Plateau to the north (Symonds *et al*., 1998);
- a comparison between the character of igneous bodies interpreted in the Houtman Sub-basin and beneath the Wallaby Plateau. In particular, the igneous body juxtaposed against the ?sedimentary section beneath the Wallaby Plateau (Figs 17–18 & 26) looks similar to igneous bodies present under the Bernier Platform (Plates 5–6; eastern ends of lines 135/08 & 135/10). These intrusions are constrained in age as pre-Valanginian by seismic correlations. This would imply, if correct, that some intrusive bodies on the Wallaby Plateau may be of pre-break-up age and have formed part of the western Australian extensional terrane prior to break-up.

Continental Fragmentation in a Warm Mantle Model

A non-mantle plume model was proposed by Planke & Symonds (1995) and Planke *et al*. (1996, 1997,1998) that accounted for features seen in the Wallaby-Cuvier area, Wallaby Plateau and Zenith Seamount. Symonds & Planke (1997) further suggested that models that seem to best explain the timing and distribution of volcanic provinces and features are those that incorporate a broad, long-lasting zone of elevated asthenospheric temperatures, which may or may not be plume related. Additionally, initiation of magmatism, its timing and distribution are controlled by dynamic processes associated with rifting, break-up and transform tectonism. The proposed models are based on the idea that significant crustal deformation associated with the break-up continues throughout evolution of a volcanic margin. This crustal deformation leads to formation of complex structures within a core of extended continental (transition zone) crust, extensional structures within volcanic complexes, and influences the character of the various volcanic sequences.

Their main arguments are as follows. Firstly, there is evidence of post-break-up fragmentation of a proto-Wallaby Plateau into the Wallaby Plateau, Zenith

Seamount, and Quokka Rise, and this was related to the major plate reorganisation with an ~90º change in drift direction between Australia and Greater India. The timing of fragmentation of the proto-Wallaby Plateau was tentatively estimated as Cenomanian (i.e. 97–91 Ma; Veevers *et al*., 1991; Royer & Coffin, 1992). Secondly, highly altered continental crust may be present in the proto-Wallaby Plateau. This crust could have been extended and fragmented in a rift-shear setting during the continent–continent transform phase along the Wallaby-Zenith Fracture Zone. Thirdly, there is widespread evidence of break-up-related volcanism along the western Australian margin at different times and in different settings, with no clear relationship to a mantle plume.

Plate-kinematic evolution

As previously discussed under section '4.3. Regional Basin Evolution', Müeller *et al*. (1998) and Mihut & Müller (1998b) interpreted magnetic lineaments in the Wallaby-Cuvier area, including the Wallaby Saddle. However, their magnetic interpretation was not fully integrated with the seismic data and in places (e.g. the Wallaby Saddle (Fig. 23), is clearly poorly constrained.

Müeller *et al*. (1998) interpreted two oceanic ridge jumps between chrons M11–M10 and chrons M5–M4. Oceanic ridge jumping relates to abandoned ridge axes, but it is also a mechanism by which continental fragments may be isolated and abandoned during the drift phase. Oceanic ridge jumping can, thus, support the argument for the presence of continental material beneath the Wallaby Plateau.

Figure 30 shows a conceptual representation of the breakup of Greater India and Australia in the Wallaby-Cuvier area. It is based partly on the work of Müller *et al*. (1998) and Mihut & Müller (1998b), particularly in the Cuvier Abysal Plain and to the west, and partly on Planke et al. (1986, 1987,1988), particularly for the Wallaby Plateau complex and the Wallaby Saddle. The reconstruction assumes that the interpretation of seafloor spreading magnetic lineations over the Wallaby Saddle is incorrect. The model shows how continental fragments were extended, modified by magmatism, and fragmented by break-up and seafloor spreading associated with ridge jumps to produce the complex arrangement of composite continental/volcanic plateaus and associated volcanic margin crust in the Wallaby-Cuvier area.

The oldest seafloor spreading magnetic lineation is interpreted as M11 (Fig. 9), and is located over the eastern edge of the Cuvier Abyssal Plain. The tectonic evolution of the region is summarised in Figure 30 as follows:

(1) Initiation of a zone of magmatism/volcanism along the line of future Cuvier Abyssal Plain break-up and extending into the proto-Wallaby Plateau complex (Fig. 30a). Segmentation of the extensional terrane into provinces with different structural and magmatic characteristics occurred about incipient fracture zone systems such as the Wallaby-Zenith and Cape Range Fracture Zones. Note how the un-extended and un-modified Wallaby Plateau, Zenith Seamount and Quokka Rise fit into the triangular area that will become the site of the future Wallaby Saddle assuming

reasonable stretching factors (β=2-3) and crustal growth through volcanism (Planke et al., 1998).

(2) Seafloor spreading commences in the Cuvier and Perth Abyssal Plains during chron M11, while extension and magmatism is occurring throughout the Wallaby Plateau complex (Fig. 30b). The SDRSs in the Wallaby Saddle probably begin forming at this time, as well as significant extension and magmatic modification of the continental crust that underpins the Wallaby Plateau complex. The ongoing extension and magmatism starts to form significant areas of volcanic margin crust.

(3) Extension and magmatism continues within the zone between the Cuvier Abyssal Plain and the developing Wallaby-Zenith Fracture Zone further modifying the Wallaby Plateau complex. Seafloor spreading and rift propogation continues in the Cuvier Abyssal Plain until sometime between chrons M5 and M4, when a ridge jump occurs (Müller *et al*., 1998) to near the western margin of the newly developing ocean basin (Fig. 30c). This creates a zone of incipient break-up to the south within the Wallaby Plateau complex between the proto-Zenith Seamount and Quokka Rise.

(4) Eventually break-up of the volcanic margin crust of the Zenith Seamount and Quokka Rise occurs between chrons M5 and M4, and seafloor spreading and rift propagation forms the Wallaby-Zenith Basin (Fig. 30d). The Wallaby-Zenith Basin is fully open by chron M0, and seafloor spreading is now continuous and systematic throughout the Wallaby-Cuvier-Gascoyne region.

(5) The end result of this complex tectono-magmatic history is that the corridor between the Cuvier Abyssal Plain to the north and the Wallaby-Zenith Fracture Zone to the south contains a series of composite plateaus formed by both highly extended and modified continental/transition zone crust and volcanic margin crust, and a small ocean basin – the Wallaby-Zenith Basin.

As noted by other workers (Berndt *et al*., 2001), the style and development history of transform margins is likely to play a significant part in determining their volcanic characteristics. For example, lateral heat transport from oceanic lithosphere to adjacent continental and volcanic margin lithosphere would decrease the ambient mantle temperature and thus melt production along the transform; however, opening up of the transform by oblique extension could result in lithospheric thinning and inceased volcanism (Berndt *et al*., 2001b). Such processes associated with the Wallaby-Zenith Fracture Zone are likely to have played a role in the tectono-magmatic evolution of the Wallaby Plateau complex.

9.4 Summary

The above observations and arguments do not unambiguously prove or disprove that a continental component is involved in the origin of the Wallaby Plateau. The geological history of the region is complex. Many of the volcano-tectonic provinces mapped in this study may be represented as having a mixed continental and magmatic origin. Only the Cuvier and Perth Abyssal Plains are likely to be the result of 'normal' seafloor spreading.

A combination of initial continental extension, ongoing volcanic margin extension, extrusion and intrusion, and seafloor spreading, rift propagation and ridge jumping in a zone adjacent to a developing transform margin segment can probably explain many of the features found in the Wallaby-Cuvier area.

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Jacques Sayers was group leader for the study and responsible for interpreting the seismic data. Irina Borissova constructed many of the images and maps and wrote aspects of Chapter 4. Doug Ramsay provided logistical support and assisted with some of the older vintage seismic datasets. Phil Symonds was project leader for the Law of the Sea Project Group and acted as mentor.

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12. APPENDICES

Appendix 1 – 1982 United Nations Convention on the Law of the Sea (UNCLOS)

Article 76: Definition of the Continental Shelf

1. The continental shelf of a coastal State comprises the seabed and subsoil of the submarine areas that extend beyond its territorial sea throughout the natural prolongation of its land territory to the outer edge of the continental margin, or to a distance of 200 nautical miles from the baselines from which the breadth of the territorial sea is measured where the outer edge of the continental margin does not extend up to that distance.

2. The continental shelf of a coastal State shall not extend beyond the limits provided for in paragraphs 4 to 6.

3. The continental margin comprises the submerged prolongation of the land mass of the coastal State, and consists of the seabed and subsoil of the shelf, the slope and the rise. It does not include the deep ocean floor with its oceanic ridges or the subsoil thereof.

4. (a) For the purposes of this Convention, the coastal State shall establish the outer edge of the continental margin wherever the margin extends beyond 200 nautical miles from the baselines from which the breadth of the territorial sea is measured, by either:

   (i) a line delineated in accordance with paragraph 7 by reference to the outermost fixed points at each of which the thickness of sedimentary rocks is at least 1 per cent of the shortest distance from such point to the foot of the continental slope; or

   (ii) a line delineated in accordance with paragraph 7 by reference to fixed points not more than 60 nautical miles from the foot of the continental slope.

   (b) In the absence of evidence to the contrary, the foot of the continental slope shall be determined as the point of maximum change in the gradient at its base.

5. The fixed points comprising the line of the outer limits of the continental shelf on the seabed, drawn in accordance with paragraph 4 (a) (I) and (ii), either shall not exceed 350 nautical miles from the baselines from which the breadth of the territorial sea is measured or shall not exceed 100 nautical miles from the 2,500 metre isobath, which is a line connecting the depths of 2,500 metres.

6. Notwithstanding the provisions of paragraph 5, on submarine ridges, the outer limit of the continental shelf shall not exceed 350 nautical miles from the baselines from which the breadth of the territorial sea is measured. This paragraph does not apply to submarine elevations that are natural components of the continental margin, such as its plateaux, rises, caps, banks and spurs.

7. The coastal State shall delineate the outer limits of its continental shelf, where that shelf extends beyond 200 nautical miles from the baselines from which the breadth of the territorial sea is measured, by straight lines not exceeding 60 nautical miles in length, connecting fixed points, defined by coordinates of latitude and longitude.

8. Information on the limits of the continental shelf beyond 200 nautical miles from the baselines from which the breadth of the territorial sea is measured shall be submitted by the coastal State to the Commission on the Limits of the Continental Shelf set up under Annex II on the basis of equitable geographical representation. The Commission shall make recommendations to coastal States on matters related to the establishment of the outer limits of their continental shelf. The limits of the shelf established by a coastal State on the basis of these recommendations shall be final and binding.

9. The coastal State shall deposit with the Secretary-General of the United Nations charts and relevant information, including geodetic data, permanently describing the outer limits of its continental shelf. The Secretary-General shall give due publicity thereto.

10. The provisions of this article are without prejudice to the question of delimitation of the continental shelf between States with opposite or adjacent coasts.

Appendix 2 – Details of Seismic Surveys

Survey	135
Contractor	AGSO
Vessel	Rig Seismic
Year	1994
Streamer length (m)	4800
Seismic channels	192
Sample rate/record length (ms)	2/16000
Group length/interval (m)	25/25
Shot interval (m)	50
Cable depth (m)	10
Source type/power or volume	20 x sleeve airguns / 49.2 litres
Nominal vessel speed (kn)	5
Primary navigation	differential GPS
Secondary navigation	differential GPS
Tertiary navigation	Magnavox sonar doppler
Primary echo-sounder	12 kHz
Secondary echo-sounder	3.5 kHz
Magnetic data	yes
Gravity data	yes

Survey	Roving reconnaissance seismic (N)
Contractor	Shell Internationale Petroleum Maatschappij N.V.
Vessel	*Petrel*
Year	1971
Streamer length (m)	2400
Seismic channels	24
Sample rate/record length (ms)	4/6000
Group length/interval (m)	50/100
Shot interval (m)	50
Cable depth (m)	15
Source type/power or volume	airgun array/6.4 litres
Nominal vessel speed (kn)	6
Primary navigation	Transit Satnav + Marquardt sonar doppler
Primary echo-sounder	Not known
Magnetic data	yes; analogue only
Gravity data	yes; analogue only

Survey	17
Contractor	CGG/BMR
Vessel	Lady Christine
Year	1972
Streamer length (m)	1000
Seismic channels	6
Sample rate/record length (ms)	analogue/continuous
Group length/interval (m)	50/200
Shot interval (m)	50
Cable depth (m)	10
Source type/power or volume	sparker/120 kJ
Nominal vessel speed (kn)	7–9
Primary navigation	Transit Satnav + Marquardt sonar doppler
Secondary navigation	Transit Satnav + Chernikeef paddle log
Tertiary navigation	Transit Satnav + pressure log
Primary echo-sounder	Elac
Secondary echo-sounder	seismic
Magnetic data	yes
Gravity data	yes

Survey	18
Contractor	CGG/BMR
Vessel	Lady Christine
Year	1972–73
Streamer length (m)	1000
Seismic channels	6
Sample rate/record length (ms)	analogue/continuous
Group length/interval (m)	50/200
Shot interval (m)	50
Cable depth (m)	10
Source type/power or volume	sparker/120 kJ
Nominal vessel speed (kn)	7–9
Primary navigation	Transit Satnav + Marquardt sonar doppler
Secondary navigation	Transit Satnav + Chernikeef paddle log
Tertiary navigation	Transit Satnav + pressure log
Primary echo-sounder	Elac
Secondary echo-sounder	seismic
Magnetic data	yes
Gravity data	yes

Appendix 3 – Geological Sample Data and Heat Flow Measurements

Note 1: Latitude and Longitude refer to the starting point of the dredge drag, two water depths are given for the start and end of the dredge.

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1. Colwell, Graham, *et al*. (1990).
2. Choi, Stagg, *et al*. (1987).
3. Marshall *et al*. (1989).
4. Exon (1979).
5. Lamont-Doherty Geological Observatory of Columbia University (1976a).
6. Lamont-Doherty Geological Observatory of Columbia University (1976b).

Sample types:

Survey BGR8: BL = boomerang corer, KA = box sampler, KD = chain bag dredge, KL = piston corer, SL = gravity corer.
Surveys RSA96 & AGSO53: BC = boomerang corer, DR = chain bag dredge, GC = gravity corer, HF = heat flow.

Site original no	Original no in other papers & database	Latitude (S)	Longitude (E)	water depth (m)	water depth (m)	Survey	Ref.	Sample or heatflow description (short)	Oldest Age	Description of oldest components
096DR038		-24.365	107.8273333	3120	2980	RS A96	1	basalt + Mn crust	N/A	Basaltic cong and Mn crusts
096DR037		-24.3766666	107.8213333	3200	3010	RS A96	1	Pleist. ooze	Pleistocene	Ooze
096DR034		-19.9378333	110.5678333	3950	3410	RS A96	1	basalt/andesite	Not available	Amygdaloidal basalt/andersite
096DR035		-20.1811666	109.9141666	5025	4050	RS A96	1	Fault breccia + igneous	Not available	Flt brec,silic mudst,basalt/gabbro
096DR036		-24.3635	107.8283333	3120	2850	RS A96	1	basalt + Mn crust	Not available	Basaltic cong and Mn crusts
096DR006		-21.8683333	112.73	4100	3340	RS A96	1	Q. mud/ooze	Quaternary	Mud/ooze
096DR007		-21.8776666	112.7185	3700	3150	RS A96	1	L. Palc. chk + sst	Late Paleocene	Chalk and sandstone
096DR008		-21.8488333	112.7615	3550	3180	RS A96	1	L. Olig. - E. Mio. chalk	L.Olig.(nanno)-E.Mio.(foram)	Chalk and sandstone
096DR009		-21.929	113.022	2650	2200	RS A96	1	L. K - L. Palc. mudst	L. Cret. - L. Palc. (nanno)	Mudstone
096DR010		-21.9381333	113.16115	2410	2100	RS A96	1	L. Eoc. mudst	Late Eocene	Mudstone
096DR011		-22.2473333	112.6346666	3700	3070	RS A96	1	E. Cret. marl	Early Cretaceous	Marl
096DR003		-23.4125	111.4815	3890	3700	RS A96	1	Bar - Apt. mudst	Barremian - Early Aptian	Mudstone
096DR004		-21.8842666	112.7490333	4200	3540	RS A96	1	sst + Q. ooze	Quaternary	Sandstone and ooze
096DR005		-21.8686666	112.7291666	4200	3150	RS A96	1	Q. sst	Quaternary	Sandstone

096DR001		-23.704	111.275	4125	3700	RS A96	1	E. Alb. siltst	Early Albian	Siltstone
096DR002		-23.399	111.056665	4994	4720	RS A96	1	E. Alb. mudst	Early Albian	Mudstone
096GC020		-23.7805	108.5035	2100		RS A96	1	Fail	Fail	Fail
096GC021		-23.7771666	108.5006666	2100		RS A96	1	Pleist. mud	Pleistocene	Mudstone
096GC022		-23.7803333	108.5036666	2106		RS A96	1	Pleist. mud	Pleistocene	Mudstone
057GC003		-28.0418316	112.9641666	760		RS A57	3			none known
057GC004		-28.2273333	112.7751666	870		RS A57	3			none known
057GC005		-28.3391666	112.6918333	1200		RS A57	3			none known
057GC006		-28.4335	112.6008333	1770		RS A57	3			none known
057GC007		-28.346	112.6666666	1250		RS A57	3			none known
057GC008		-28.775	112.3333333	4475		RS A57	3			none known
057GC009		-28.4726666	112.9766666	840		RS A57	3			none known
057GC010		-28.3951666	113.1588316	755		RS A57	3			none known
057GC011		-28.7176666	113.3905	930		RS A57	3			none known
057GC015		-25.3816666	113.2166666	2700		RS A57	3			none known
057GC018		-27.491	110.884	5440		RS A57	3			none known
057GC019		-27.3201666	111.627	2780		RS A57	3			none known
057GC020		-27.2655	111.8198333	1820		RS A57	3			none known
057GC021		-27.1936666	112.0885	1060		RS A57	3			none known
057GC022A		-27.104165	112.4765	650		RS A57	3			none known
057GC022B		-27.113165	112.4748333	650		RS A57	3			none known
057GC023		-27.047165	112.7731666	245		RS A57	3			none known
057GC024		-27.064665	112.789	240		RS A57	3			none known
057GC025		-27.091665	112.7983333	230		RS A57	3			none known
057GC026		-27.14	112.825	240		RS A57	3			none known
057GC027		-27.249	112.8423333	287		RS A57	3			none known
057HF008		-28.3421666	112.6721666	1220		RS A57	3			none known
057HF003		-28.2198333	112.7921666	865		RS A57	3			none known
057HF004		-28.2251666	112.795	890		RS A57	3			none known
057HF018		-27.54	110.9483333	5450		RS A57	3			none known
057HF019		-27.31	111.6101666	2785		RS A57	3			none known
057HF020		-27.2665	111.8175	1820		RS A57	3			none known
057HF021		-27.2038333	112.091	1070		RS A57	3			none known
057GR006	057GB/006	-27.8833333	113.074	320		RS A57	3			none known
057GR007	057GB/007	-27.0373316	112.763	250		RS A57	3			none known
057GR007B	057GB/007(1)	-27.028	112.7731666	240		RS A57	3			none known
057GR008A	057GB/008(A)	-27.0648316	112.788	240		RS A57	3			none known

057GR008B	057GB/008(B)	-27.065	112.7766666	250		RS A57	3			none known
057GR009A	057GB/009(A)	-27.091665	112.7983333	240		RS A57	3			none known
057GR009B	057GB/009(B)	-27.091665	112.79	230		RS A57	3			none known
057GR010	057GB/010	-27.141665	112.825	240		RS A57	3			none known
057GR011	057GB/011	-27.142165	112.816	240		RS A57	3			none known
057GR012	057GB/012	-27.1981666	112.8211666	280		RS A57	3			none known
057GR013	057GB/013	-27.1921666	112.834	230		RS A57	3			none known
057GR014	057GB/014	-27.248	112.8433333	245		RS A57	3			none known
057GR015	057GB/015	-27.2488333	112.841	290		RS A57	3			none known
057BC001	057BC/001	-27.25	112.8333333	290		RS A57	3			none known
057BC001B	057BC/001B	-27.2485	112.8288333	290		RS A57	3			none known
057BC002	057BC/002	-27.2496666	112.8311666	290		RS A57	3			none known
057BC003	057BC/003	-27.262	112.8261666	312		RS A57	3			none known
057CM001	057CA-001	-27.25	112.847	240	250	RS A57	3			none known
057DR001	057DR001	-27	112	2050	1350	RS A57	3			none known
057DR008		-28.8501666	113.2563333	2000	1800	RS A57	3			none known
057DR011		-27.365	111.0183316	4900	4400	RS A57	3			none known
057DR010		-27.9583333	112.355	2300	1900	RS A57	3			none known
053HF035	53-EP-HF10	-19.5578166	113.7828833	1175		AGSO53	2	HF 27 mW/sq m	Q heat flow (mW/sqm)	HF 27 mW/sq m
053HF036	53-EP-HF11	-19.6426833	113.6733333	1098		AGSO53	2	HF 45 mW/sq m	Q heat flow (mW/sqm)	HF 45 mW/sq m
053GC010	53-EP-GC04	-19.58515	113.5342	956		AGSO53	2	Sand	N/A	Sand
053HF037	53-EP-HF12	-19.5879666	113.513	947		AGSO53	2	HF mW/sq m error	Q heat flow (mW/sqm)	HF mW/sq m error
053HF038	53-EP-HF13	-19.4982333	113.3548	922		AGSO53	2	HF 29 mW/sq m	Q heat flow (mW/sqm)	HF 29 mW/sq m
053HF039	53-EP-HF14	-19.41065	113.2316	980		AGSO53	2	HF 20 mW/sq m	Q heat flow (mW/sqm)	HF 20 mW/sq m
053GC011	53-EP-GC05	-19.3253166	113.10655	1279		AGSO53	2	Silt-mud	N/A	Silt-mud
053HF040	53-EP-HF15	-19.3318	113.1073816	1266		AGSO53	2	HF 60 mW/sq m	Q heat flow (mW/sqm)	HF 60 mW/sq m
053HF041	53-EP-HF16	-19.2419666	112.9867833	1490		AGSO53	2	HF 69 mW/sq m	Q heat flow (mW/sqm)	HF 69 mW/sq m
053HF042	53-EP-HF17	-19.1286	112.8544333	1671		AGSO53	2	HF 57 mW/sq m	Q heat flow (mW/sqm)	HF 57 mW/sq m
053HF043	53-EP-HF18	-19.0668816	112.7407166	2000		AGSO53	2	HF 49 mW/sq m	Q heat flow (mW/sqm)	HF 49 mW/sq m
053GC012	53-EP-GC06	-19.0528316	112.7523166	1979		AGSO53	2	Silt-mud	N/A	Silt-mud
053GC014	53-EP-GC08	-19.5223666	113.2246833	936		AGSO53	2	Silt-mud	N/A	Silt-mud
053HF048	53-EP-HF22	-19.5346666	113.21215	935		AGSO53	2	HF 33 mW/sq m	Q heat flow (mW/sqm)	HF 33 mW/sq m
053HF049	53-EP-HF23	-19.6335833	113.154965	940		AGSO53	2	HF 95 mW/sq m	Q heat flow (mW/sqm)	HF 95 mW/sq m
053HF050	53-EP-HF24	-19.7331333	113.09205	952		AGSO53	2	HF 39 mW/sq m	Q heat flow (mW/sqm)	HF 39 mW/sq m
053HF051	53-EP-HF25	-19.8329	113.034565	947		AGSO53	2	HF 31 mW/sq m	Q heat flow (mW/sqm)	HF 31 mW/sq m
053GC015	53-EP-GC09	-20.004215	112.9313333	962		AGSO53	2	Silt-mud	N/A	Silt-mud

