AGSO

DEEP STRUCTURE OF THE OTWAY BASIN, SOUTHEASTERN AUSTRALIA, SURVEY 137 (PHASES 1 & 2)

POST-CRUISE REPORT

BY

J.E. BLEVIN, M. FELLOWS, G.W. O'BRIEN, N.F. EXON AND SURVEY 137 SHIPBOARD PARTIES

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AGSO

AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

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Marine, Petroleum and Sedimentary Resources Division

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DEEP STRUCTURE OF THE OTWAY BASIN, SOUTHEASTERN AUSTRALIA, SURVEY 137 (PHASES 1 AND 2) POST-CRUISE REPORT

J.E. Blevin, M. Fellows, G.W. O'Brien, N. F. Exon,

and Survey 137 Shipboard Parties* (Phases 1 and 2)

*Phase 1: M. Alcock, B. Dickinson, A. Hinds, T. Hunter, M. James, H. Miller, S. Milnes, T. McNamara, A. Radley, H. Reynolds, S.Ridgway, C. Saroch, M. Timms, and K. Webber (Ship Manager)

*Phase 2: G. Atkinson, J. Bedford, G. Burns, G. Cassim (Ship Manager), M. de Deuge, N. Ford, A. Hislop, A. Hogan, P. Hyde, S. Laidlaw, D. Maidment, T. McNamara, J. Reid, S. Rucinski, C. Saroch, F. Stradwick, and S. Wiggins

DEPARTMENT OF PRIMARY INDUSTRIES AND ENERGY

Minister for Resources: Hon. David Beddall, MP

Secretary: Greg Taylor

AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

Executive Director: Dr. Neil Williams

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EXECUTIVE SUMMARY

The Offshore Otway Basin Cruise (Survey 137) was the second of AGSO's deep-seismic surveys to be undertaken on the Australian southern margin. The principal objective of the survey was to collect approximately 3,500 km of high-quality, regional deep seismic and other geophysical data across the offshore Otway Basin (O'Brien et al., 1994b). The dataset will provide scientific information on the deep crustal architecture of the offshore Otway Basin, and will be used to characterise the linkages between the Otway Basin and the flanking Bass Basin, Kanmantoo High and oceanic crust. Ultimately, the data will be used to characterise the large scale extensional processes which led to the development of the Otway Basin as part of the larger "Southern Rift System" (Willcox and Stagg, 1990). Survey 137 was designed to complement AGSO's recent acquisition of aeromagnetic and deep-seismic datasets in the onshore and shallow offshore areas of the Otway Basin, as well as test many of the concepts which have arisen from the interpretation of these data.

Survey 137 was split into two periods of acquisition, Phases 1 and 2. The survey vessel R.V. *Rig Seismic* departed from Portland, Victoria, on 26 November 1994, on Phase 1 of the survey. After four days of equipment trials, seismic acquisition commenced on 30 November 1994. Phase 1 was completed on 21 December 1994, with the ship docking in Melbourne over the Christmas period. During Phase 1, nine seismic lines were completed (or partially completed) for a total of 2,524.85 km at an average of 121 km per day.

On 4 January 1995, the *Rig Seismic* departed Melbourne to undertake a commercial seismic survey in the western Otway Basin on behalf of Cultus Petroleum Australia N.L. (Survey 146). Following a limited crew change at the completion of Survey 146 on 13 January, the vessel began transiting to the western Otway Basin to commence Phase 2 of Survey 137. Seismic acquisition began on 14 January and was completed on 22 January 1995, with the vessel arriving at port in Melbourne on 23 January 1995. A total of 940.05 km of seismic data was acquired on eight lines (five existing lines and three new lines) during Phase 2, with a daily average of 117.5 km of acquisition. Seismic acquisition for Phases 1 and 2 of Survey 137 totalled 3,464.90 km on 13 lines. Ten exploration wells in the nearshore region of the basin were tied by the survey.

The seismic data was recorded using a 4800 m streamer configured with 192 x 25 m active groups. The record length was 16 seconds and the sample interval was 2 ms. The seismic source consisted of dual sleeve gun arrays with a capacity of 50 litres, automatically fired every 50 m to give 48-fold CDP coverage. Navigation for the survey was provided by differential Global Positioning System (dGPS), using shore reference stations at Sydney, Melbourne and Adelaide.

The seismic acquisition system operated without major problems, although the gravity meter was inoperable during Phase 1 of the survey. The magnetometer head was lost on 4 December 1994 during retrieval in shallowing waters on Line 137/200. A replacement head was operational on 12 December 1994 and acquisition of magnetic data recommenced. The execution of Survey 137 as originally planned (O'Brien et al., 1994b) was greatly affected by fishing activities associated with the October to March crayfish season in South Australia and Victoria. The presence of craypots caused numerous deviations from the original transect waypoints, as well as the early termination of several lines in the inshore area. The southern terminations of all lines were extended beyond the original waypoints to ensure that each transect crossed the continent-ocean boundary (COB). The decision to extend each line was made at the time of survey by AGSO's shipboard Scientific Representative based on data displayed on a single channel monitor. A medical evacuation to Portland (Victoria) was undertaken on 12 - 13 December 1994. Weather conditions were variable, with a moderate southwesterly swell (typical of the Southern Ocean) prevailing throughout 80% of the survey. A limited program of seismic refraction data acquisition at selected onshore stations was also carried out and should provide important information on crustal velocities for key lines.

Preliminary scientific observations support earlier findings which suggest that the COB south of the main Otway Basin depocentre is not a sharp geologic boundary as suggested by the GEOSAT data. The COB in this area is marked by a broad transitional zone (up to 50 km wide) of highly-rotated continental fault blocks and volcanic mounds. A moderately thick sequence (up to 1.5 s TWT) of well-layered sediment onlaps and drapes these structures. The sediment pile grades upward from basal layers of possible volcanoclastics to well-layered shallow marine sediments of Late Cretaceous to Tertiary age. The transitional zone appears to extend southward from the lower continental slope to the abyssal plain in water depths of approximately 4800 to 5000+ metres. Despite the transitional nature of the zone, a preliminary location for the continental-ocean boundary was made (using the single channel monitor records) on the basis of surface morphology and reflection characteristics of the fault blocks and volcanic mounds. This assessment indicates that the COB is a WNW-to-NW trending boundary that is separated along NNE-to-NNW offsets. The final determination of this zone, along with the relationship between the COB, proposed fractures systems (Veevers, 1988) and the GEOSAT data will await processing of the deep seismic data.

INTRODUCTION

The Australian Geological Survey Organisation (AGSO) conducted a deep crustal seismic survey (AGSO Survey 137) in the offshore Otway Basin over a six week period during November-December, 1994 and January, 1995. The survey was part of the acquisition phase of AGSO Project 101.200 and will complement AGSO's recently acquired aeromagnetic data set covering the inshore and onshore areas of the Otway Basin, the 1994 *l'Atalante* swath-mapping of the lower continental slope (Exon, Hill et al., 1994.), and the existing regional dataset of GEOSAT imagery.

The northwest-trending Otway Basin straddles the coast of Australia's southeastern margin for a distance of 500 km from Mornington Peninsula in Victoria to Cape Jaffa in South Australia (Figure 1). Covering an area of 150,000 km^2, the Otway Basin is part of the greater 'Southern Rift System" (Willcox, 1990; Willcox and Stagg, 1990; Stagg et al., 1990), which comprises from west to east, the Bremer, Great Australian Bight, Duntroon, Otway, Bass and Gippsland Basins. These basins developed as a series of extensional and oblique extensional rift segments during the late Jurassic to Early Cretaceous. The Survey 137 deep crustal data set from the Otway Basin will be used to address the following scientific objectives:

- determine the regional, deep crustal architecture of the offshore Otway Basin;
- characterise the linkages between the Otway Basin and the flanking Bass Basin, Kanmantoo High and oceanic crust; and,
- characterise the large scale extensional processes which led to the development of the Otway Basin as part of the larger Southern Rift System.