053HF053	53-EP-HF27	-20.0941316	112.8680333	909		AGSO53	2	HF 73 mW/sq m	Q heat flow (mW/sqm)	HF 73 mW/sq m
053HF054	53-EP-HF28	-20.1998333	112.7975166	848		AGSO53	2	HF 204 mW/sq m	Q heat flow (mW/sqm)	HF 204 mW/sq m
053HF055	53-EP-HF29	-20.2896666	112.7358666	852		AGSO53	2	HF 49 mW/sq m	Q heat flow (mW/sqm)	HF 49 mW/sq m
053HF056	53-EP-HF30	-20.3985666	112.6661333	875		AGSO53	2	failed HF mW/sq m	Q heat flow (mW/sqm)	failed HF mW/sq m
053GC016	53-EP-GC10	-20.4983166	112.5859	947		AGSO53	2	Silt-mud	N/A	Silt-mud
053HF057	53-EP-HF31	-20.4981166	112.57745	953		AGSO53	2	HF 92 mW/sq m	Q heat flow (mW/sqm)	HF 92 mW/sq m
053HF058	53-EP-HF32	-20.5901333	112.52525	1103		AGSO53	2	HF 26 mW/sq m	Q heat flow (mW/sqm)	HF 26 mW/sq m
053HF059	53-EP-HF33	-20.7062166	112.4485166	1264		AGSO53	2	HF 42 mW/sq m	Q heat flow (mW/sqm)	HF 42 mW/sq m
053HF060	53-EP-HF34	-20.8006666	112.3976166	1426		AGSO53	2	HF 43 mW/sq m	Q heat flow (mW/sqm)	HF 43 mW/sq m
053HF061	53-EP-HF35	-20.8874833	112.3377166	1427		AGSO53	2	HF 64 mW/sq m	Q heat flow (mW/sqm)	HF 64 mW/sq m
053HF062	53-EP-HF36	-21.0201	112.2630166	1541		AGSO53	2	52 HF mW/sq m	Q heat flow (mW/sqm)	52 HF mW/sq m
053HF063	53-EP-HF37	-20.9938666	112.074365	1270		AGSO53	2	failed HF mW/sq m	Q heat flow (mW/sqm)	failed HF mW/sq m
053HF064	53-EP-HF38	-21.0893316	112.0081	1780		AGSO53	2	failed HF mW/sq m	Q heat flow (mW/sqm)	failed HF mW/sq m
053HF065	53-EP-HF39	-21.6707833	111.6451833	5053		AGSO53	2	HF 60 mW/sq m	Q heat flow (mW/sqm)	HF 60 mW/sq m
053GC018	53-PB-GC12	-28.6045833	112.1571816	4557		AGSO53	2			
053PC010	53-EP-PC02	-21.6501333	111.6771333	5050		AGSO53	2		Failed	
054BC025	SO8-KA91	-20.34	112.94	820		BGR8	4		? Failed	
054BC026	SO8-KA92	-20.3216666	112.93	820		BGR8	4		? Failed	
054BC027	SO8-KA93	-20.3466666	112.9383333	820		BGR8	4	Q. ooze	Quaternary	Ooze
054BC028	SO8-KA95	-20.2816666	112.95	820		BGR8	4	Q. ooze	Quaternary	Ooze
054BC029	SO8-KA96	-20.2333333	112.96	820		BGR8	4	Q. ooze	Quaternary	Ooze
054BC030	SO8-KA97	-19.9983333	113.8383333	1120		BGR8	4	Q. ooze	Quaternary	Ooze
054BC031	SO8-BL98	-20	113.8166666	1130		BGR8	4	Q. ooze	Quaternary	Ooze
054BC032	SO8-BL99	-20	113.8383333	1120		BGR8	4	Q. ooze	Quaternary	Ooze
054BC033	SO8-BL100	-20	113.8433333	1120		BGR8	4	Q. ooze	Quaternary	Ooze
054BC034	SO8-BL101	-20	113.8533333	1120		BGR8	4	Q. ooze	Quaternary	Ooze
054BC035	SO8-BL102	-20	113.8583333	1120		BGR8	4	? Failed	? Failed	
054BC041	SO8-BL113	-21.111665	113.615	1198		BGR8	4	Q. ooze	Quaternary	Ooze
054BC042	SO8-BL114	-21.1083316	113.6116666	1198		BGR8	4	Q. ooze	Quaternary	Ooze
054BC043	SO8-BL115	-21.105	113.6083333	1202		BGR8	4	Q. ooze	Quaternary	Ooze

054BC044	SO8-BL116	-21.101665	113.6066666	1203		BGR8	4	Q. ooze	Quaternary	Ooze
054BC045	SO8-BL117	-21.096665	113.6033333	1205		BGR8	4	Q. ooze	Quaternary	Ooze
054BC046	SO8-KA118	-21.1333316	112.7766666	1502		BGR8	4	Q. ooze	Quaternary	Ooze
054BC047	SO8-BL125	-20.9733333	111.92	1455		BGR8	4	Q. ooze	Quaternary	Ooze
054BC048	SO8-BL126	-20.9766666	111.9233333	1466		BGR8	4	Q. ooze	Quaternary	Ooze
054BC049	SO8-BL127	-20.98	111.9266666	1489		BGR8	4	Q. ooze	Quaternary	Ooze
054BC050	SO8-BL128	-20.9833333	111.93	1515		BGR8	4	Q. ooze	Quaternary	Ooze
054BC051	SO8-BL129	-20.9866666	111.9333333	1541		BGR8	4	? Failed	? Failed	? Failed
054BC052	SO8-BL130	-20.99	111.9366666	1568		BGR8	4	???	???	? Failed
054BC053	SO8-KA133	-21.9516666	111.77	5040		BGR8	4	Q. clay	Quaternary	Clay
054BC054	SO8-KA136	-21.6633333	112.4683333	3986		BGR8	4	? Failed	? Failed	? Failed
054BC055	SO8-KA137	-21.6283333	112.49	4078		BGR8	4	? Failed	? Failed	? Failed
054BC056	SO8-KA141	-21.4733333	112.5166666	2918		BGR8	4	Q. ooze	Quaternary	Ooze
054BC057	SO8-KA145	-21.33	110.4816666	5060		BGR8	4	Q. clay	Quaternary	Clay
054BC058	SO8-BL153	-22.02	109.3116666	4780		BGR8	4	? Failed	? Failed	? Failed
054GC008	SO8-SL94	-20.3083333	112.9433333	815		BGR8	4	Q. ooze	Quaternary	Ooze
054GC013	SO8-SL119	-21.1233316	112.7733333	1493		BGR8	4	Q. ooze	Quaternary	Ooze
054GC014	SO8-SL134	-21.95	111.71	5045		BGR8	4	? Failed	? Failed	? Failed
054GC015	SO8-SL135	-21.9666666	111.745	5045		BGR8	4	? Failed	? Failed	? Failed
054GC016	SO8-SL138	-21.6183333	112.5316666	4017		BGR8	4	Q. ooze + Mn mudst	Quaternary + ? Mesozoic	Ooze + mudstone
054GC017	SO8-SL142	-21.46	112.5083333	2798		BGR8	4	Q. ooze + Oligo. chalk	Quaternary + Mid Olig.	Ooze + chalk
054GC018	SO8-SL144	-21.3633333	112.5583333	2330		BGR8	4	M. Mio. chalk	Mid Miocene	Chalk
054GC019	SO8-SL146	-21.2583333	110.5016666	5060		BGR8	4	Q. clay	Quaternary	Clay
054PC012	SO8-KL122	-20.9366666	111.705	2065		BGR8	4	Q. ooze	Quaternary	Ooze
054PC013	SO8-KL124	-21.055	111.8383333	2170		BGR8	4	Q. ooze	Quaternary	Ooze
054PC014	SO8-KL132	-21.1433316	112.3	1715		BGR8	4	M. Mio sand	Mid Miocene	Sand
054PC015	SO8-KL152	-22.02	109.3116666	4780		BGR8	4	? Q. clay	? Quaternary	Clay
054PC016	SO8-KL156	-21.8883333	109.235	4780		BGR8	4	L. Palc/Eoc. clay	Lower Paleocene/Eocene	Clay
054PC017	SO8-KL158	-21.8833333	109.2366666	4845		BGR8	4	? Q. clay	? Quaternary	Clay
054PC018	SO8-KL162	-24.4	109.6883333	4060		BGR8	4	? E. K. volc sst	? Early Cretaceous	Volcaniclastic sandstone
054DR038	SO8-KD120	-20.8783333	111.7066666	1750	1820	BGR8	4	? Failed	? Failed	? Failed
054DR039	SO8-KD121	-20.9583333	111.6533333	2360	2000	BGR8	4	? Failed	? Failed	? Failed
054DR040	SO8-KD123	-21.06	111.8416666	2140	1750	BGR8	4	? Failed	? Failed	? Failed
054DR041	SO8-KD131	-21.34	111.8666666	4415	3770	BGR8	4	? Tri/Ju. sst	? Triassic or Jurassic	Sandstone
054DR042	SO8-KD139	-21.5866666	112.555	3960	3400	BGR8	4	? Failed	? Failed	? Failed
054DR043	SO8-KD140	-21.5666666	112.82	3740	3370	BGR8	4	? Failed	? Failed	? Failed

054DR044	SO8-KD143	-21.38	112.5733333	2480	2290	BGR8	4	? Failed	? Failed	? Failed
054DR045	SO8-KD147	-21.21	110.515	5060	5000	BGR8	4	Tert/Q. marl	Tertiary/Quaternary	Marl
054DR046	SO8-KD148	-20.9733333	110.5583333	4875	4540	BGR8	4	?E.Cret.Volc+Q.Mn nods	? Early Cretaceous	? E. Cret. Volc + Q. Mn nods
054DR047	SO8-KD149	-21.415	110.3083333	4930	4920	BGR8	4	? E. Cret. volcs	? Early Cretaceous	Volcaniclastic breccia
054DR048	SO8-KD150	-21.4033333	110.2833333	4010	3550	BGR8	4	? Failed	? Failed	? Failed
054DR049	SO8-KD151	-22.011665	109.3233333	5060	4800	BGR8	4	? Failed	? Failed	? Failed
054DR050	SO8-KD154	-22.016665	109.3233333	5050	4790	BGR8	4	? Failed	? Failed	? Failed
054DR051	SO8-KD155	-21.8666666	109.27	5060	4830	BGR8	4	? Basalt + volcs breccia	? Early Cretaceous	?Basalt+volcaniclastic breccia
054DR052	SO8-KD157	-21.8716666	109.28	5060	4840	BGR8	4	? Failed	? Failed	? Failed
054DR053	SO8-KD159	-24.3916666	109.7183333	4470	4130	BGR8	4	? E. Cret sst with volcs	? Early Cretaceous	Sandstone with volcanic clasts
054DR054	SO8-KD160	-24.3966666	109.7133333	4470	4260	BGR8	4	Q. ooze	Quaternary	Ooze
054DR055	SO8-KD161	-24.4	109.75	4470	4230	BGR8	4	? E. Cret sst with volcs	? Early Cretaceous	Volcaniclastic sandstone
054DR056	SO8-KD163	-24.32	109.735	4600	4020	BGR8	4	? Failed	? Failed	? Failed
054DR057	SO8-KD164	-24.3883333	109.7116666	4460	4020	BGR8	4	? Failed	? Failed	? Failed
054DR058	SO8-KD165	-24.395	109.7066666	4415	4240	BGR8	4	? E. Cret sst with volcs	? Early Cretaceous	Volcaniclastic sandstone
054DR059	SO8-KD166	-24.37	109.1333316	3450	3010	BGR8	4	? Failed	? Failed	? Failed
054DR060	SO8-KD167	-25.65	108.6083333	5340	4750	BGR8	4	? E. Cret clayst with volcs	? Early Cretaceous	Volcaniclastic claystone
054DR061	SO8-KD168	-25.5816666	108.5716666	5100	4050	BGR8	4	? E. Cret volcs	? Early Cretaceous	Volcanics
054DR062	SO8-KD169	-25.5633333	108.5133333	5230	4260	BGR8	4	? Failed	? Failed	? Failed
054DR063	SO8-KD170	-25.5266666	108.5316666	4620	3970	BGR8	4	? E. Cret volcs	? Early Cretaceous	Volcanics
054DR064	SO8-KD171	-25.5616666	108.53	5030	3860	BGR8	4	? Failed	? Failed	? Failed
054DR065	SO8-KD172	-25.5883333	108.5683333	4930	3960	BGR8	4	? Failed	? Failed	? Failed
054DR066	SO8-KD173	-25.9633333	109.096665	4980	3885	BGR8	4	Sil lst+?E.Cre mud (?tuf)	? Silurian + ? E. Cret	Cherty ls+mudst(?Alt tuff)
	RC11-145	-25.4833	110.0167	3869	core	L11	5	chalk		foram chalk
	RC11-146	-21.4167	112.8000	2371	core	L11	5	chalk		foram chalk
	RC11-147	-19.0583	112.7500	1953	core	L11	5	chalk		foram chalk
	RC14-59	-20.25	106.3333	5550	core	L14	5	brown clay		brn clay, Mn micro-nodules
	RC14-60	-19.1667	110.0000	4526	core	L14	5	marl, clay		orange marl, clay
	V18-214	-27.9833	108.6667	5147	core	L18	6	lutite		lutite, red-brown, with MnO2
	V28-350A	-10.45	100.5167	5066	core	L28	6	radiolarian clay + ash		radiolarian clay plus vol ash

Appendix 4 – Interpreted Seismic Horizons

Note 1: first set of horizons refers to horizons used for sediments or features on continental crust. Second set of horizons refer to horizons used for volcanogenic and volcanostratigraphic complexes in an oceanic setting.

Seismic Horizon	Colour of horizon	Horizon details	Type section/location
olig	orange	Oligocene	135/05, sp 110000–117000 (Plate 5)
cret	tan	Cretaceous, near base carbonates	135/03, sp 300–1300 (Plate 6)
tur	red-brown	Turonian	135/02, not extensively mapped (Plate 6)
apt	lt green	Aptian-Albian, top Muderong Shale	135/02, not extensively mapped (Plate 6)
val	dk green	Valanginian, break-up horizon	N306, sp 2500–3500 (Plate 6)
tr	med blue	Triassic	135/08, sp 7200–8000 (Plate 5)
Pz	dk pink	Palaeozoic	N306, sp 2900-3500 (Plate 6)
intr	dk pink	Top of individual intrusions in continental crust	135/05, sp 10990-11300 (Plate 5)
icc	purple	Top of intruded continental crust	N301 (Plate 6)
mz	yellow	Form lines in Mesozoic sediments	N306, sp 2500–3500 (Plate 6)
pz	yellow	Form lines in Paleozoic sediments	135/05, sp 11080–11750 (Plate 5)
sill	purple	Sills & dykes	135/11 (Plate 6)
buil	dk blue	Top volcanic build-up	135/04, sp 2450–2650 (Plate 5)
cvcc	dk pink	Top composite volcanics on ?continental crust	N318 (Plate 6)
cvvm	lt blue	Top composite volcanics on volcanic margin crust	135/04, sp 100–1500 (Plate 5)
cvlc	lt pink	Top composite volcanics on layered volcanic margin crust.	135/05, sp 5100–6500 (Plate 5)
flow	emerald green	Top flows overlying continental sediments or landward flow of Planke *et al*. (2000)	135/08, sp 3150–3650 (Plate 5)
moho	black	Top moho	135/11 (Plate 6)
vflo	lt blue	Top flows/sills	135/02 (Plate 6)
sd	yellow	Form lines in SDRS	135/08, sp 2300–3900 (Plate 5)

slop	orange	Top lower slope ?volcanics	N303, sp 127000–127250 (Plate 6)
tdeb	med green	Top debris flows	135/05, sp 7700–7950 (Plate 5)
tiv	orange	Top volcanics extruded along transform faults	135/09, sp 400–1300 (Plate 6)
tobs	red	Top smooth oceanic basement	135/11, sp 7600–8600 (Plate 6)
tobr	red	Top rough ?oceanic/volcanic margin basement	135/04, sp 1800–2400 (Plate 5)
tobl	red	Top layered oceanic basement	135/03, sp 300–1300 (Plate 6)
tsdr	purple	Top seaward dipping reflector sequence (SDRS)	135/08, sp 2300–3900 (Plate 5)
udif	yellow	Top undifferentiated volcanic build-ups between SDRSs	135/08, sp 3870–4050 (Plate 5)
vo	yellow	Form lines in volcanics	135/05, sp 5100–6500 (Plate 5)

Appendix 5 – Velocity Analyses

Expanding-Seismic Profiles (ESP) from Francis & Raitt (1967)

Station	*Latitude*	*Longitude*	*Nearest reflection seismic line*
C1	-20.336667	112.667500	135/11, SP 15400, offset 7 km
C2	-20.558333	112.283333	135/11, SP 14500, offset 5 km
C2A	-20.675000	112.041667	135/11, SP 13950
C3	-20.791667	111.783333	135/11, SP 13350, offset 5 km
C4	-21.258333	111.304167	135/11, SP 11900

Station C1

Vel. (km.s^{-1})	*Depth (km)*	*TWT (s)*
1.5	0	0
1.5	-0.9	1.2
3.6	-2.7	2.61
3.8	-3.0	2.77
4.1	-3.2	2.87
4.1	-4.2	3.36
4.5	-4.5	3.5
4.8	-5.7	4.02

Station C2

Vel. (km.s^{-1})	*Depth (km)*	*TWT (s)*
1.5	0	0
1.5	-1.2	1.6
3.5	-3.0	3.04
3.9	-3.7	3.42
4.2	-4.2	3.67
4.2	-7.5	5.24
4.8	-7.5	5.24

Station C2A

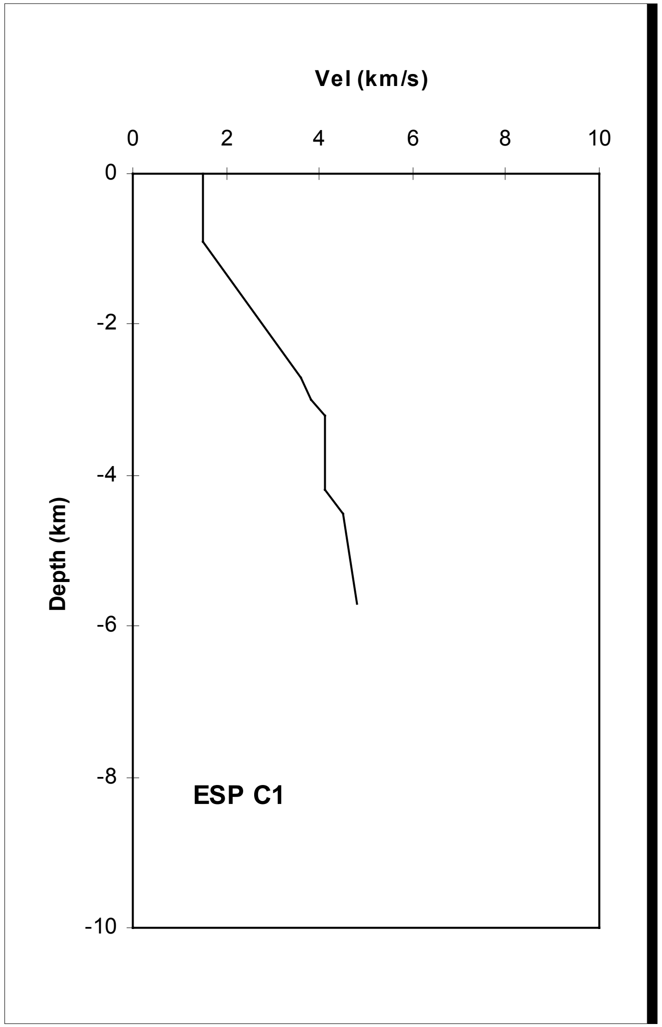
Vel. (km.s^{-1})	*Depth (km)*	*TWT (s)*
1.5	0	0
1.5	-1.3	1.73
1.8	-1.7	2.21
2.0	-1.9	2.42
2.3	-2.4	2.89
2.9	-2.7	3.12
3.4	-3.3	3.5
3.5	-3.6	3.67
3.8	-3.7	3.72
4.2	-4.3	4.02
4.5	-4.7	4.2

Station C3

Vel. (km.s^{-1})	*Depth (km)*	*TWT (s)*
1.5	0	0
1.5	-1.5	2.0
2.0	-1.5	2.0
2.7	-2.3	2.68
3.1	-3.1	3.23
3.7	-3.3	3.35
4.1	-3.8	3.61
4.4	-4.5	3.94
4.8	-5.1	4.20
5.0	-9.8	6.12
5.4	-9.8	6.12
5.4	-16.8	8.71
7.0	-16.8	8.71
7.0	-26.8	11.57
8.0	-26.8	11.57

Station C4

Vel. (km.s^{-1})	Depth (km)	TWT (s)
1.5	0	0
1.5	-5.0	6.67
2.0	-5.6	7.27
3.2	-5.6	7.27
4.9	-6.3	7.62
5.0	-6.9	7.86
5.2	-7.1	7.94
5.3	-8.1	8.32
6.1	-8.7	8.53
6.7	-10.0	8.94
6.8	-12.2	9.59
8.3	-13.6	9.96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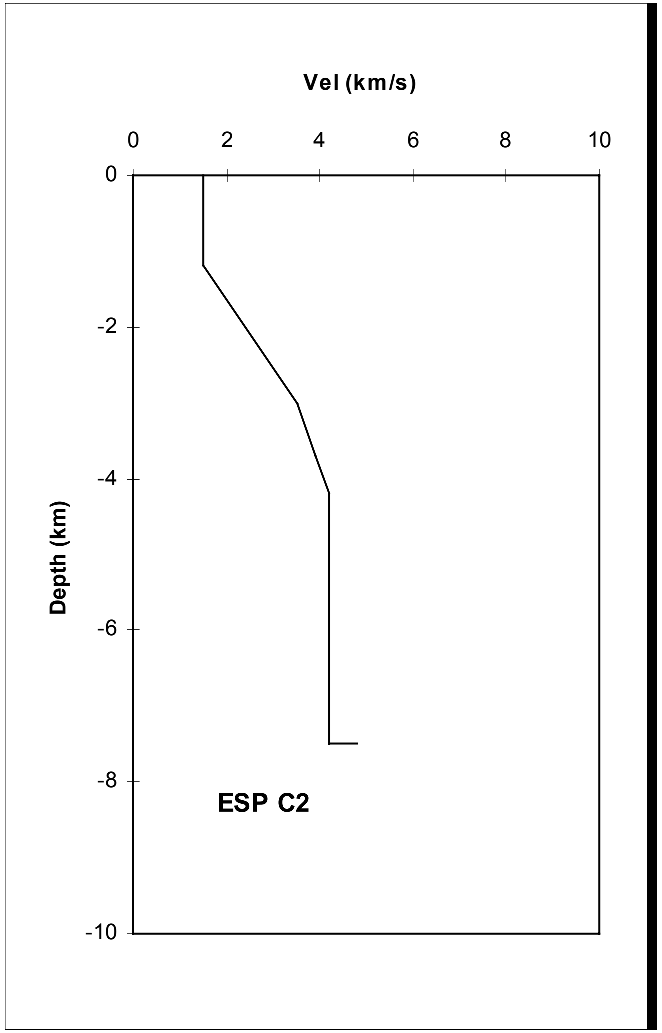
4
6
8
10
0
-2
-4
-6
-8
-10
Depth (km)
ESP C1


Vel (km/s)
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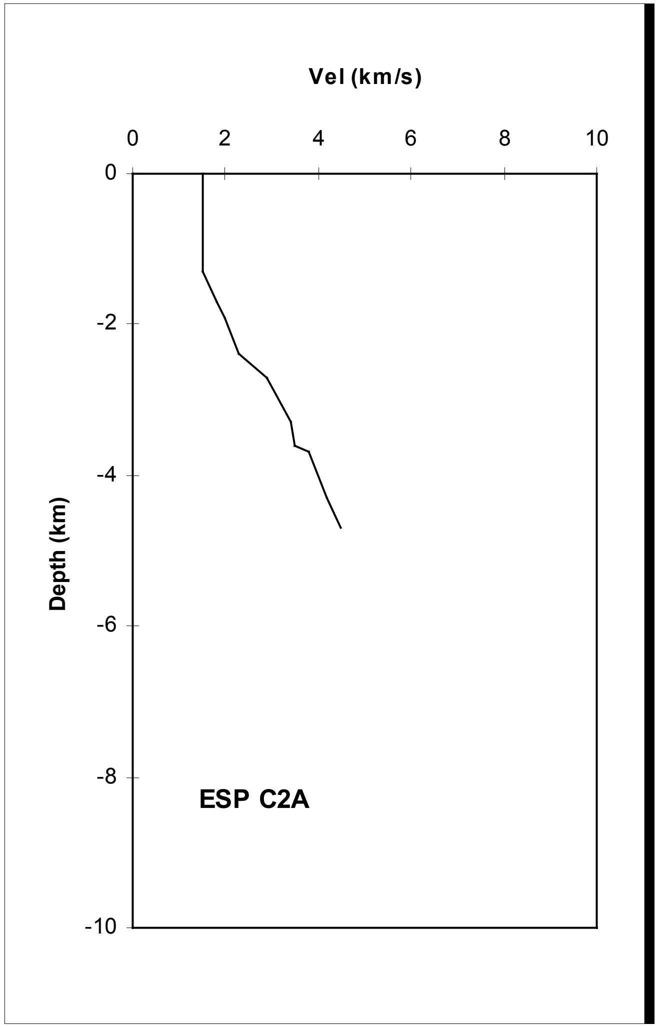
4
6
8
10
0
-2
-4
-6
-8
-10
Depth (km)
ESP C2