SUMMARY OF DATA ACQUISITION

Seismic acquisition of Survey 137 was split into two phases. Phase 1 was undertaken from late November to late December, 1994, while Phase 2 covered the period from mid-to-late January, 1995. AGSO's research vessel *Rig Seismic* departed from Portland (Victoria) on Phase 1 of the survey on 26 November 1994. Four days of transit and equipment testing followed during which sleeve gun trials were conducted, along with testing of modified gun bundles, a new gun controller box and a Dynamic Positioning device at a location west of King Island. Seismic acquisition of Line 137/100 commenced on 30 November 1994. The survey was

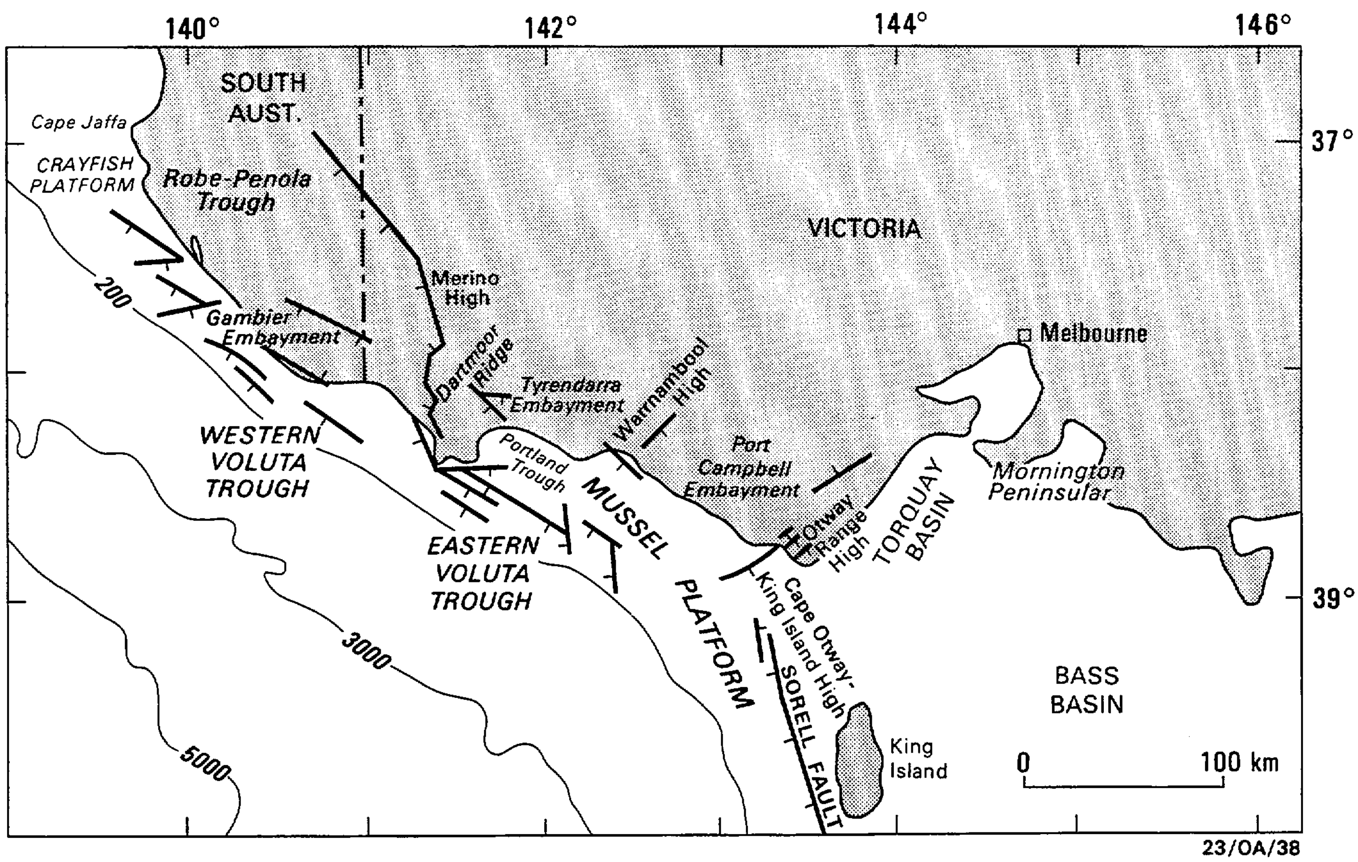

Figure 1: Location and structural elements map of the Otway Basin, offshore Victoria and South Australia (Williamson, et al., 1988).

completed on 20 December, and the *Rig Seismic* returned to port in Melbourne on 21 December 1994. The shipboard party on Phase 1 (Appendix 5a) comprised 16 AGSO scientific and technical personnel and 14 Australian Maritime Safety Authority (AMSA) crew.

The *Rig Seismic* departed Melbourne for the western Otway Basin on 4 January 1995 to undertake a commercial seismic acquisition program for Cultus Petroleum Australia N.L. (Cultus Suewin Survey, AGSO Survey 146). The contract work was undertaken using a 4 x 4 G.I. gun string, and was completed on 9 January 1995. Following gun trials from 10 to 13 January, a overshoot of Phase 1 seismic lines 137/200 and 201 was undertaken using the 4 x 4 G.I. gun array. The G.I. line will be used as a technical comparison of data quality between the G.I. and sleeve gun energy sources, and