Vel (km/s)
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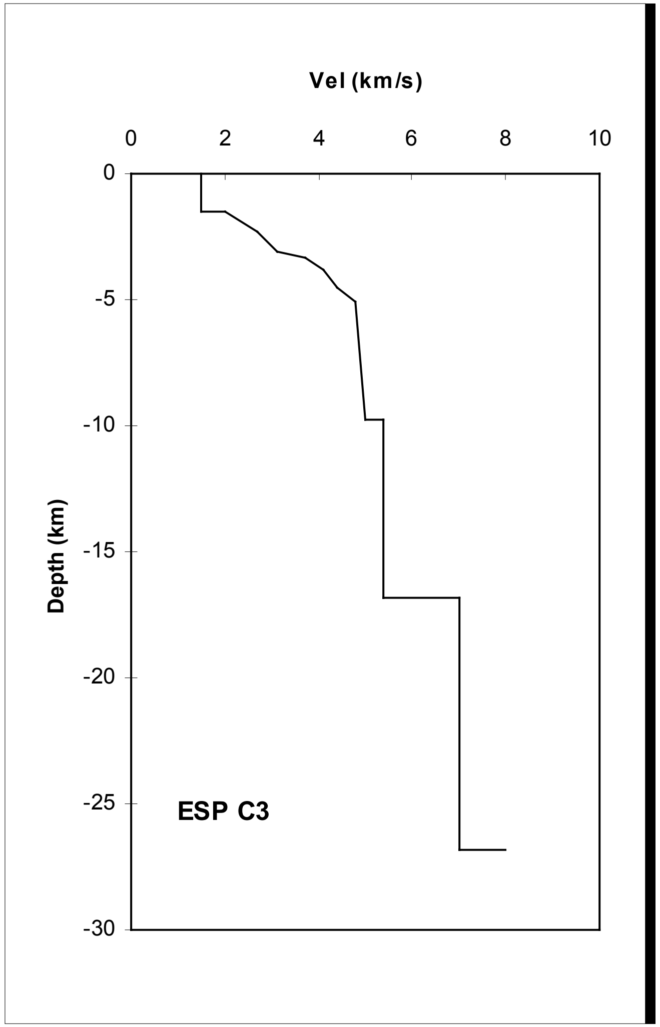
4
6
8
10
0
-2
-4
-6
-8
-10
Depth (km)
ESP C2A


Vel (km/s)
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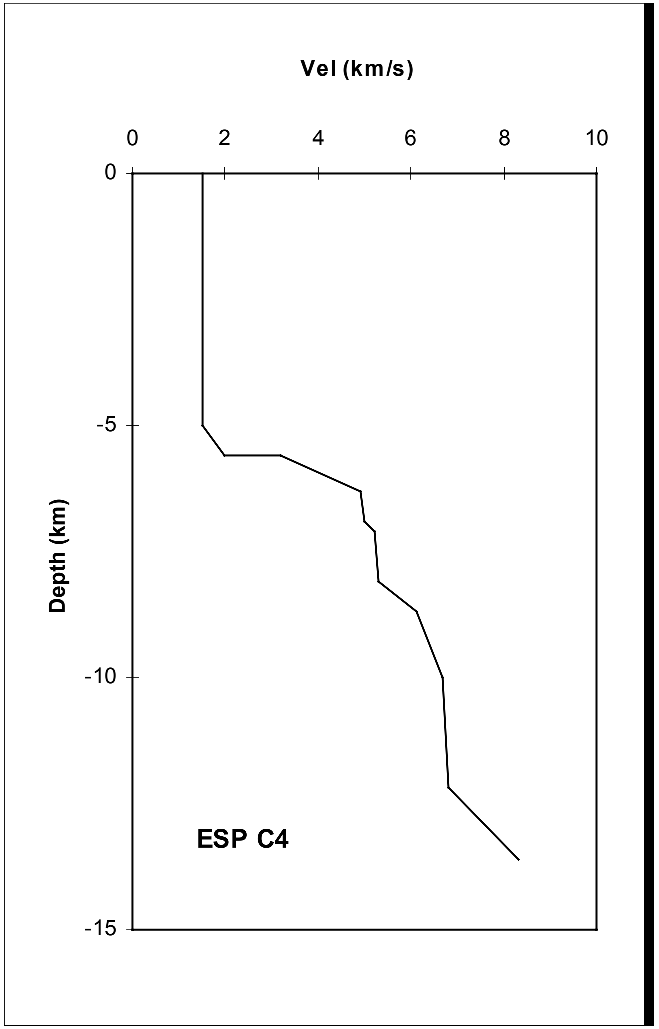
4
6
8
10
0
-5
-10
-15
-20
-25
-30
Depth (km)
ESP C3


Vel (km/s)
0
2
4
6
8
10
0
-5
-10
-15
Depth (km)
ESP C4

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14. LIST OF FIGURES

Figure 6. Seismic survey track chart and bathymetric contours. Isobaths shown in blue and labelled in metres; straight, coloured lines represent different seismic surveys – survey numbers are shown in equivalent colours.

Figure 7. Satellite gravity image with marine jurisdictional boundaries. Blue colours are Free Air Anomaly gravity lows, red colours are gravity highs. Green line – Australian Exclusive Economic Zone (AEEZ), pink line represents the preliminary outer limit of extended Continental Shelf (after Symonds et al., 1998). The latter line is not necessarily indicative or representative of the final outer limit of the Continental Shelf that might be used by Australia in any submission it makes to the Commission on the Limits of the Continental Shelf.

Figure 8. Bathymetric map showing wells, sample stations and other geophysical stations. Green colours – shallow water, blue colours – deep water, isobaths in blue and labelled in metres.

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15. LIST OF PLATES

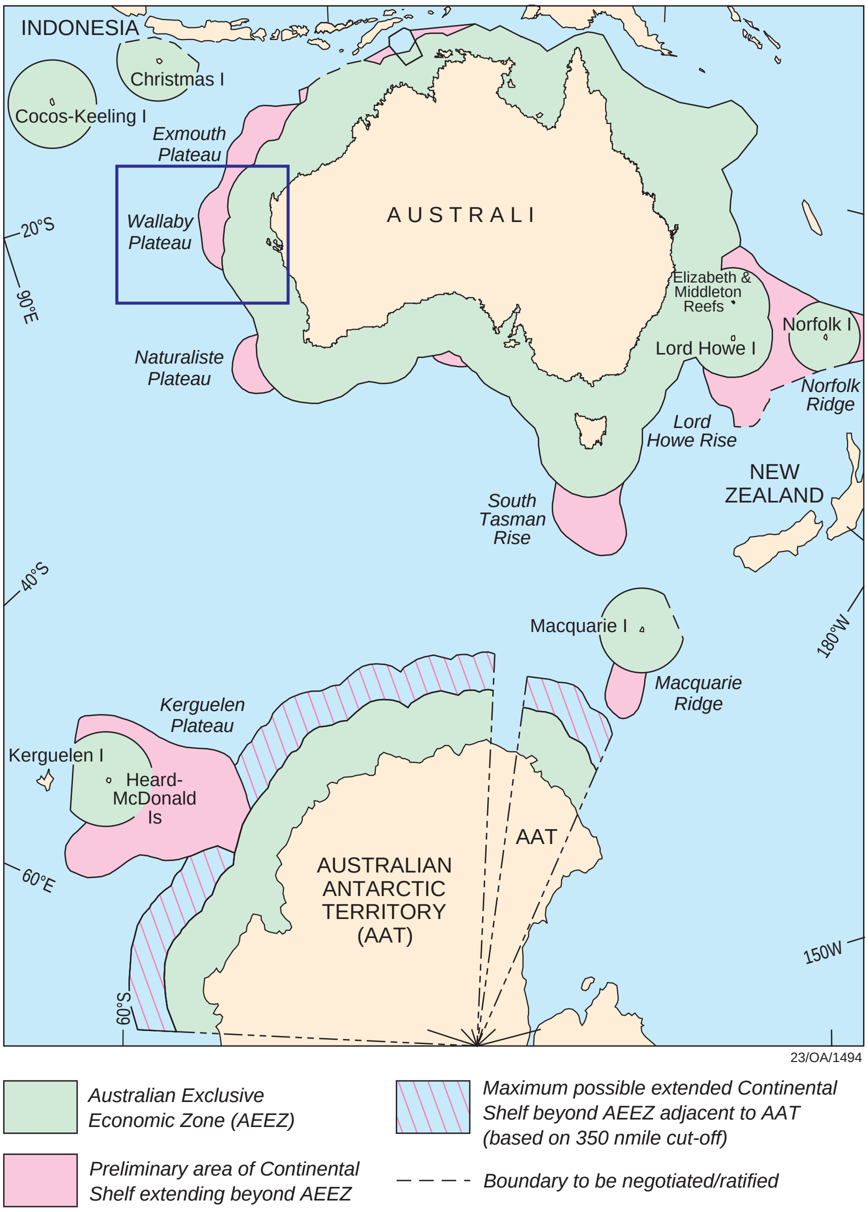


Figure 1. Sketch map showing the main marine jurisdictional zones around Australia and its territories (after Symonds et al., 1998), as well as the location of the Wallaby Plateau study area.

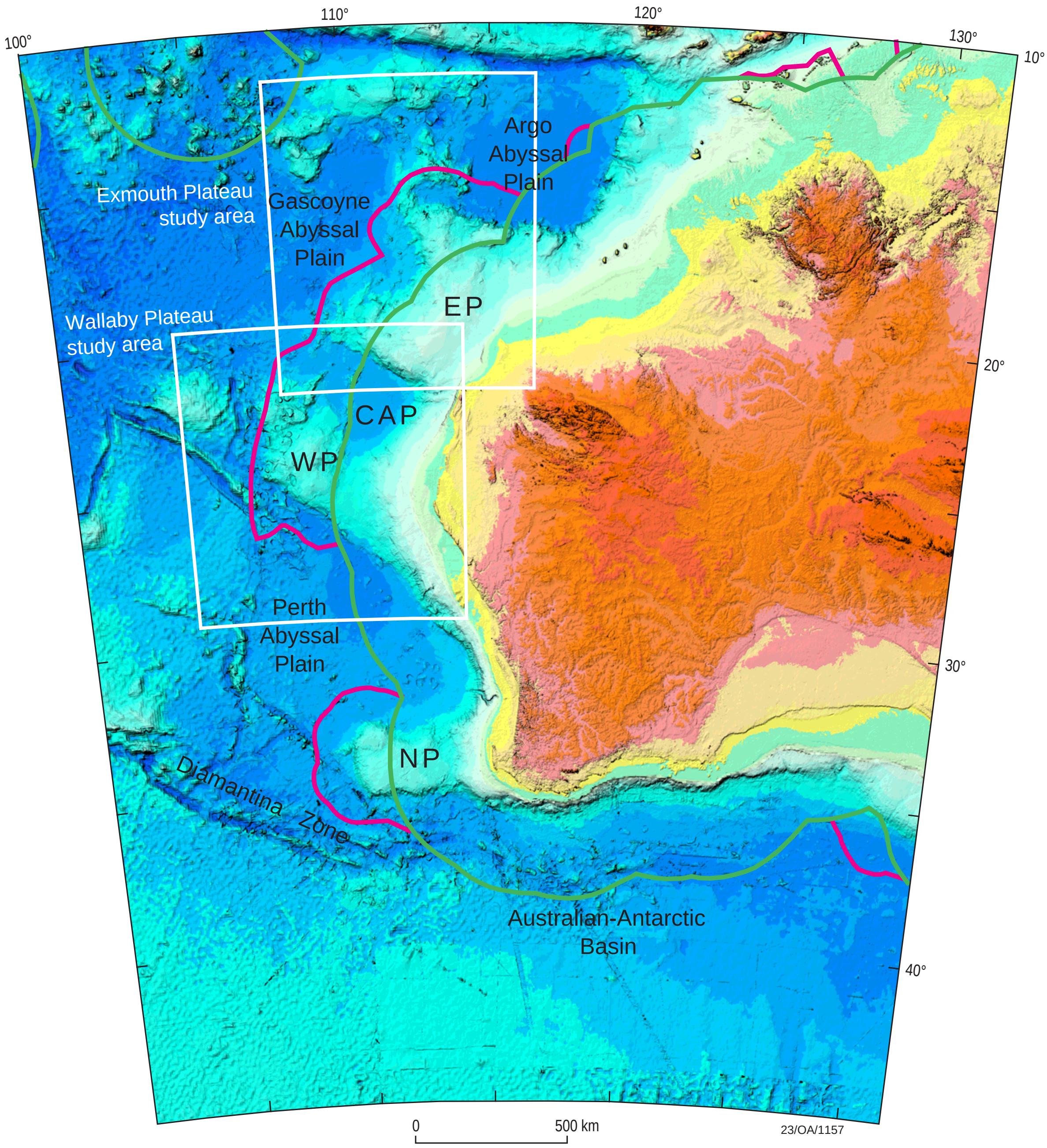


Figure 2. Bathymetric image showing location of the Wallaby and Exmouth Plateau study areas (white boxes). Green line is the Australian Exclusive Economic Zone boundary and pink line is the preliminary boundary of the extended Continental Shelf (after Symonds & Willcox, 1989). The latter line is not necessarily indicative or representative of the final outer limit of the Continental Shelf that might be used by Australia in any submission it makes to the Commission on the Limits of the Continental Shelf. NP -Naturaliste Plateau, WP - Wallaby Plateau, EP - Exmouth Plateau, and CAP - Cuvier Abyssal Plain.

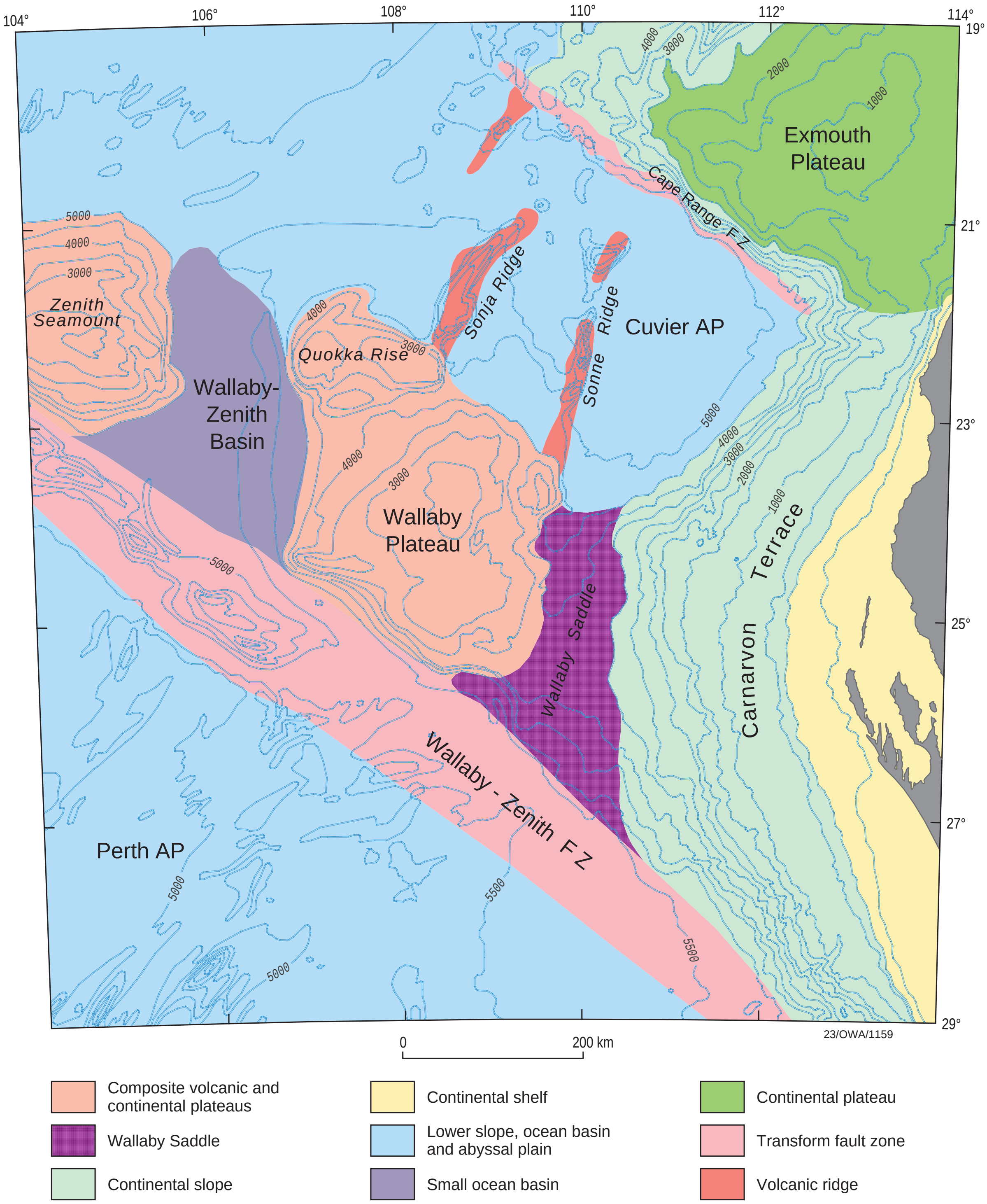


Figure 3. Physiography of the Wallaby Plateau study area. Grey area - landmass; FZ - fracture zone; and AP - abyssal plain. Isobaths shown in blue and labelled in metres.

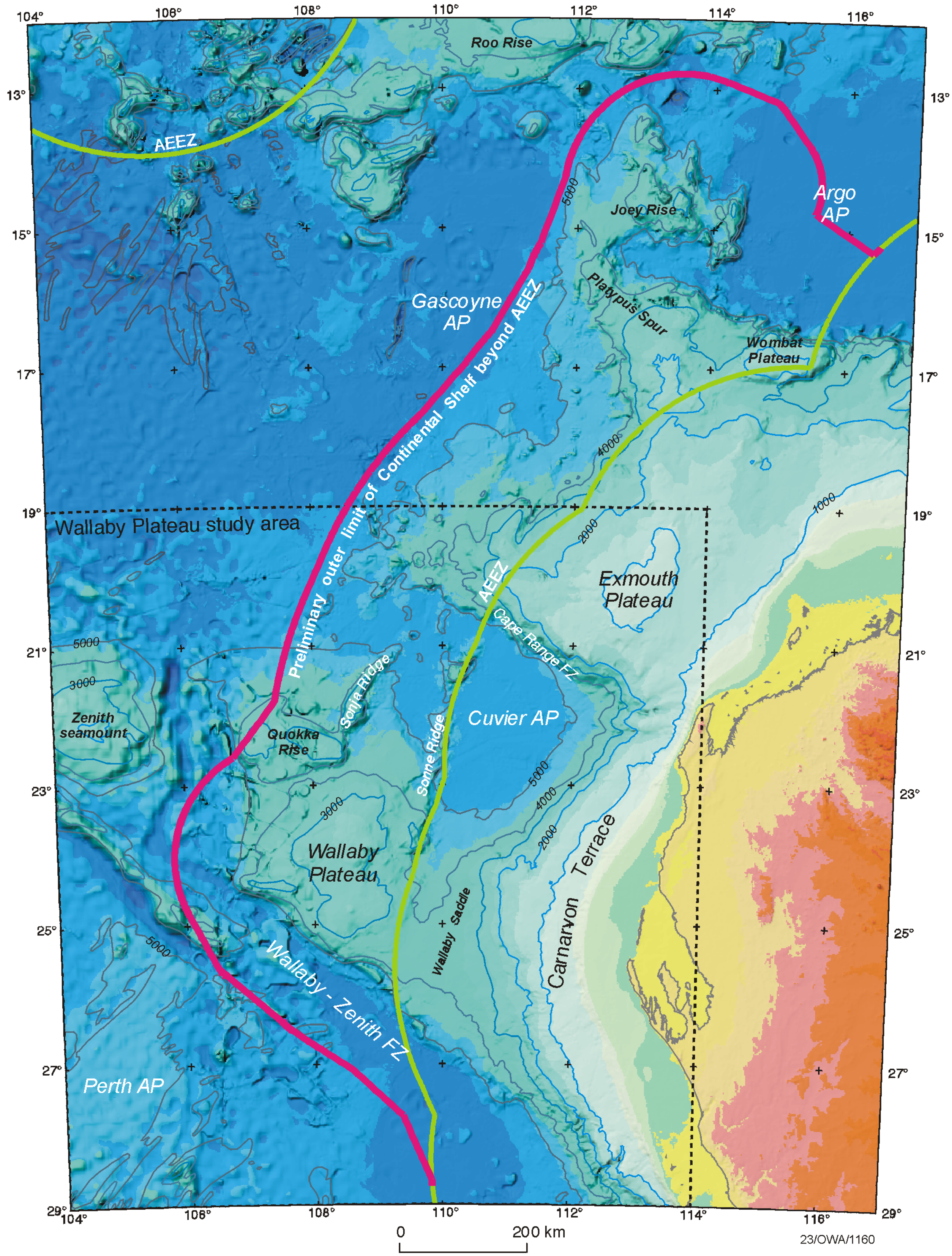


Figure 4. Bathymetry image and marine jurisdictional boundaries. Blue colours - deep water; green colours - shallower water; yellow/orange colours - inner shelf and land; FZ - fracture zone; AP - abyssal plain. Isobaths shown in blue and labelled in metres. Green line is the outer limit of the Australian Exclusive Economic Zone (AEEZ); pink line represents the preliminary outer limit of Continental Shelf that extends beyond AEEZ (after Symonds et al., 1998). The latter line is not necessarily indicative or representative of the final outer limit of the Continental Shelf that might be used by Australia in any submission it makes to the Commission on the Limits of the Continental Shelf.

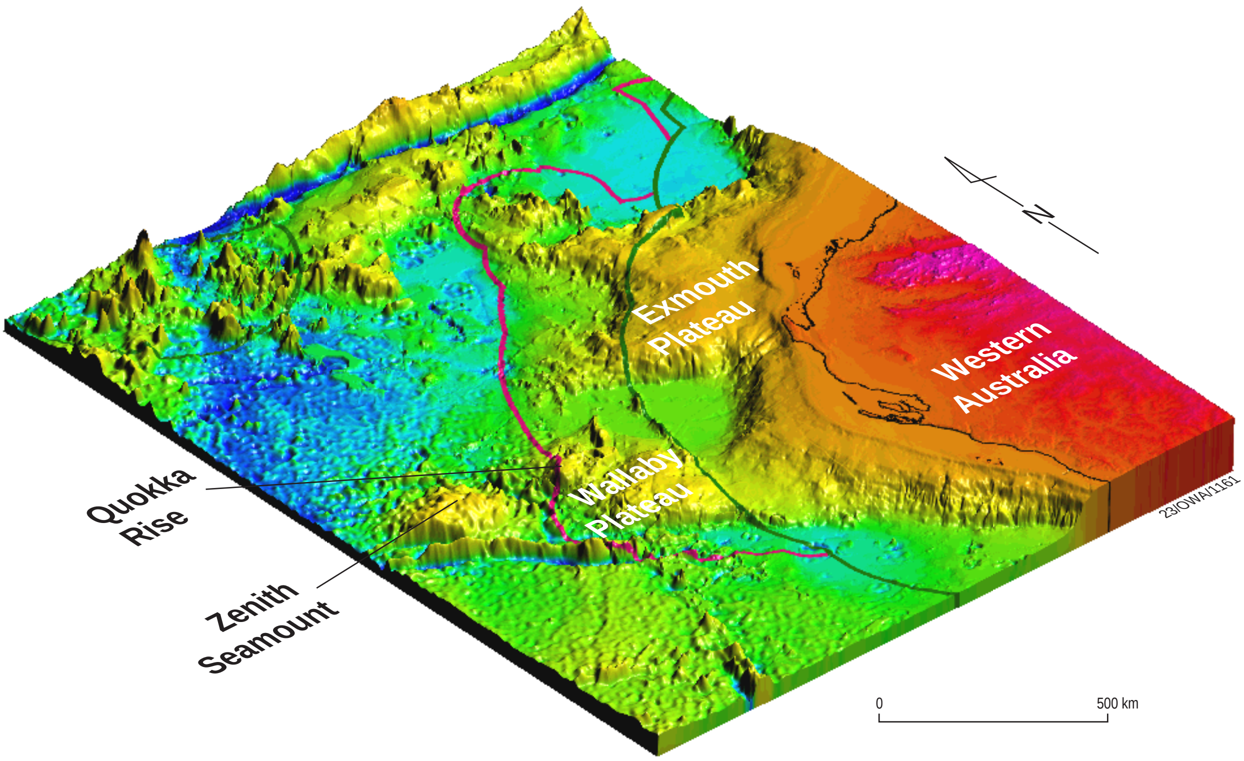


Figure 5. 3D perspective view of the seafloor in the Exmouth-Wallaby area. Orange/yellow colours - shallow water; blue/green colours - deep water; black line - coastline. Green line is the AEEZ and pink line represents the preliminary outer limit of the Continental Shelf that extends beyond the AEEZ. This latter line is not necessarily indicative or representative of the final outer limit that might be used by Australia in any submission it makes to the Commission on the Limits of the Continental Shelf.

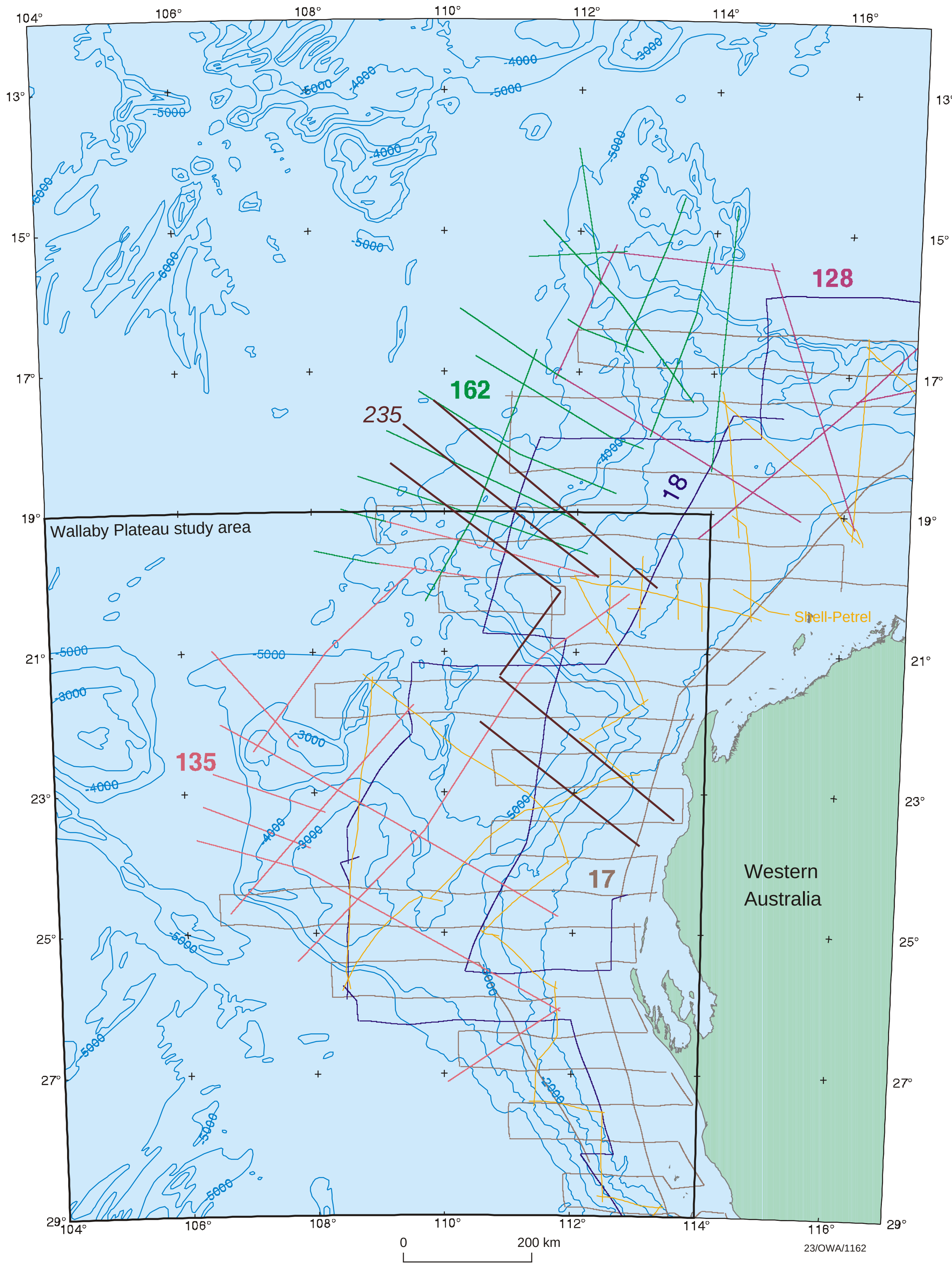
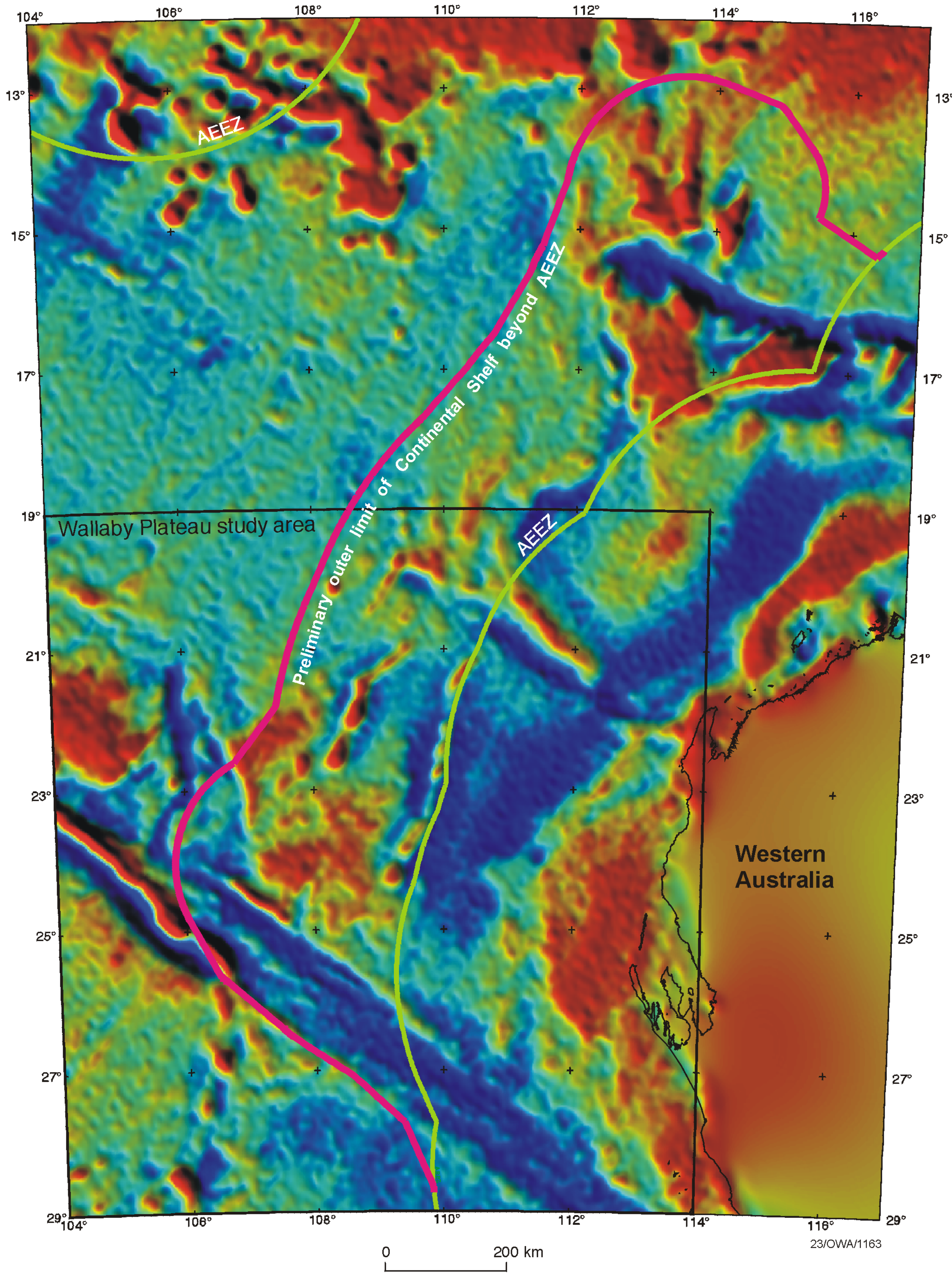


Figure 6. Seismic survey track chart and bathymetric contours. Isobaths shown in blue and labelled in metres; straight, coloured lines represent different seismic surveys - survey numbers are shown in equivalent colours.



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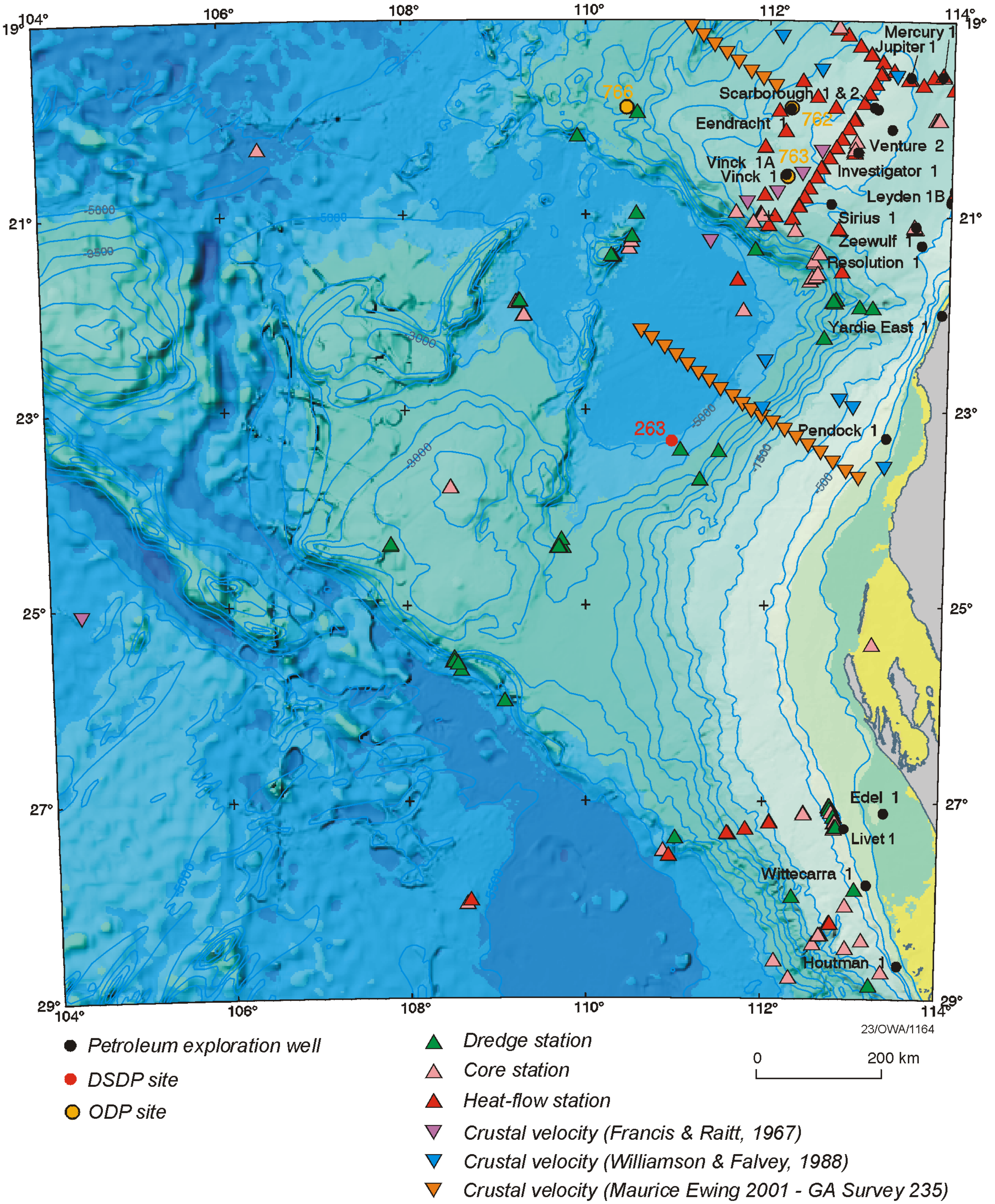

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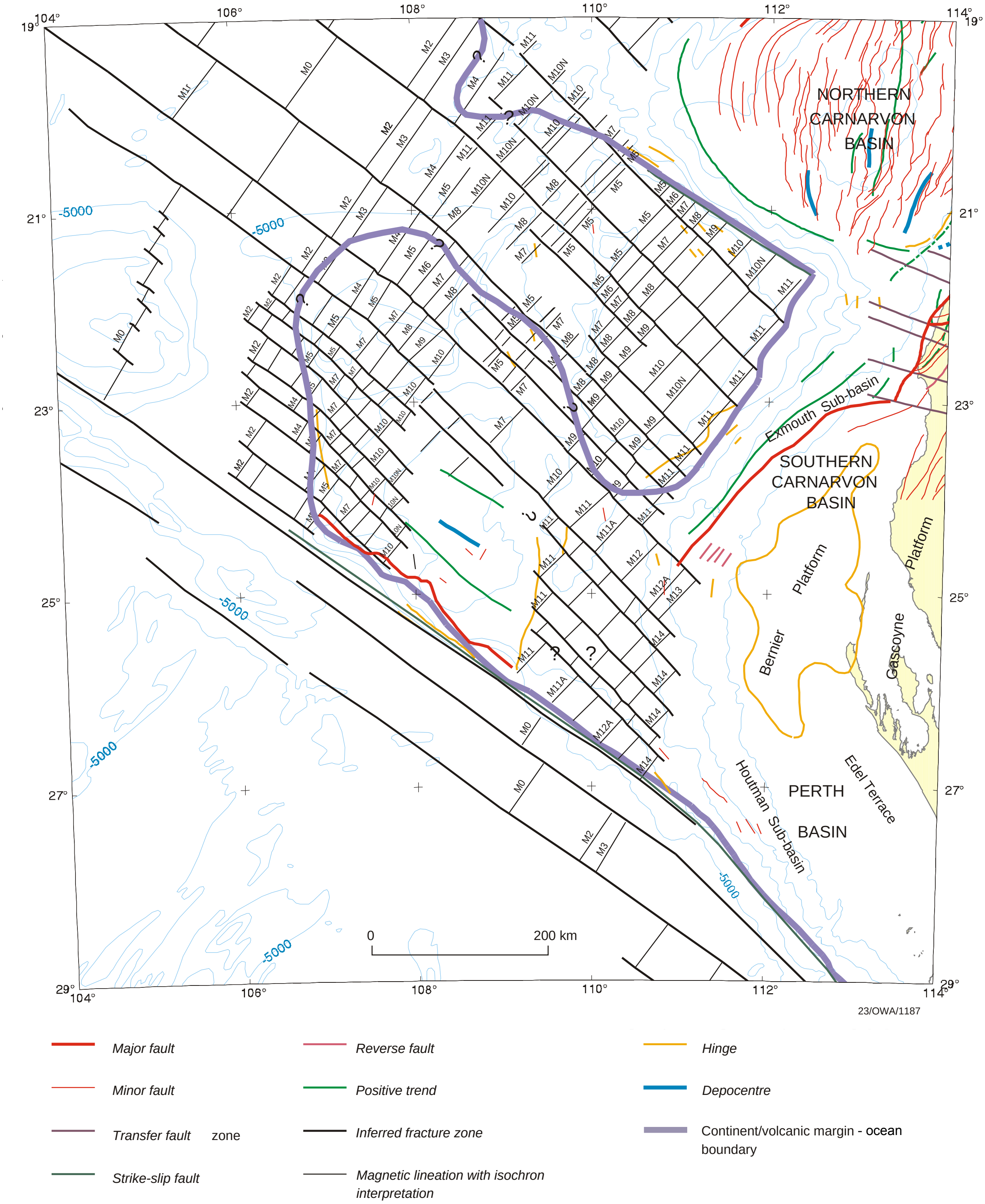

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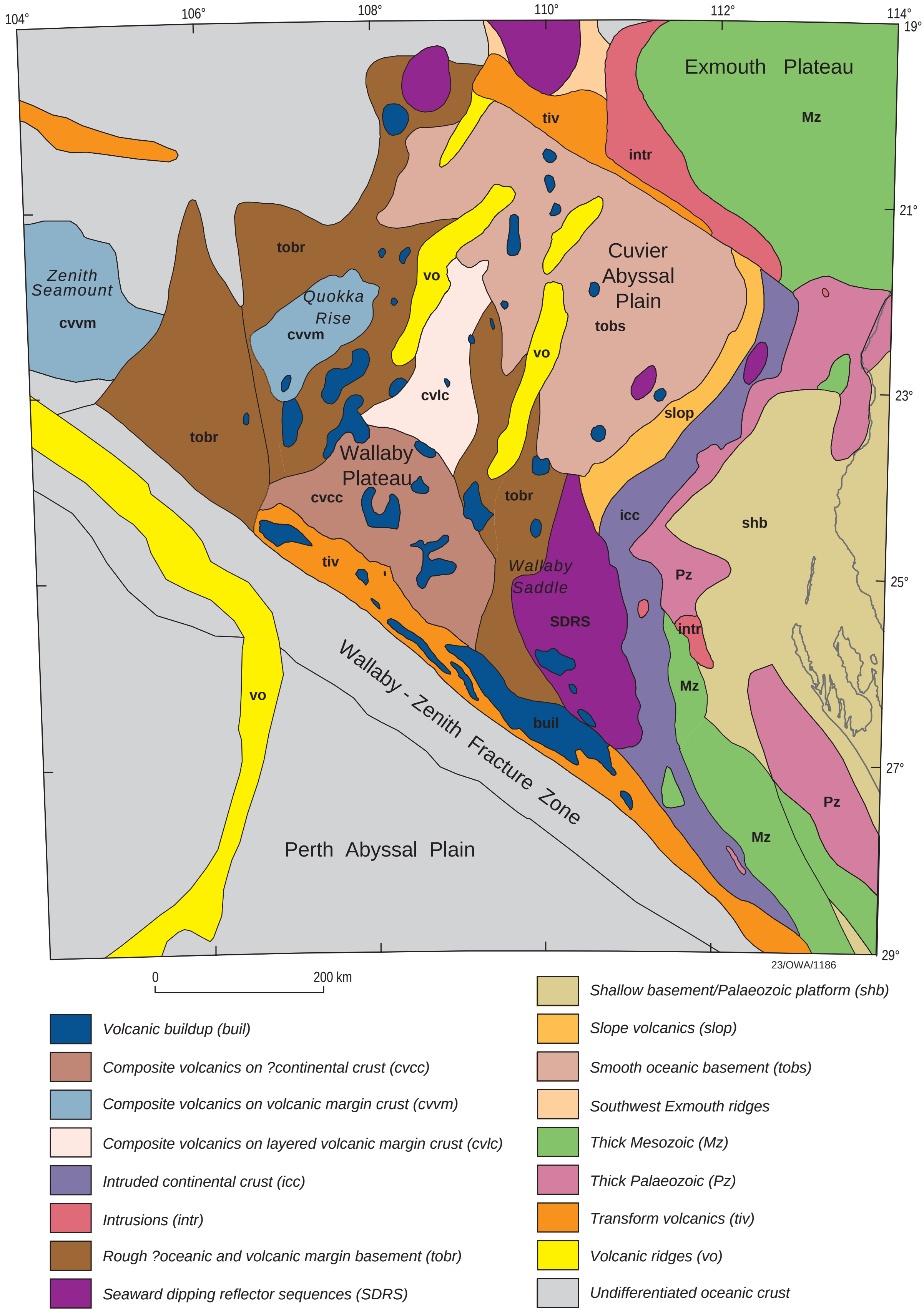

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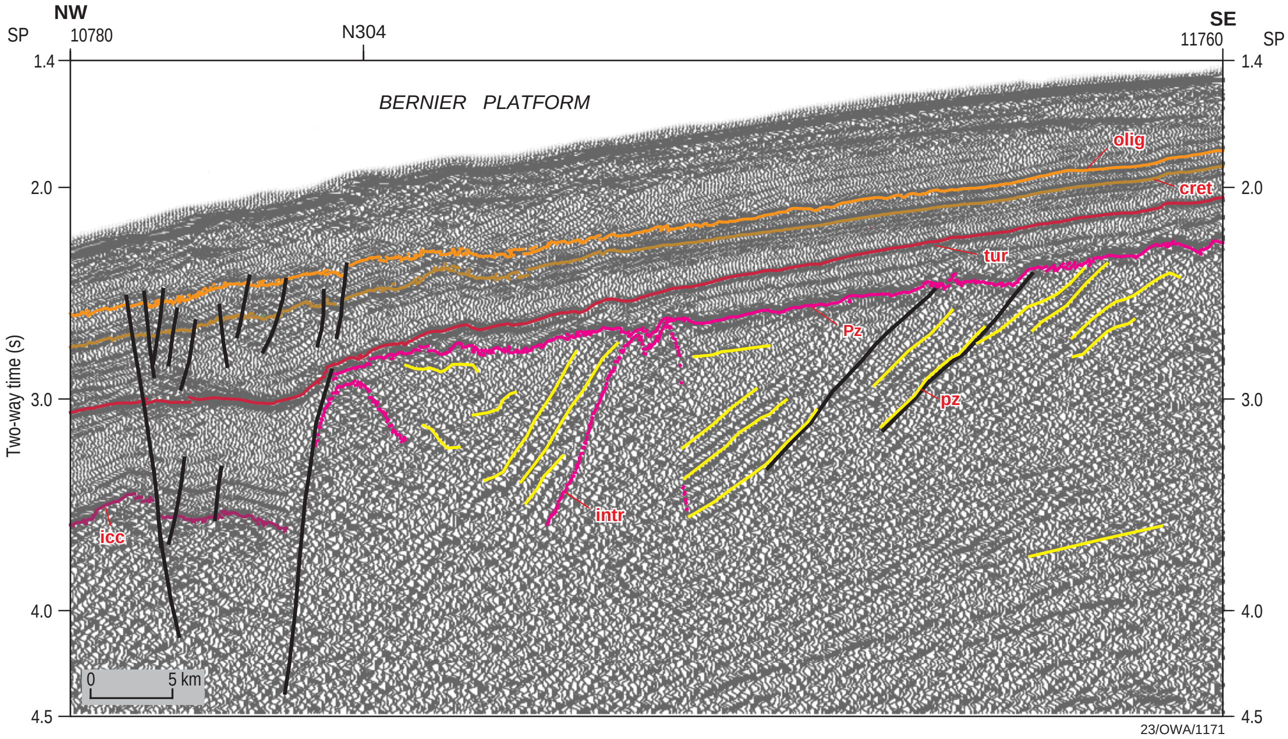