is not considered as part of Survey 137 acquisition. Phase 2 of Survey 137 recommenced on 14 January using the AGSO standard deep seismic 2 x 10 sleeve gun array. Survey 137, Phase 2 was completed on 22 January, and the research vessel returned to port in Melbourne on 23 January 1995. The shipboard personnel on Phase 2 (Appendix 5b) comprised 18 AGSO scientific and technical personnel and 14 Australian Maritime Safety Authority (AMSA) crew.

A total of 3,464.90 km of seismic data was acquired during Survey 137, with Phases 1 and 2 recording 2,524.85 km of data on nine lines and 940.05 km on eight lines, respectively (Figure 2). With few exceptions (mainly due to temporary equipment malfunction), the data comprise 16 sec record-length, 48-fold seismic, bathymetry and magnetics. The seismic data was recorded using a 4800 m streamer configured with 50 litre dual airgun array and 192 x 25 m active groups. Gravity data was not collected during Phase 1 of the survey due to equipment malfunction. Navigation for the survey was provided by differential Global Positioning System (dGPS), using shore reference stations at Sydney, Melbourne and Adelaide.

Data acquisition in the inshore region of the basin was frequently hampered by local fishing activities. During the October to March crayfish season in South Australian and Victorian waters, craypots are anchored on rocky substrates and marked by surface and sub-surface buoys. The chase boat MV *Pretty Lady* was contracted to clear a 200 m wide track for each seismic transect in shelfal areas shallower than 200 metres. In addition, data acquisition in the inshore areas (<200 m water depth)