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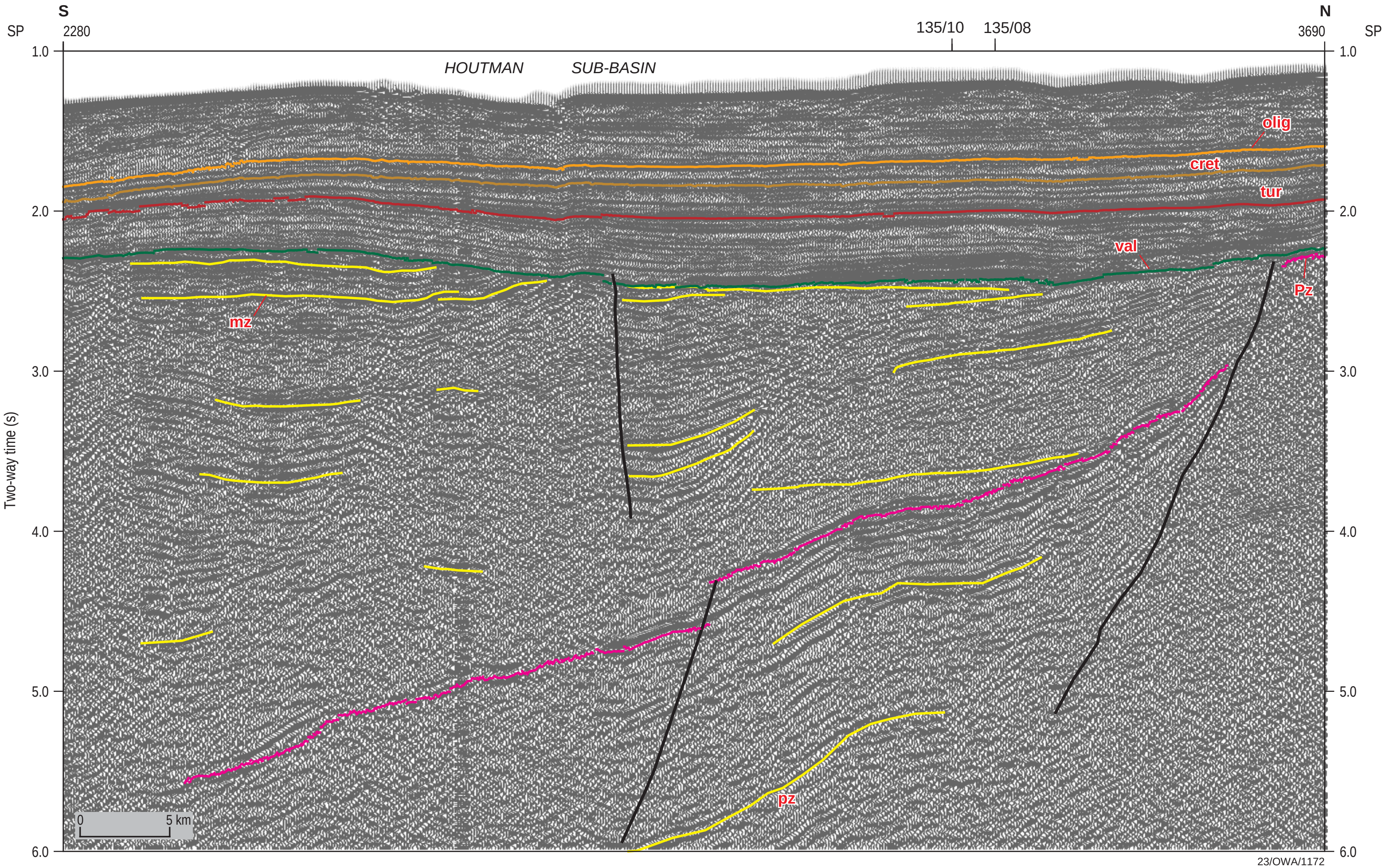

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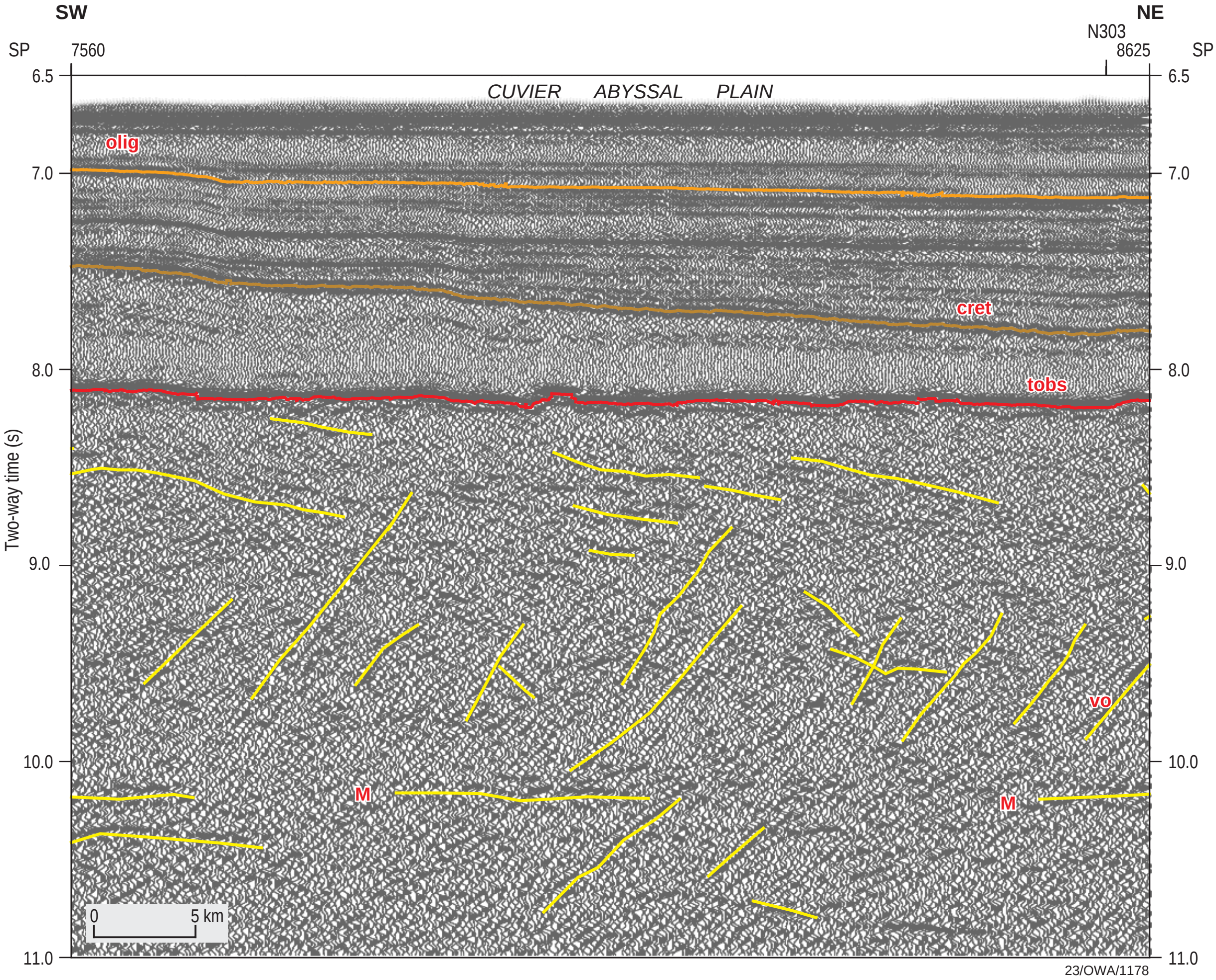

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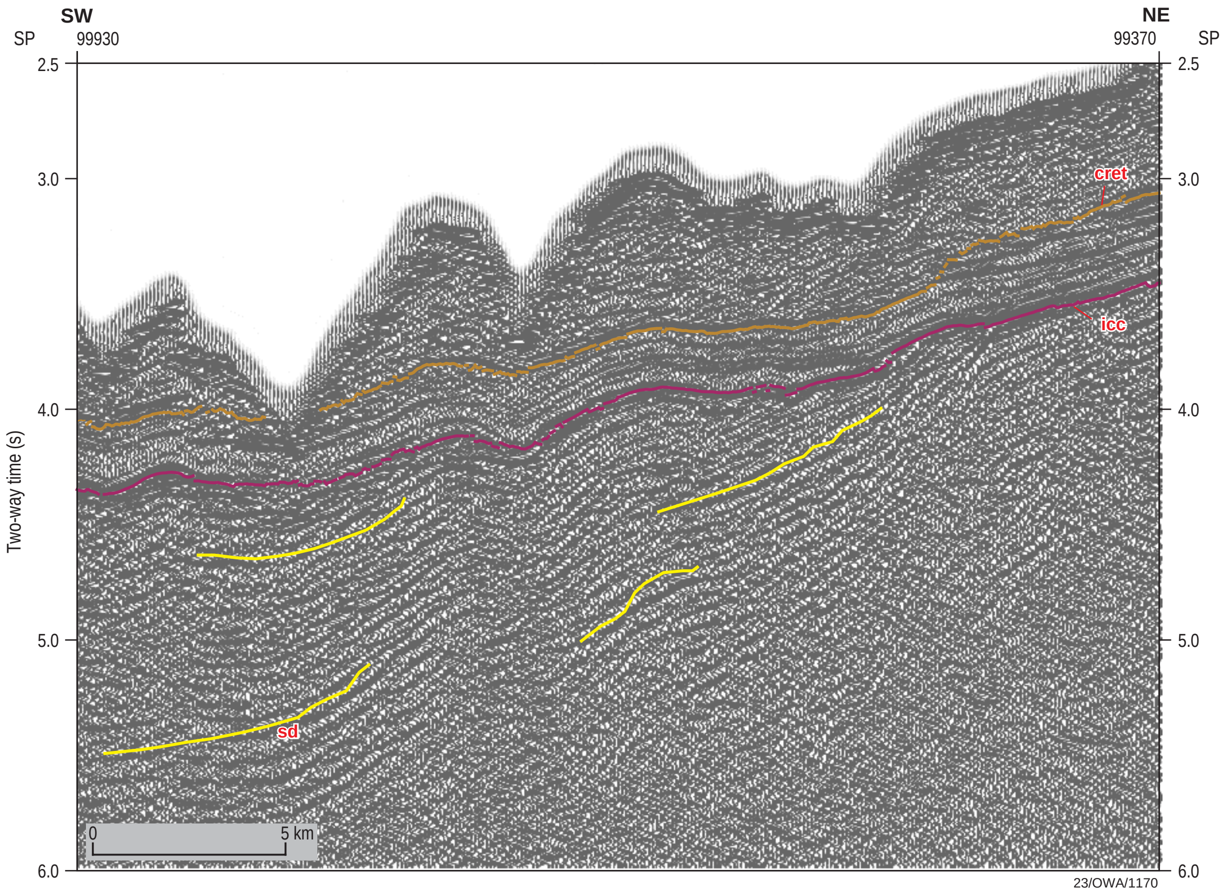

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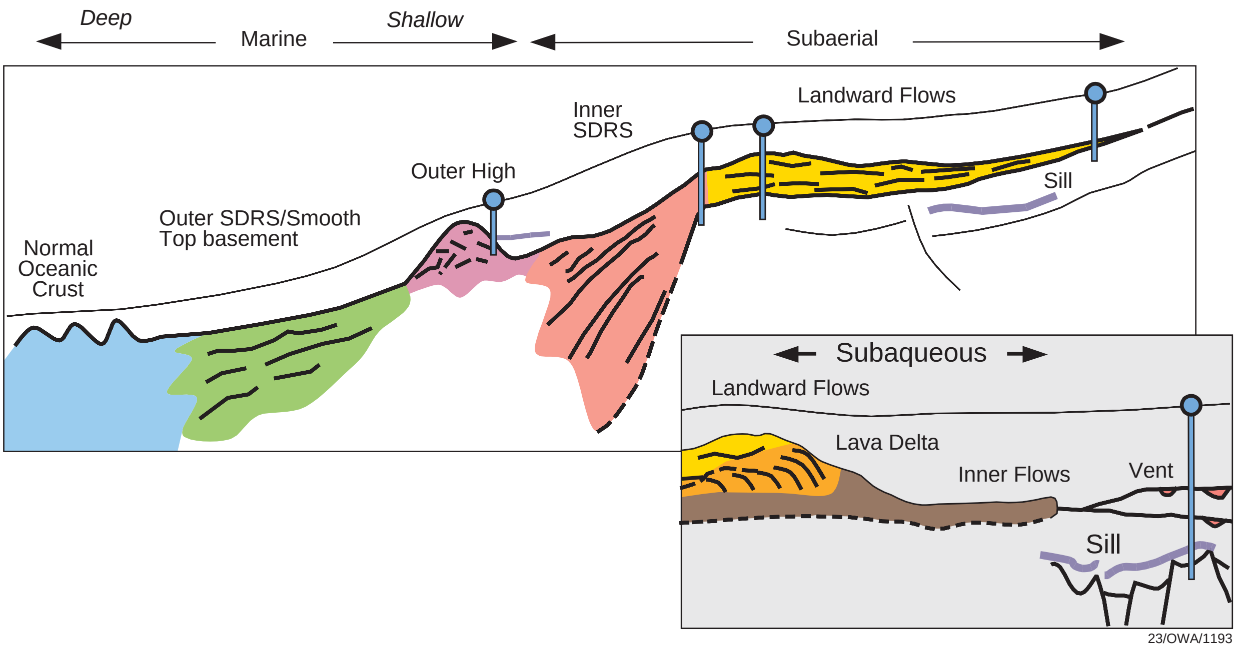

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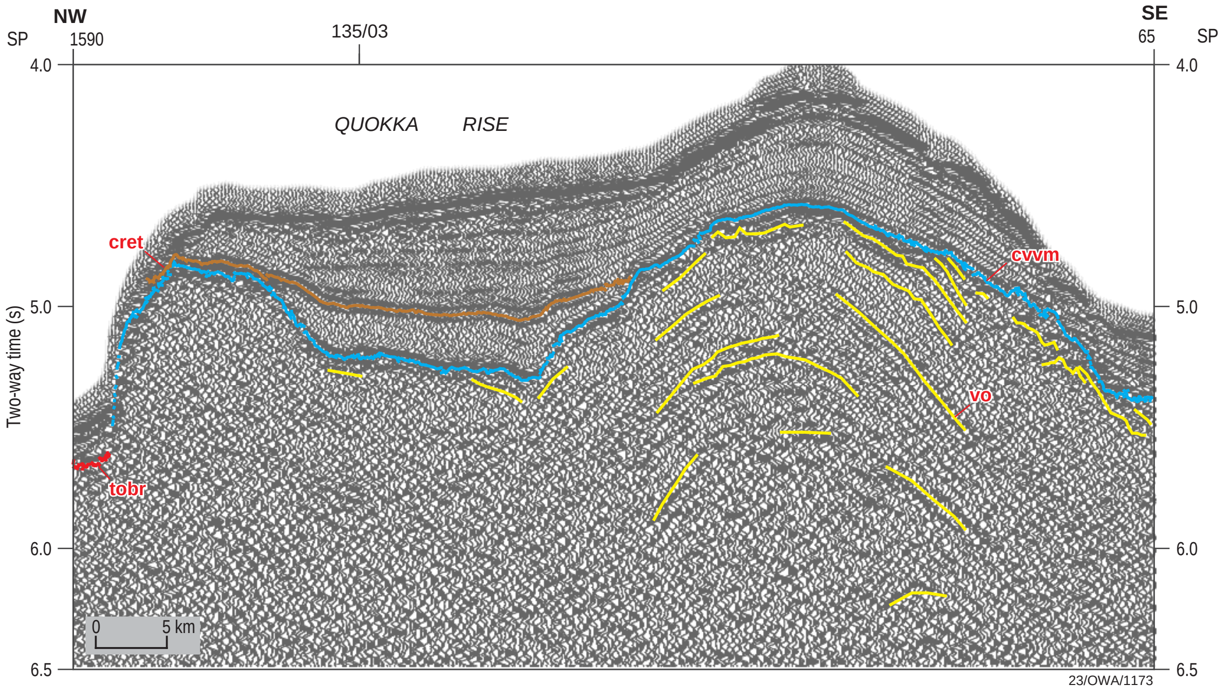

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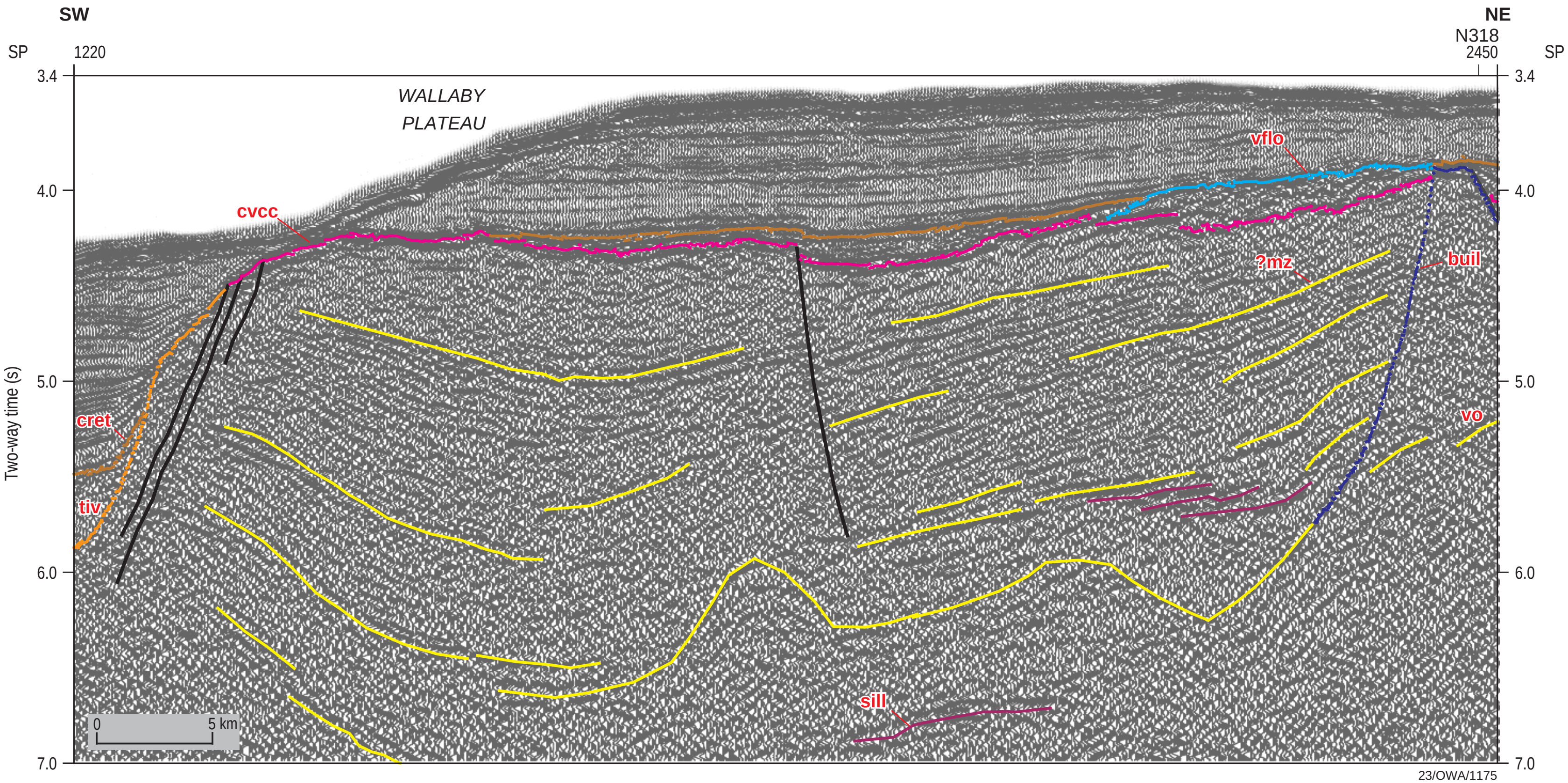

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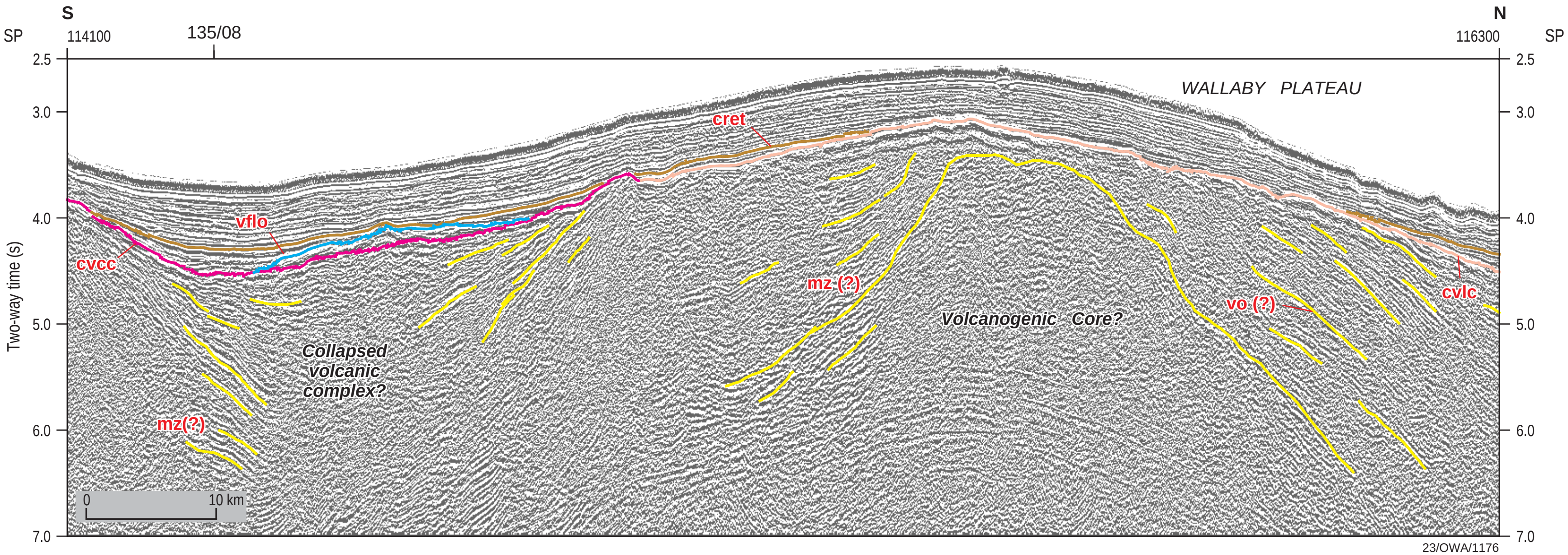

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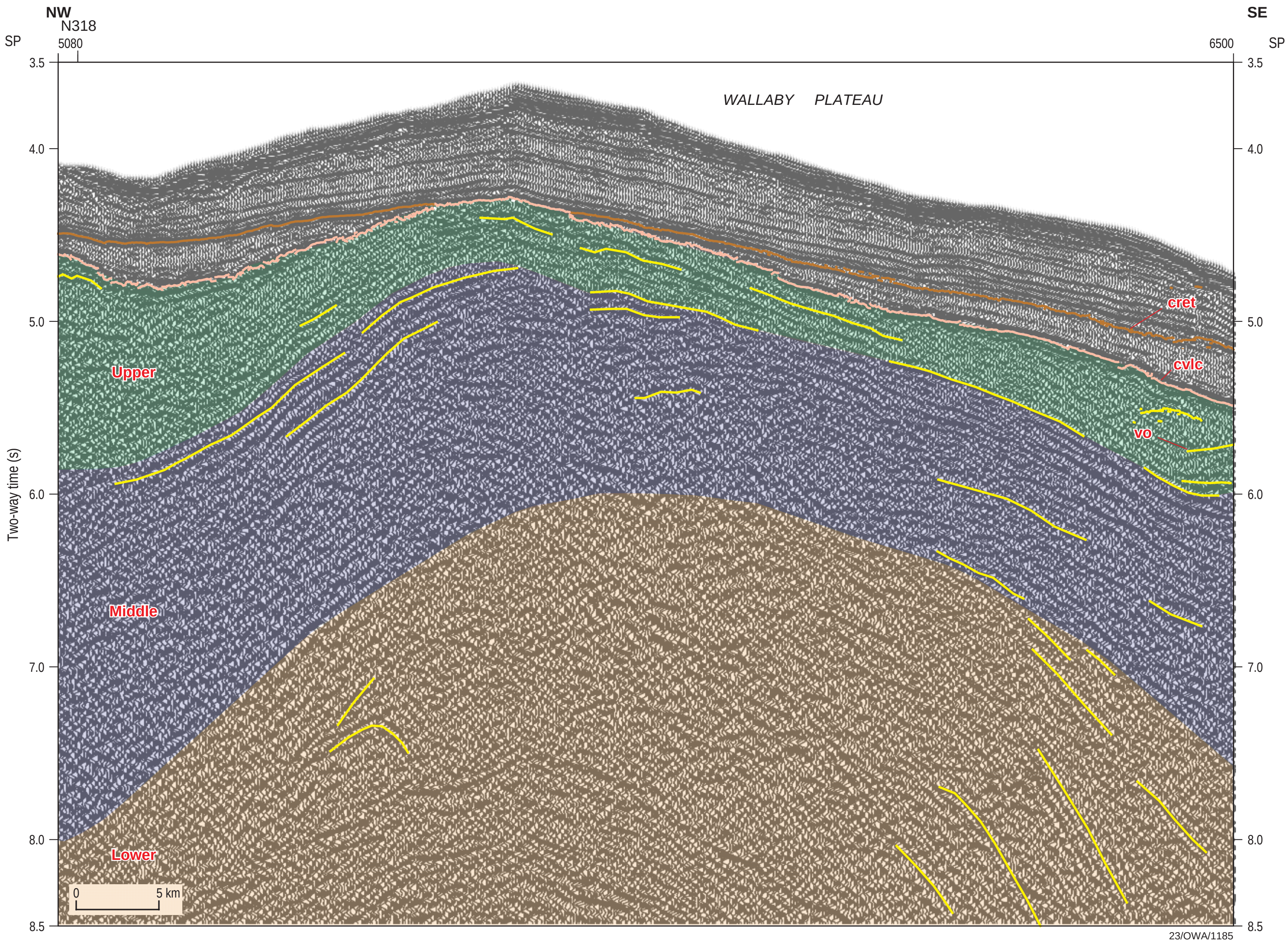