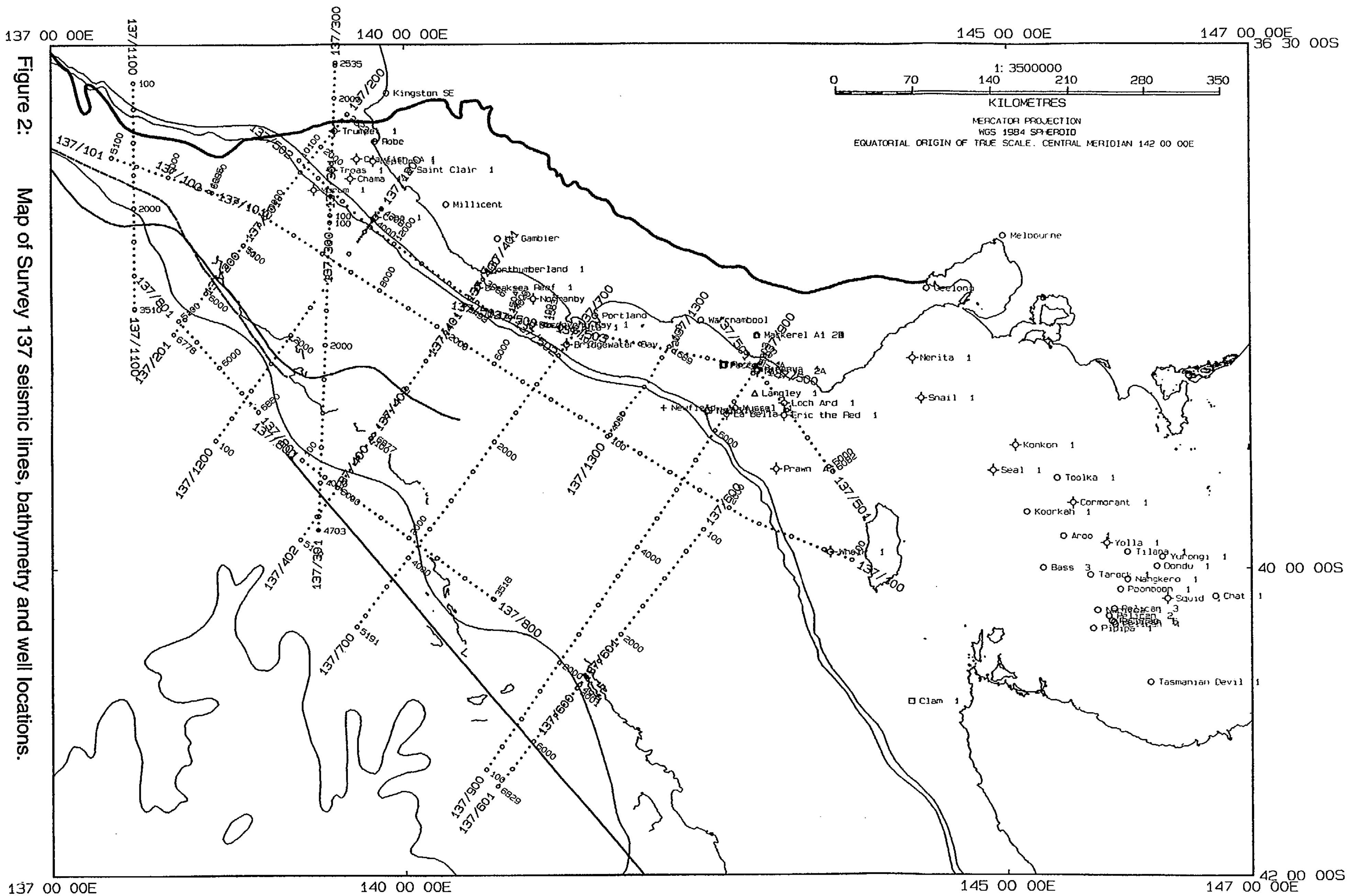

Figure 2: Map of Survey 137 seismic lines, bathymetry and well locations.

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had to be undertaken during daylight hours to avoid interference from local fishing vessels. Despite these efforts, several craypots were hooked by the seismic cable, resulting in deviation from the original waypoints and/or the early termination of lines due to excessive cable noise. Details of these incidents and the required response are presented in the ***Cruise Narrative*** and ***Seismic Data Recorded*** sections of this Record.