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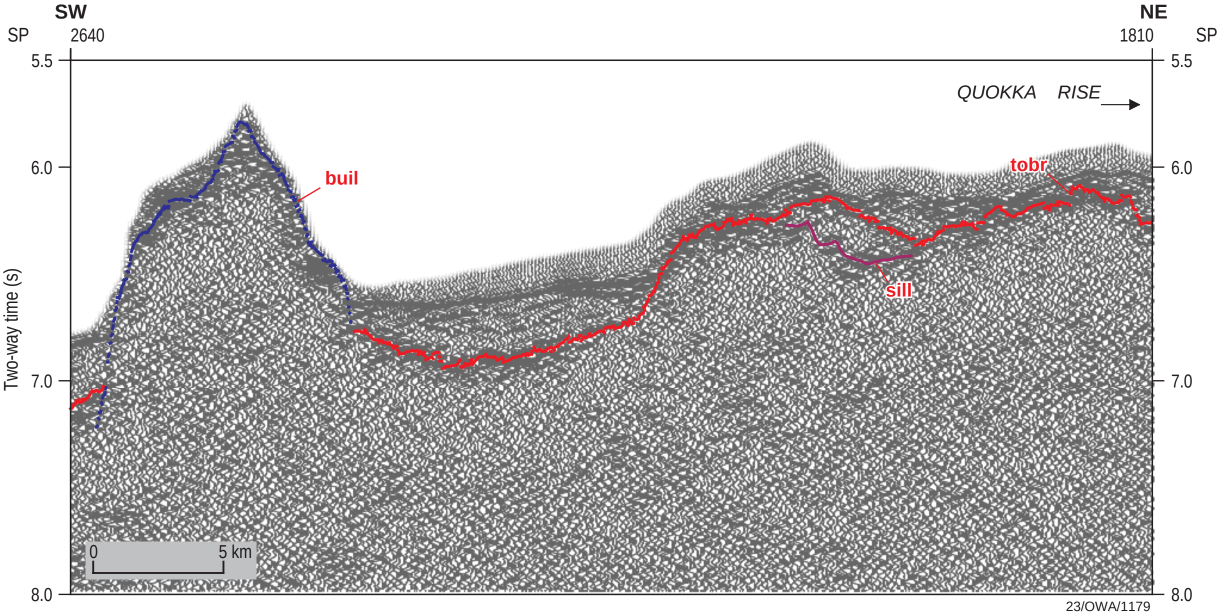

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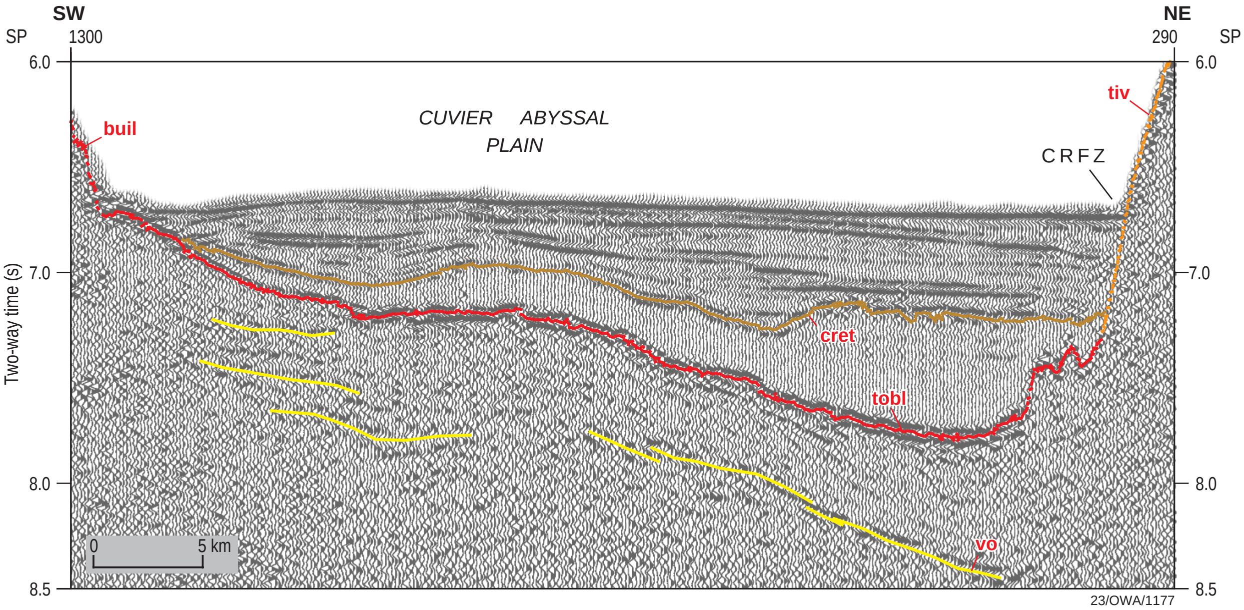

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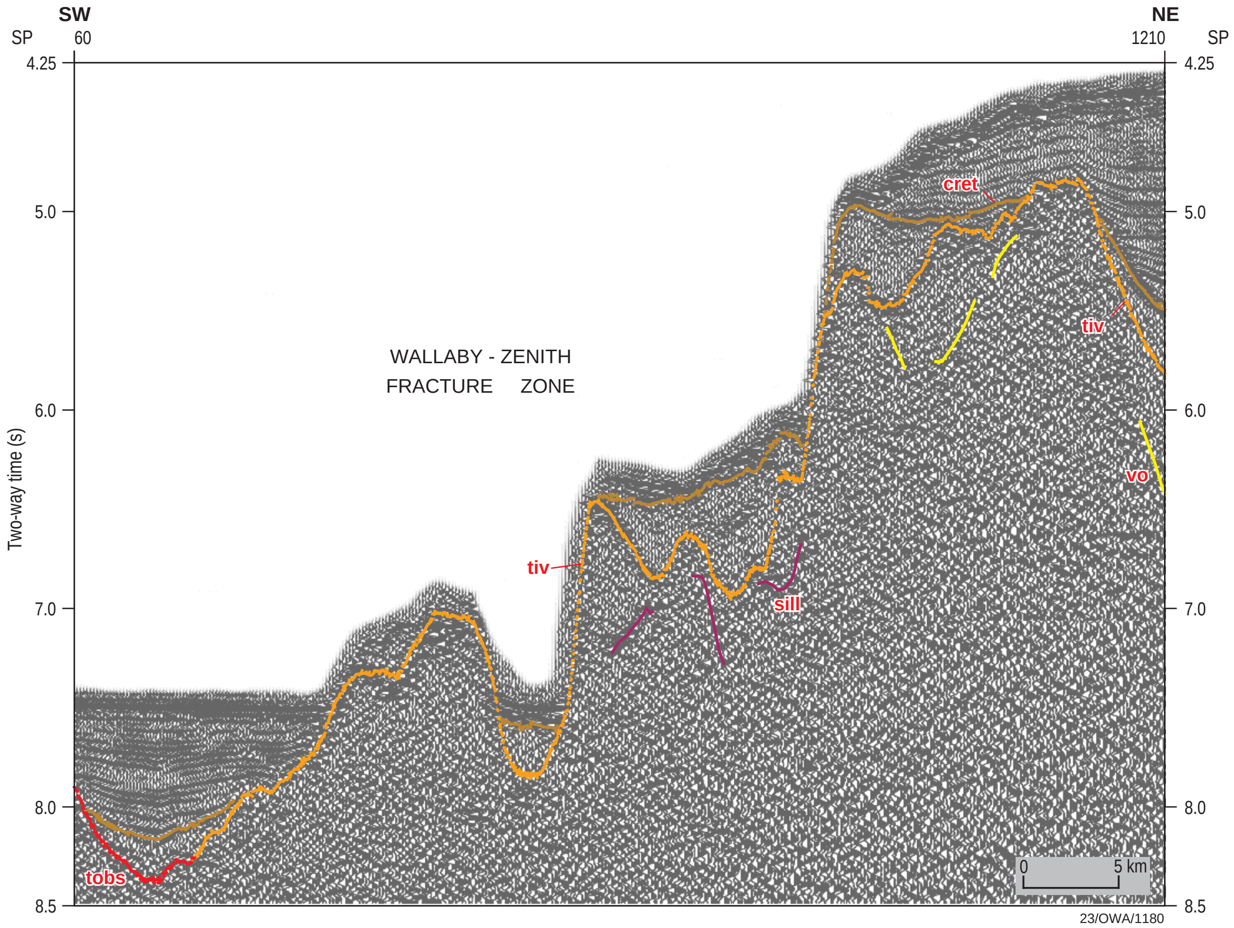

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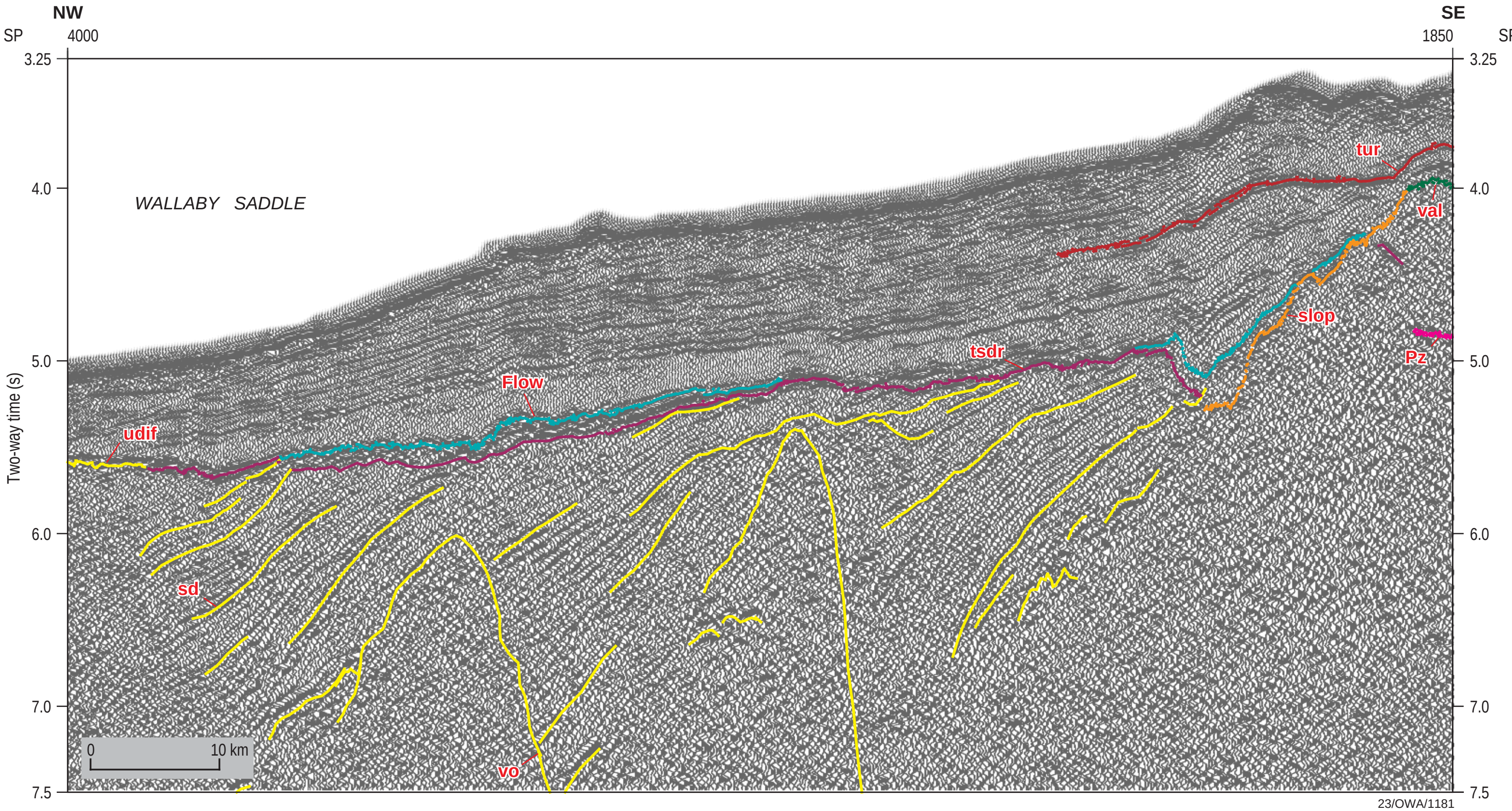

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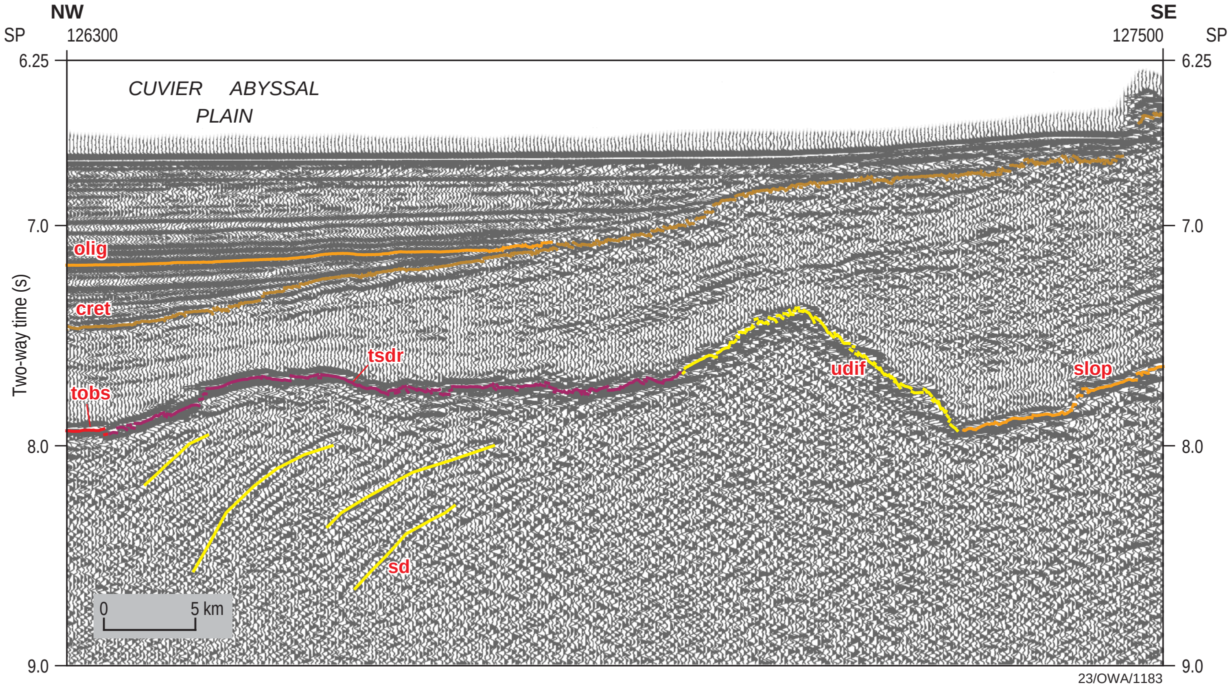
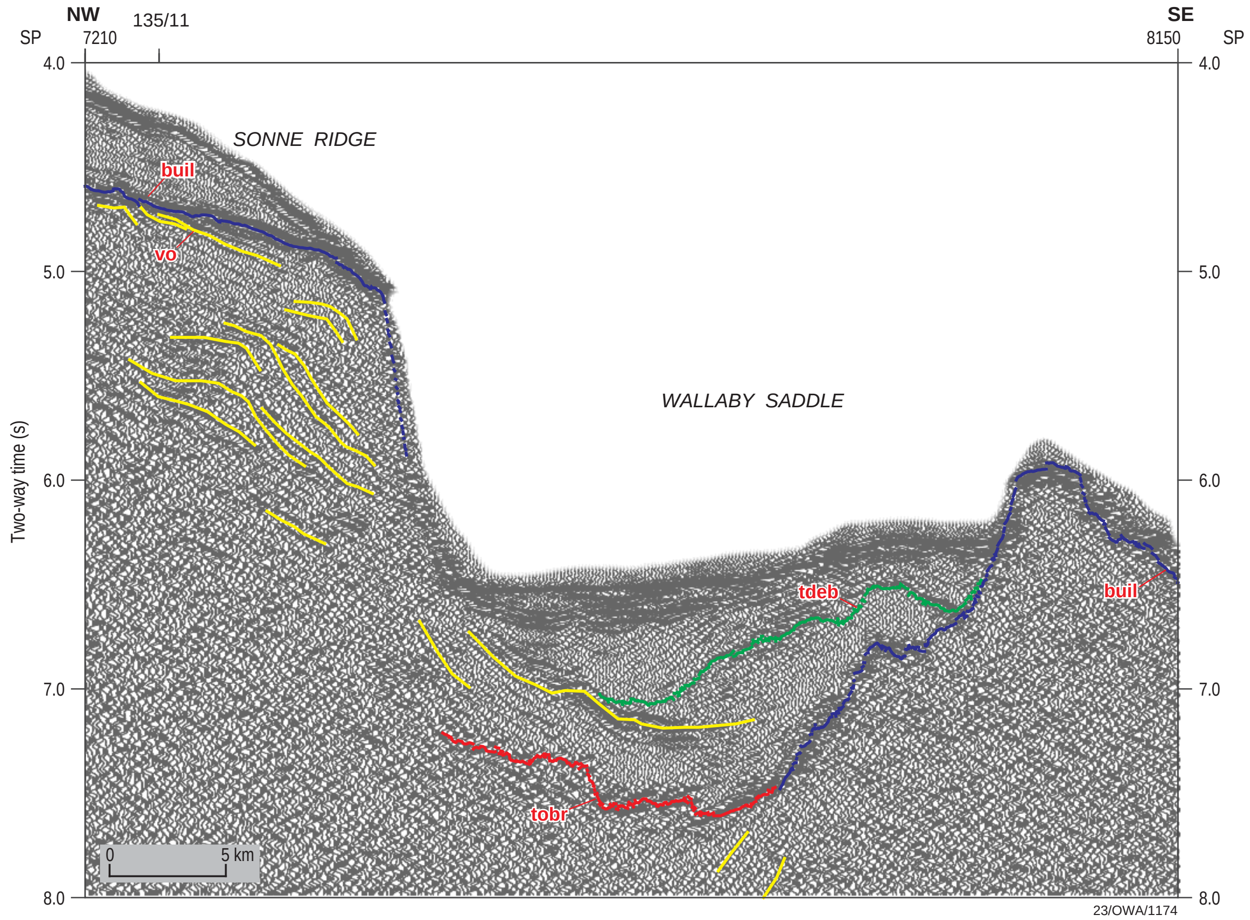


Figure 24. Seaward dipping reflector sequence (SDRS) and undifferentiated volcanic build-up beneath eastern edge of Cuvier Abyssal Plain, Shell-*Petrel* seismic line N303. olig - mid-Oligocene, cret - Cretaceous, tobs - top of smooth oceanic basement, tsdr - top of seaward dipping reflector sequence, udif - undifferentiated volcanic build-up, slop - top lower slope volcanics, sd - form lines in SDRS.



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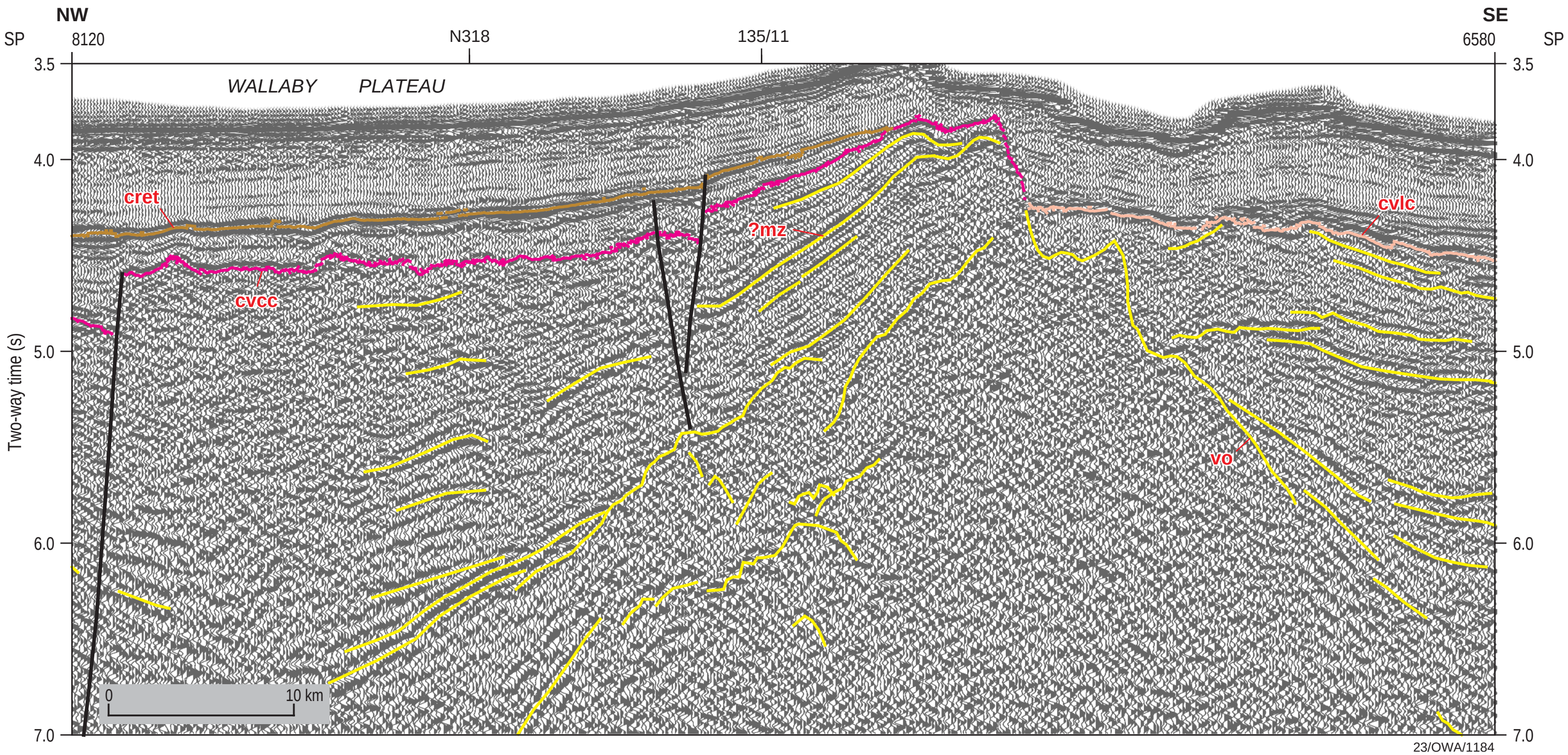

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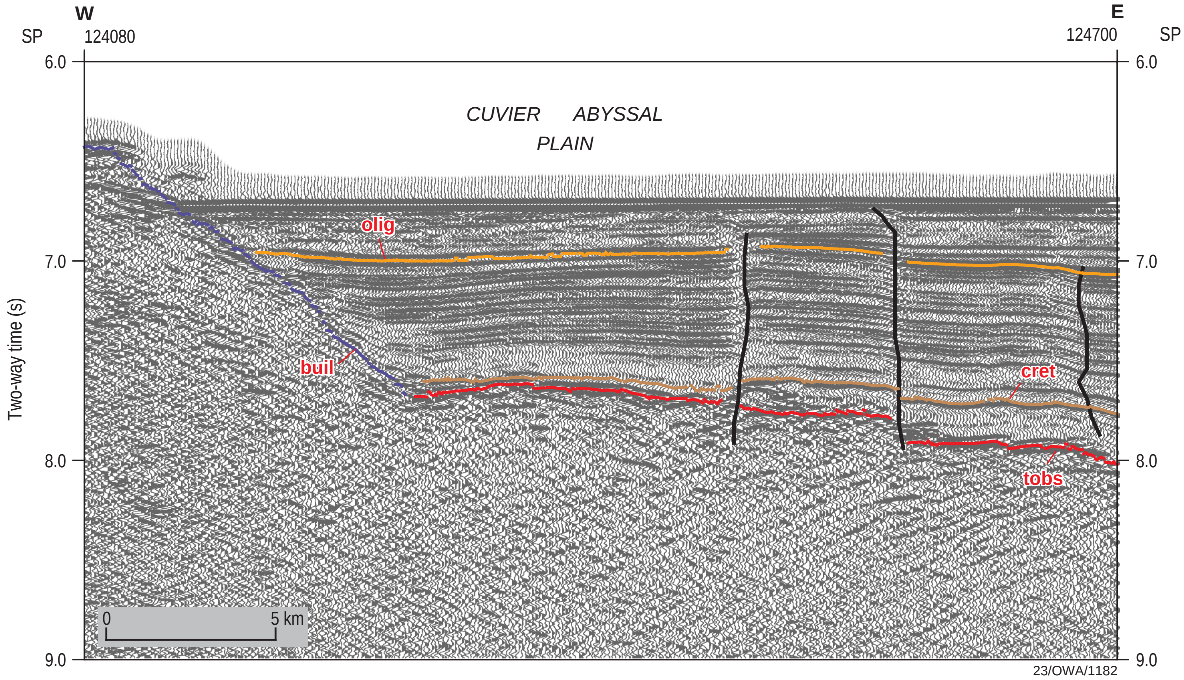


Figure 27. Late Miocene faulting beneath Cuvier Abyssal Plain, Shell-*Petrel* seismic line N303. cret - Cretaceous, olig - mid-Oligocene, buil - volcanic build-up, tobs - top of smooth oceanic basement.

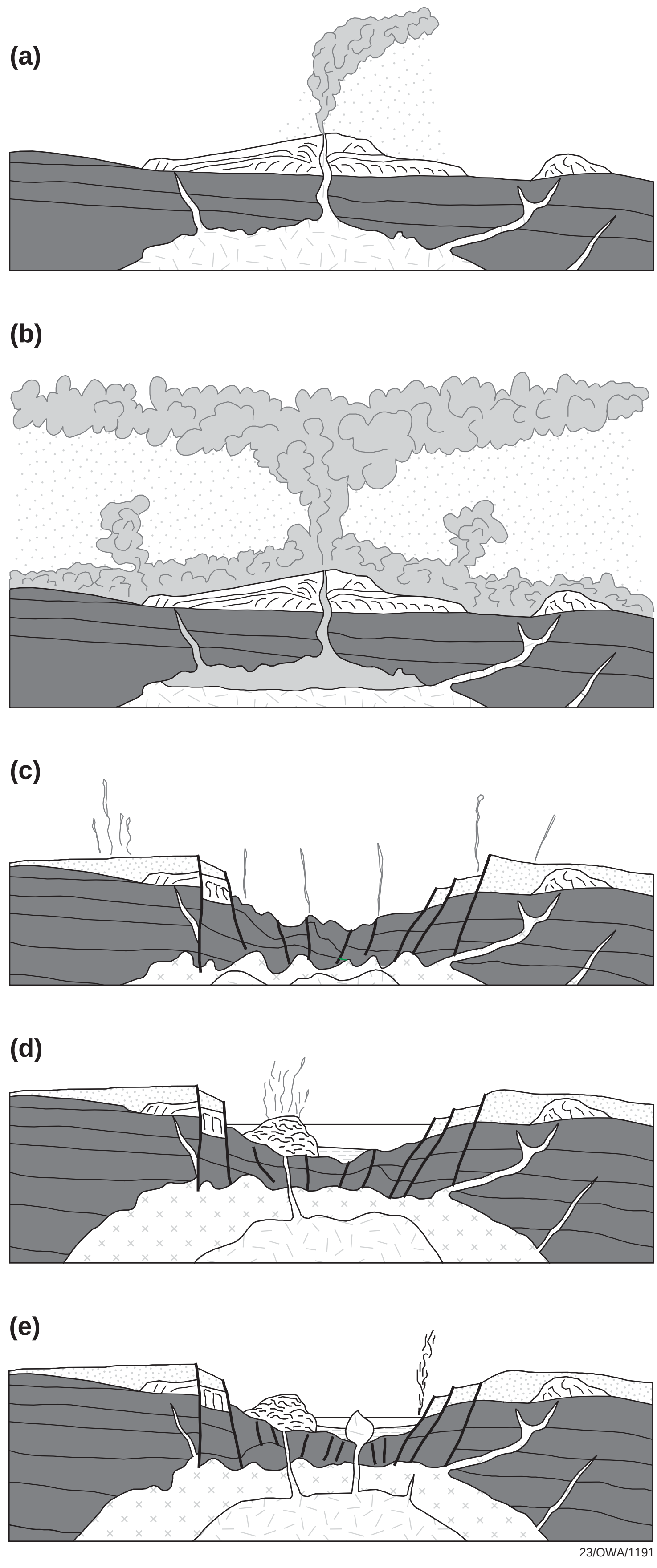


Figure 28. Formation of the Rotorua Caldera (after Bailey & Carr, 1994). A possible analogue, although in a different tectonic setting, for the cross-dipping reflectors beneath the Wallaby Plateau that are interpreted as a collapsed caldera. (a) eruption phase, (b) magma chamber forming under developing volcano complexes, (c) blowout and caldera formation, (d) sub-aqueous lava flows and sediment infill, (e) localised hot zone feeding lava flows.

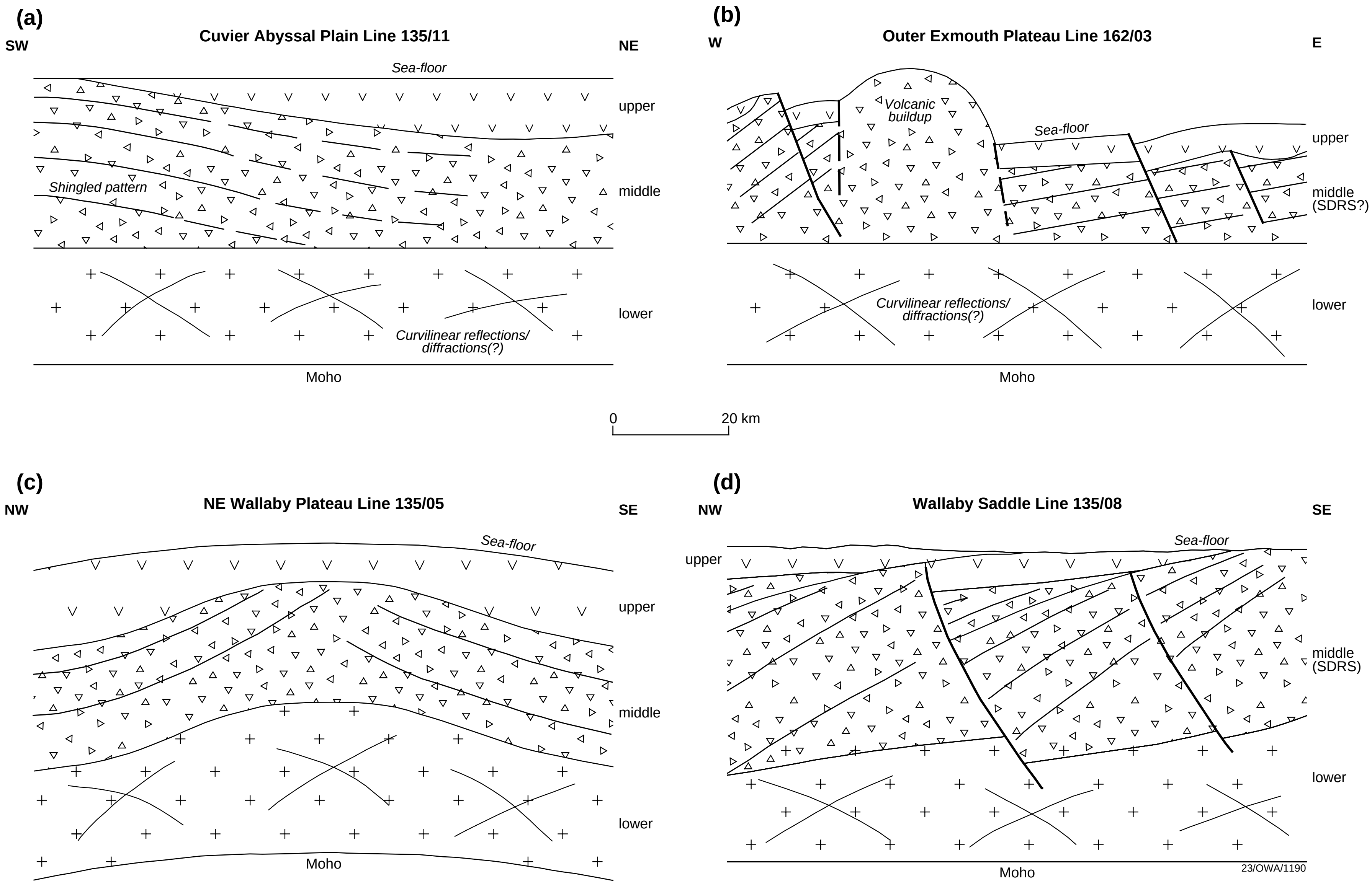


Figure 29. Comparison of crustal layering (upper, middle, lower) throughout the study area. SDRS - seaward dipping reflector sequence.

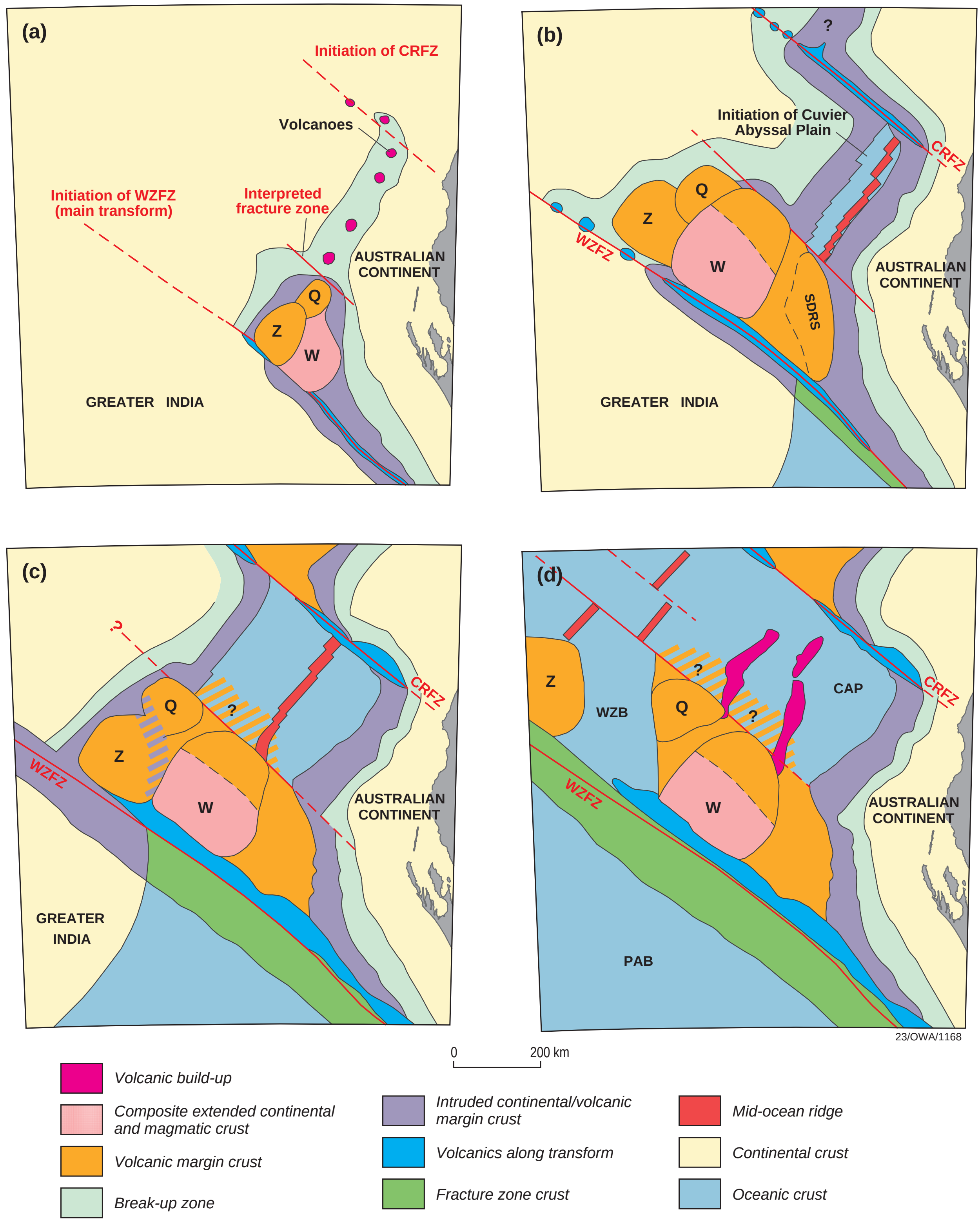
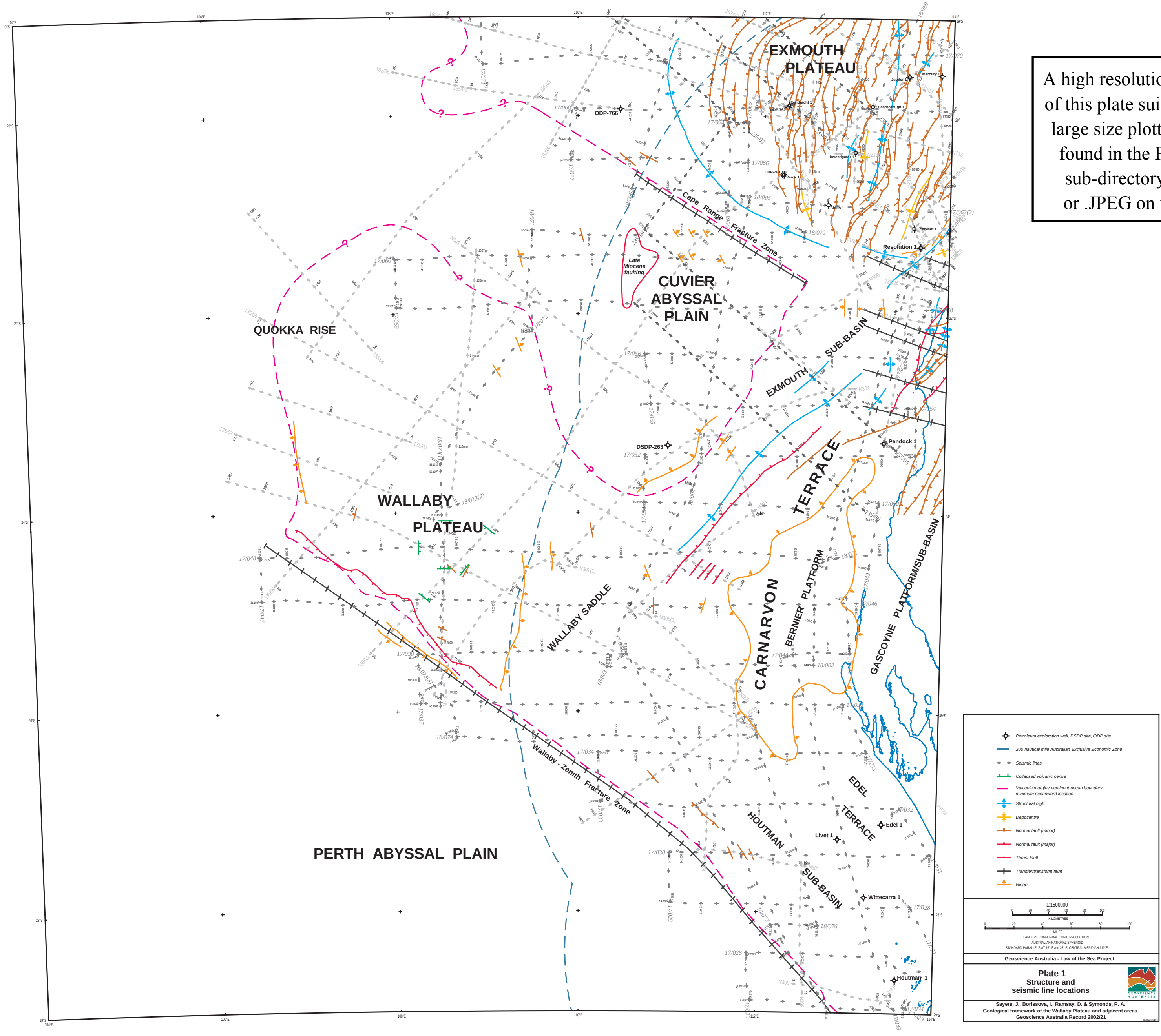
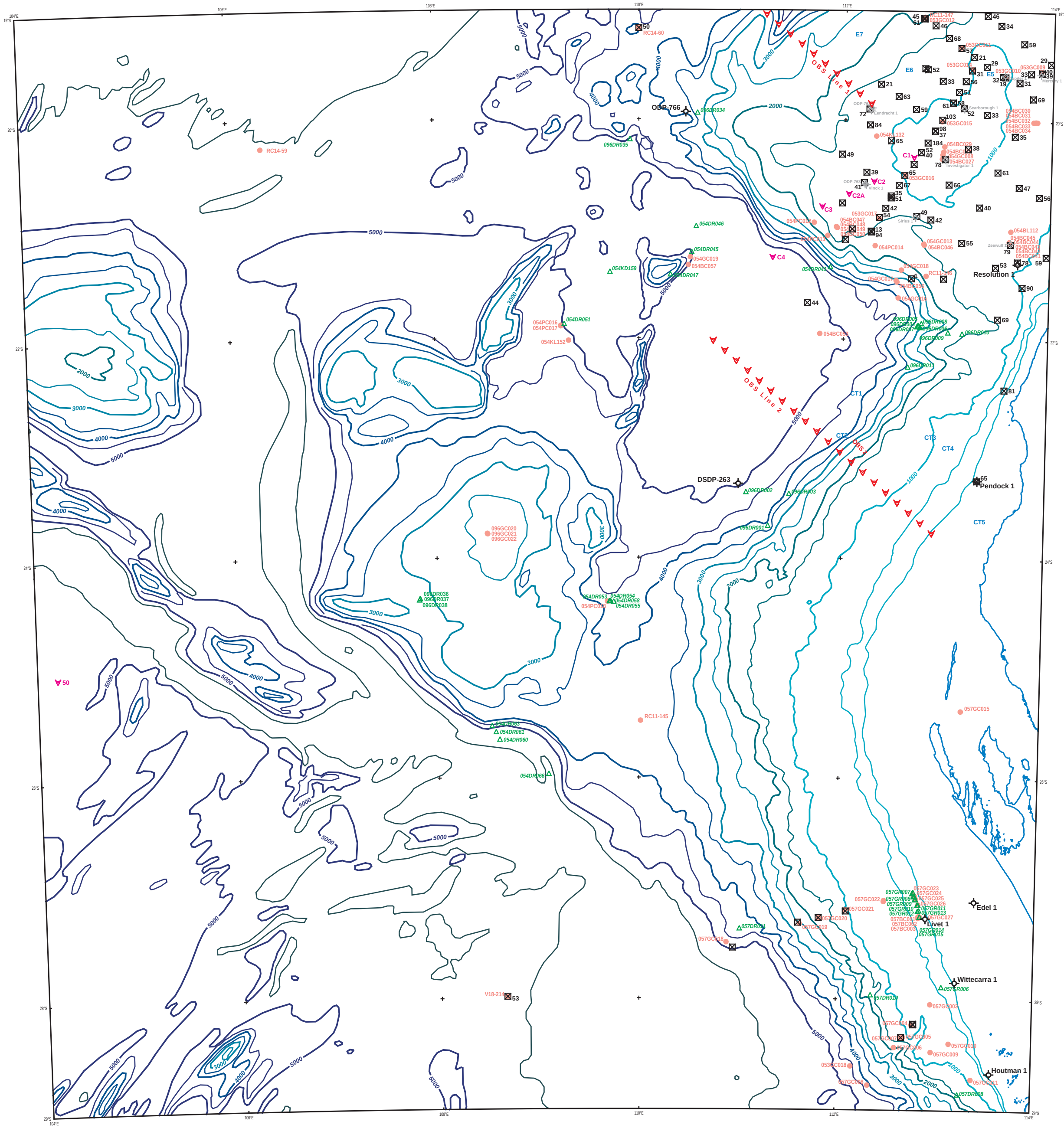


Figure 30. Conceptual evolution of the Wallaby Plateau region. (a) Plate reconstruction during chron M13. (b) Plate reconstruction during chron M11. (c) Plate reconstruction during chron M4. (d) Plate reconstruction during chron M0. WZFZ - Wallaby-Zenith Fracture Zone, CRFZ - Cape Range Fracture Zone; W - Wallaby Plateau, Q - Quokka Rise, Z - Zenith Seamount; CAP - Cuvier Abyssal Plain; PAB - Perth Abyssal Plain; WZB - Wallaby-Zenith Basin.

A high resolution plot file of this plate suitable for a large size plotter can be found in the Plot files sub-directory as .PS or .JPEG on this CD





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Altair 1 — Well used in study
Zeewulf 1 — Well not used in study
096DR002 — Dredge station
057GC022 — Core station
The 054 numbers shown here are from our database. The true S08 numbers are shown in Table 3 and Appendix 3.
94 — Heat-flow station and value
C1 — Crustal velocity measurements (Francis & Raitt, 1967)
Crustal velocity measurements (AGSO Survey 235)
E6/CT1 — Crustal velocity measurements (Williamson & Falvey, 1988)

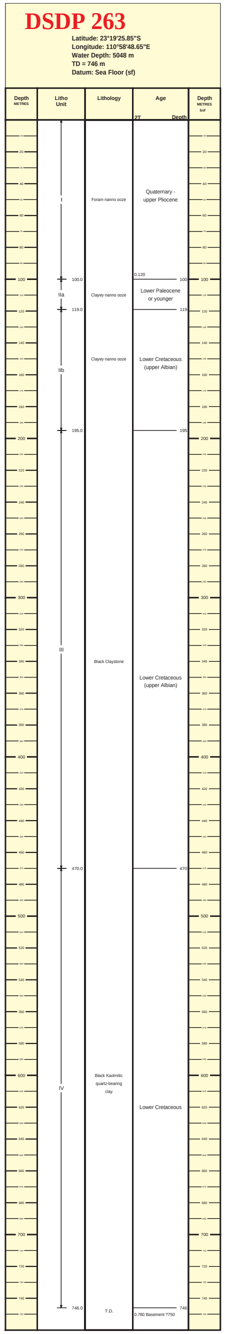
1:1500000
0 20 40 60 80 100
KILOMETRES
0 20 40 60 80 100
MILES
LAMBERT CONFORMAL CONIC PROJECTION
AUSTRALIAN NATIONAL SPHEROID
STANDARD PARALLELS AT 16° S and 25° S, CENTRAL MERIDIAN 110°E

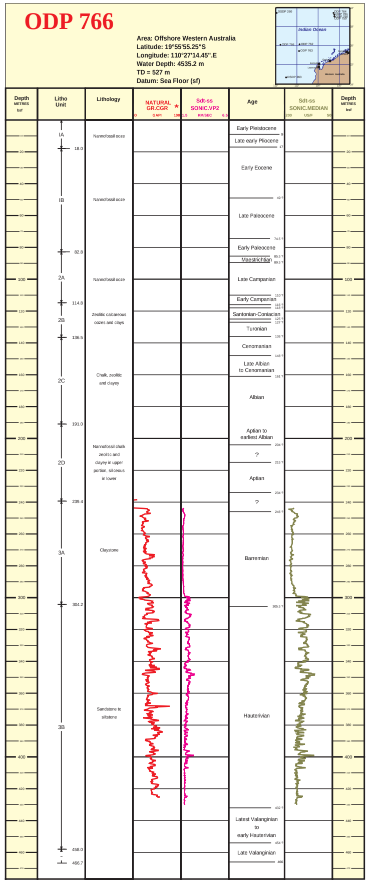
Geoscience Australia - Law of the Sea Project

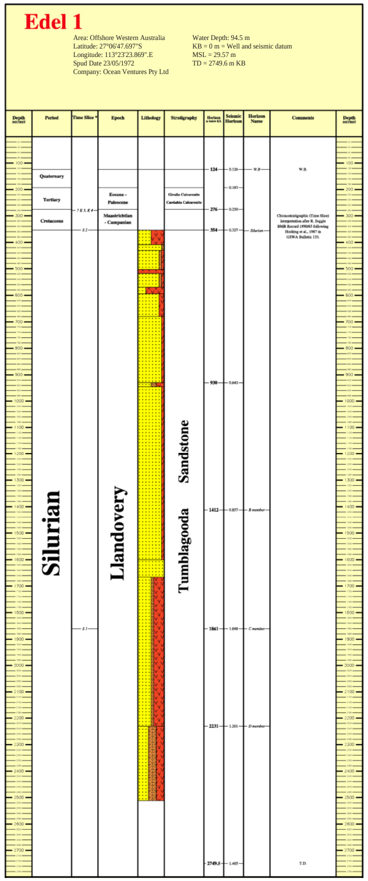
Plate 2
Wells, geological sampling sites, heat flow & crustal measurement velocity sites

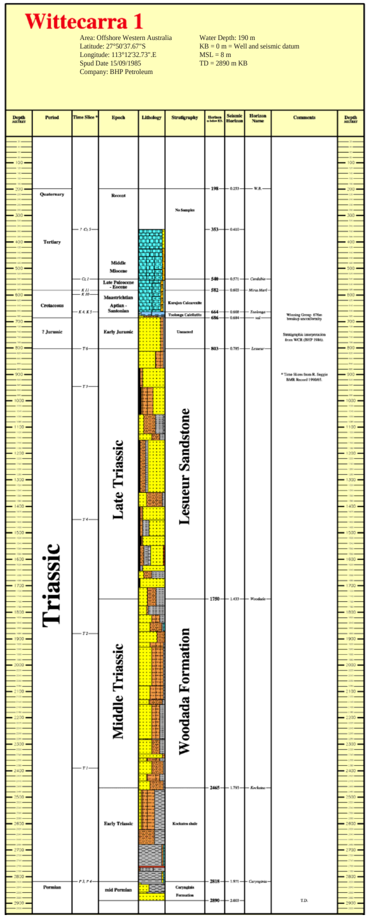
Sayers, J., Borissova, I., Ramsay, D. & Symonds, P. A.
Geological framework of the Wallaby Plateau and adjacent areas.
Geoscience Australia Record 2002/21

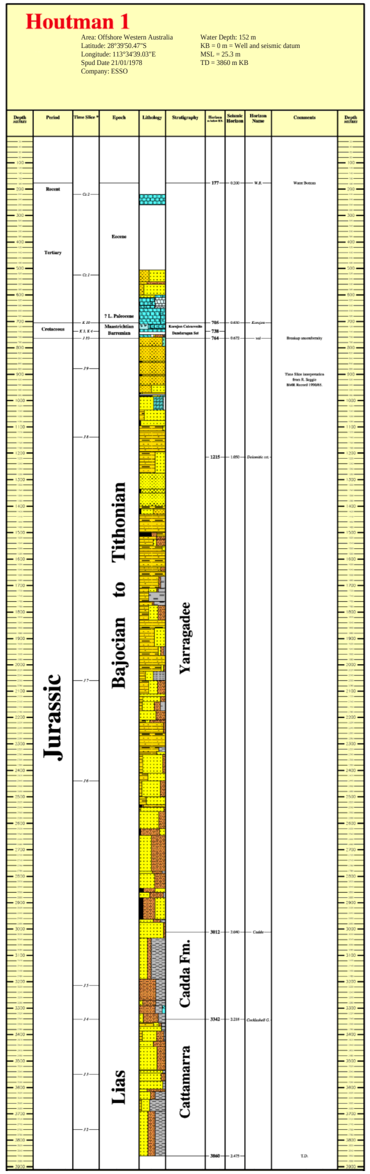
23/OWA/1195











Data Sources

Latitude, Longitude, Water Depth, Total Depth, Lithology, Lithology Unit and Age derived from Proceedings of the Ocean Drilling Program, ODP Volume 122 (Hag et al., 1992) and 123, Scientific Results (Gladstein, Ludden et al., 1991).

Digital Wire Logs derived from ODP web site.

*** Note the range of the scale for gamma logs on this display has been reduced because of low log readings. The range is shown at the top of the display.**

Geoscience Australia has tried to make the information in this product as accurate as possible. However, it does not guarantee that the information is totally accurate or complete. THEREFORE YOU SHOULD NOT RELY SOLELY ON THIS INFORMATION WHEN MAKING A COMMERCIAL DECISION.

Well Composites produced by Peter Butler and Chris Lawson for the Law of the Sea Project. Date: 17-Dec-1998

Data Sources

Latitude and Longitude from WCR - datum unknown.

WD, KB and TD derived from WCR. Lithology derived from WCR.

Geoscience Australia has tried to make the information in this product as accurate as possible. However, it does not guarantee that the information is totally accurate or complete. THEREFORE YOU SHOULD NOT RELY SOLELY ON THIS INFORMATION WHEN MAKING A COMMERCIAL DECISION.

Date: 23-Jul-1999

A high resolution plot file of this plate suitable for a large size plotter can be found in the Plot files sub-directory as .PS or .JPEG on this CD

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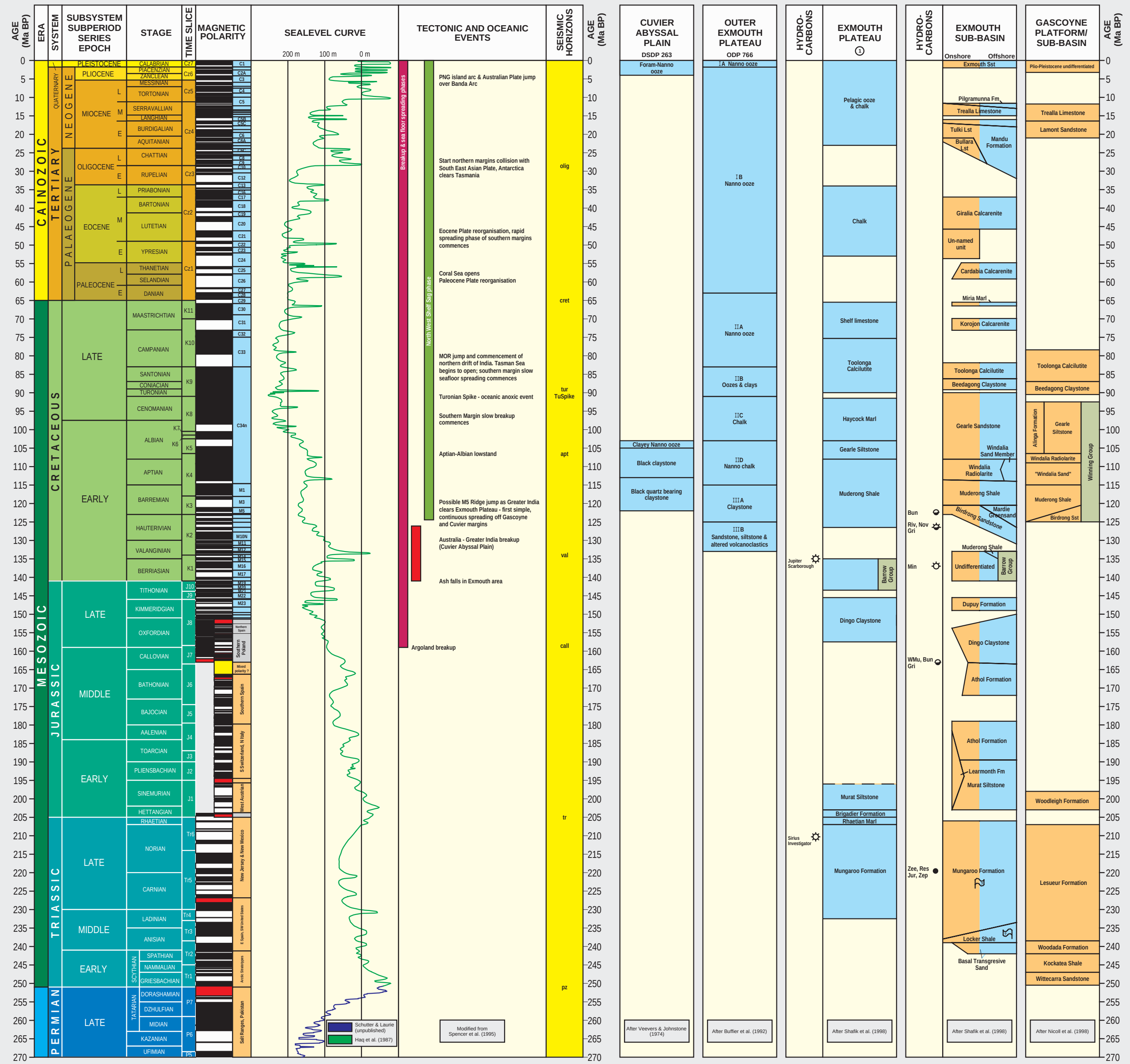
Plate 3
Composite logs for DSDP-263, ODP-766, Edel-1, Wittecarra-1 & Houtman-1

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

23/OWA/1196

WALLABY PLATEAU - CUVIER ABYSSAL PLAIN REGION



1 Southern & Central Exmouth Plateau ODP & exploration wells

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Plate 4

Composite stratigraphic chart showing stratigraphy, sea-level, tectonic & oceanic events & seismic horizons

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

23/OWA/1197

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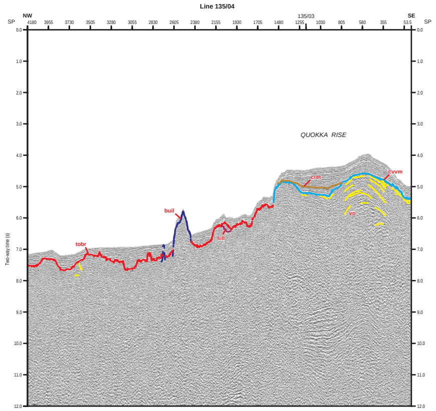
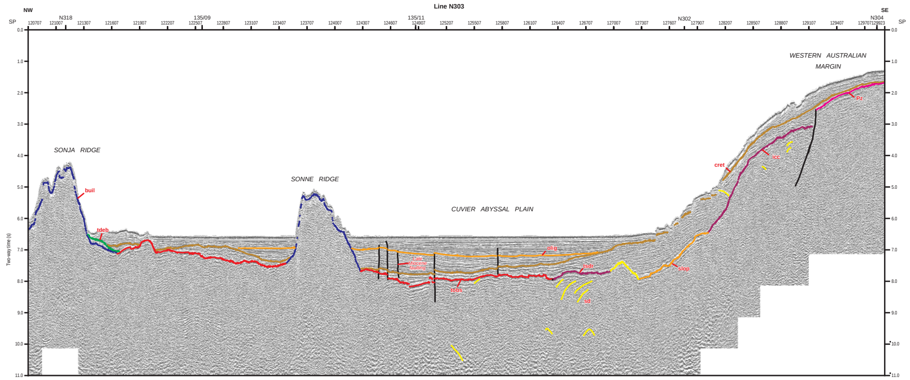
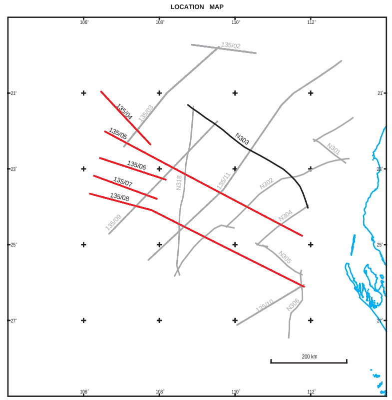
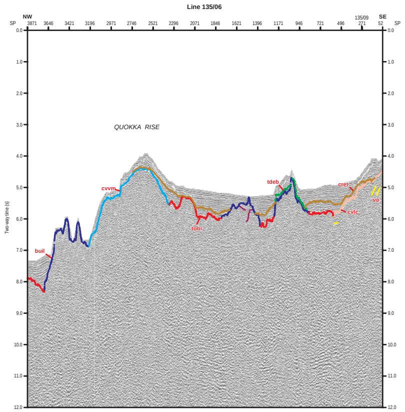
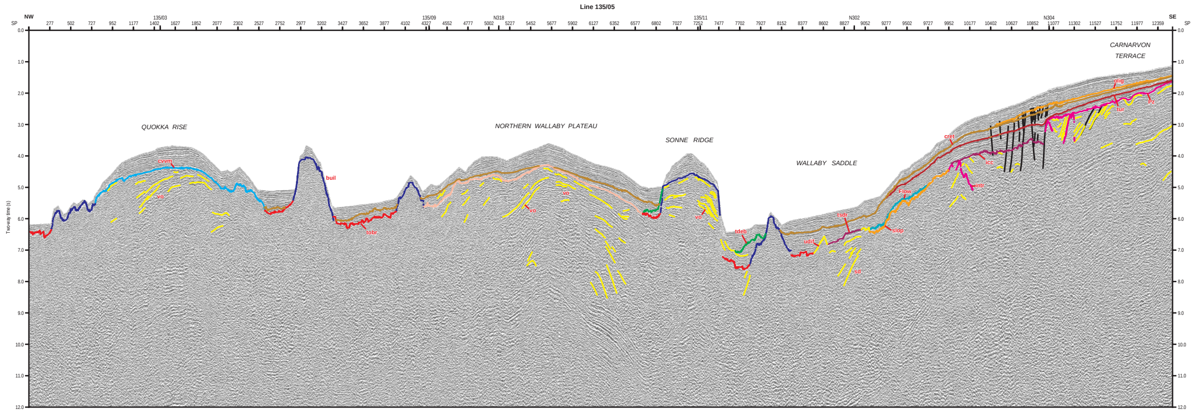


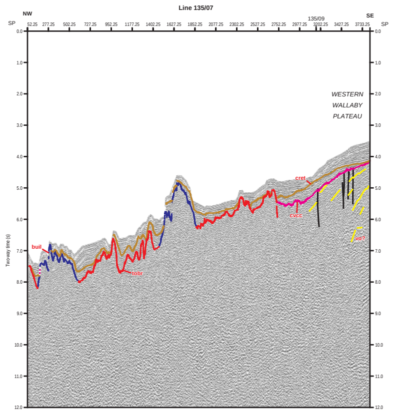


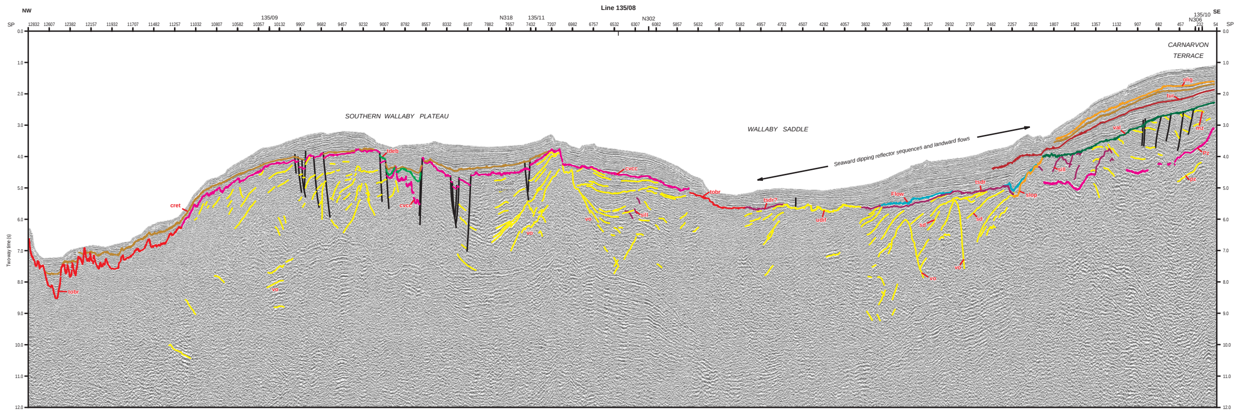






A high resolution plot file of this plate suitable for a large size plotter can be found in the Plot files sub-directory as .PS or .JPEG on this CD





Seismic Horizon	Description
olig	Oligocene
cret	Cretaceous (near base carbonates)
tur	Turonian
val	Valanginian (Gascoyne-Cuvier breakup)
Pz	Paleozoic
intr	Top of individual intrusions in continental crust
icc	Top of intruded continental crust
buil	Top volcanic build-up
cvcc	Top composite volcanics on ?continental crust
cvvm	Top composite volcanics on volcanic margin crust
cvlc	Top composite volcanics on layered volcanic margin crust
tdeb	Top debris flows
tsdr	Top seaward dipping reflector sequence (SDRS)
flow	Top landward lava flows over SDRSs and rifted crust
udif	Top undifferentiated volcanic build-up between SDRSs
slop	Top lower slope volcanics
tobs	Top smooth oceanic basement
tobr	Top rough ?oceanic and volcanic margin basement
mz	Form lines in Mesozoic sediments
pz	Form lines in Paleozoic sediments
sd	Form lines in SDRS
vo	Form lines in volcanics
sill	Sills and dykes in continental crust

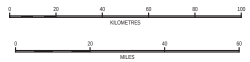


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Plate 5
Interpreted seismic sections
AGSO Survey 135 & Shell-Petrel Survey

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

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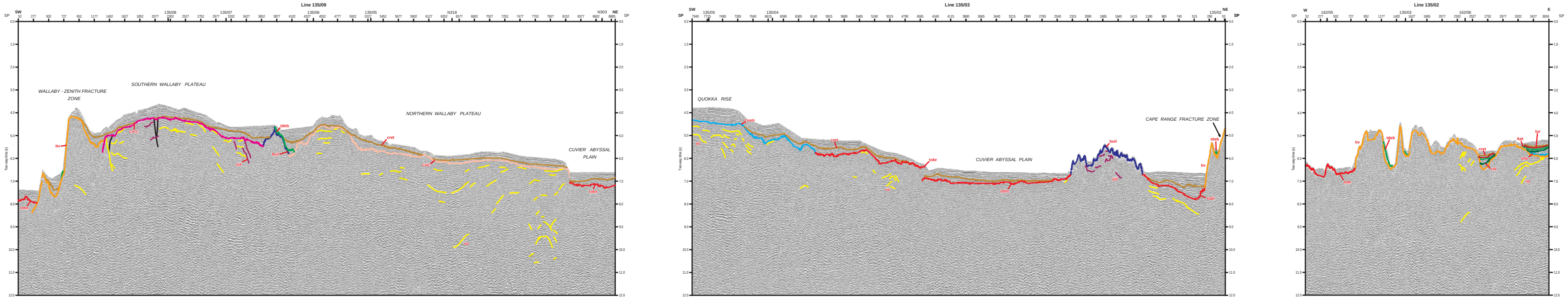
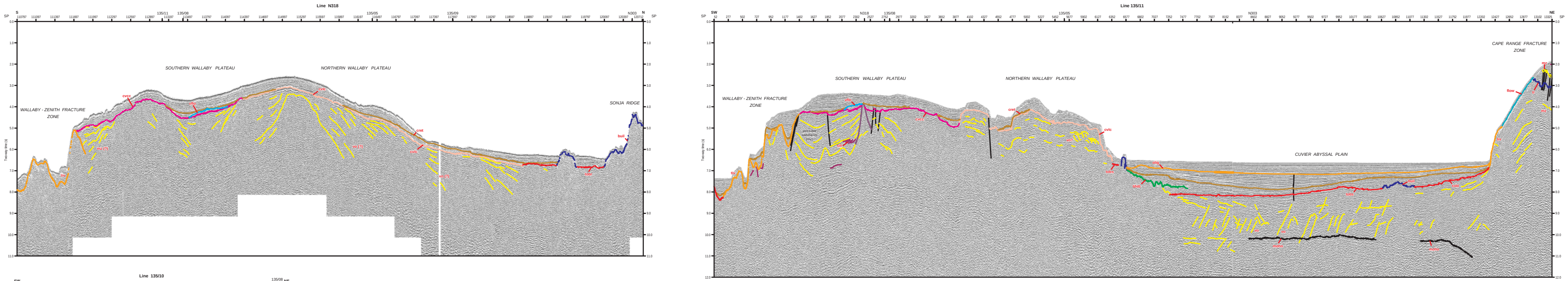
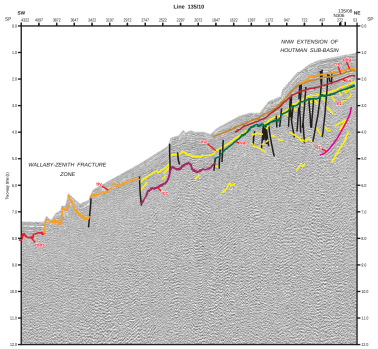
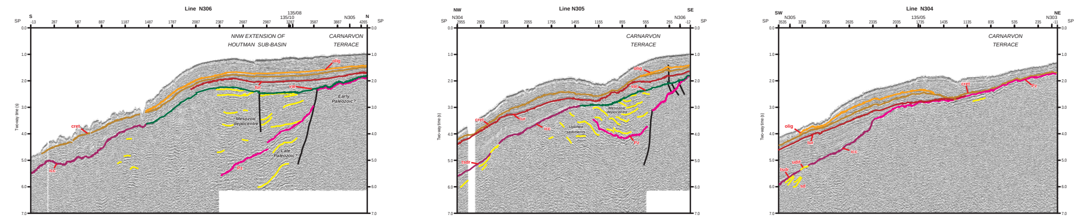
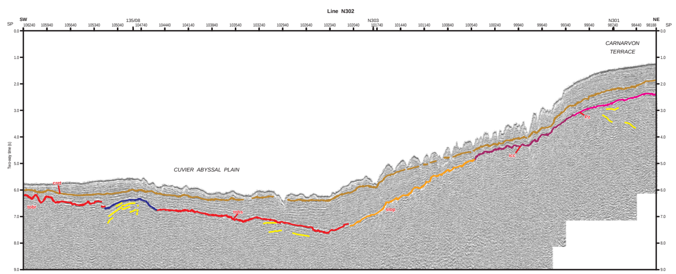


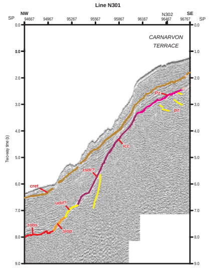


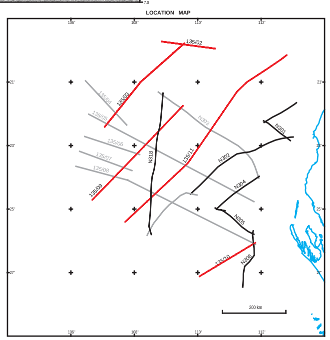




A high resolution plot file of this plate suitable for a large size plotter can be found in the Plot files sub-directory as .PS or .JPEG on this CD







Seismic Horizon	Description
olig	Oligocene
cret	Cretaceous (near base carbonates)
tur	Turonian
apt	Aptian - Albian (top Muderong)
val	Valanginian (Gascogne-Cuvier breakup)
tr	Triassic
Pz	Paleozoic
icc	Top of intruded continental crust
buil	Top volcanic build-up
cvcc	Top composite volcanics on ?continental crust
cvvm	Top composite volcanics on volcanic margin crust
cvlc	Top composite volcanics on layered volcanic margin crust
tdeb	Top debris flows
tsdr	Top seaward dipping reflector sequence (SDRS)
flow	Top landward lava flows over SDRSs and rifted crust
udif	Top undifferentiated volcanic build-up between SDRSs
slop	Top lower slope volcanics
tiv	Top volcanics extruded along transform faults
tobs	Top smooth oceanic basement
tobr	Top rough ?oceanic and volcanic margin basement
tobl	Top layered oceanic basement
vflo	Top flows/sills on volcanic basement
moho	Moho
mz	Form lines in Mesozoic sediments
pz	Form lines in Paleozoic sediments
sd	Form lines in SDRS
vo	Form lines in volcanics
sill	Sills and dykes in continental crust

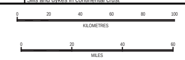


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Plate 6
Interpreted seismic sections
AGSO Survey 135 & Shell-Petrel Survey

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

Instructions for the CD-ROM

Geological framework of the Wallaby Plateau and adjacent areas

This CD-ROM contains the above-titled document as GeoscienceAustraliaRecord2002_21.pdf

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Once the reader is installed, go to the Record directory, double click on the GeoscienceAustraliaRecord2002_21.pdf to launch the document.

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Directories on this CD

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Sub-directories of Adobe Acrobat Reader installation files for Win_NT, Macintosh, Unix and Help, which includes © Acrobat copyright, Adobe Acrobat Reader Guide and information on Adobe.

Plot files directory:
With sub-directories containing PostScript (.PS) and Joint Photographic Experts Group (.JPG) plot files of the six A0 and plates used in this Record. These are all suitable for plotting to large format plotters.

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