To achieve the scientific objectives as outlined, the southernmost end of each seismic transect was intended to cross the continental/ocean boundary (COB). The approximate location of this boundary was determined from GEOSAT data during the pre-cruise planning stage. The original waypoints for the southern termination of each transect (O'Brien et al., 1994b) were therefore intended only as a guide. The final southern termination waypoints were determined on a "line-by-line" basis by AGSO's shipboard Scientific Representatives based on seismic displays on a single channel monitor. In each instance, the transects were extended southward beyond the original waypoints for a distance of between 1 and 10 kilometres. All revisions to the original proposed transects are presented in the ***Cruise Narrative*** section of this Record, with the final waypoints summarised in ***Appendix 8A***. Preliminary scientific observations based on the single channel monitor data are summarised under ***Preliminary Scientific Results***.

EXPLORATION HISTORY OF THE OTWAY BASIN

The Otway Basin has been an area of active hydrocarbon exploration since the late 1950s. Australia's first oil exploration well was drilled in the western Otway Basin at Alfred Flat, near Coorong, South Australia, in 1866 (Sprigg, 1986). In the onshore Otway Basin, a sub-commercial gas discovery was encountered in the Port Campbell-1 well (Victoria) in 1959, while in 1967, a small commercial carbon dioxide (CO_2) discovery was made in South Australia at Caroline-1 (Mulready, 1977). More recently, exploration has resulted in the discovery of small but significant gas accumulations at North Paaratte (1979), Katnook (1987) and Ladbroke Grove (1989) (Parker, 1992), and Iona (1988) (Miyazaki et al., 1990). Significant CO_2 was associated with the gas at Ladbroke Grove. Oil shows were recorded in the Lindon-1 well in 1984, while some heavy crude oil was recovered from Sawpit-1 in 1992.

Offshore, the only significant hydrocarbon shows recorded between 1967 and 1993 were minor gas flows from the Pecten-1A (eastern Otway Basin), Loch Ard-1 and Troas-1 (western Otway Basin) wells. However, a recent upsurge in exploration activity in the offshore area has been rewarded by two large gas discoveries in early 1993 (the Minerva accumulation in the upper Early Cretaceous Otway Group and the and La Bella accumulation in the Late Cretaceous Waare Sandstone) off Port Campbell, in western Victoria. These discoveries, as well as previous finds in the onshore part of the basin, have established the Otway Basin as a potential major gas province.

PREVIOUS AGSO-BMR ACQUISITION PROGRAMS IN THE OTWAY BASIN

In 1985, the Bureau of Mineral Resources (BMR) acquired 3,700 km of conventional regional seismic data in the offshore Otway Basin (BMR Survey 48) (Exon, et al., 1987). This data set, in conjunction with earlier regional lines acquired in 1972 by Shell using M.V. *Petrel*, provides a regional seismic grid extending from nearshore to the abyssal plain (Figure 3). Interpretation of these data, along with information from the GEOSAT imagery and the 1994 *l'Atalante* swath-mapping and seismic survey in the southeast (Exon, Hill et al., 1994.), indicate that the edge of the abyssal plain is not equivalent to the continent-ocean boundary (COB). It is estimated that the COB lies approximately 50 km southwest of the foot of the continental slope as mapped by the *l'Atalante* survey.

The seismic data indicate that faulting in the continental crust occurs primarily along oceanward-dipping normal faults (Heggie et al., 1988; Schwab, 1993). Faults along the upper slope dip steeply southward and show little extension. Faulting shallows oceanward along the lower slope to the inner abyssal plain where highly extended (stretched) continental crust occurs. Sampling at the foot of the slope has recovered basement volcanics and metamorphic rocks, and Late Cretaceous and Palaeogene shallow marine detrital sediments (Exon et al., 1992). A summary of existing (non-industry) scientific surveys in the offshore Otway Basin is presented in Appendix 1.

In 1993, the Australian Geological Survey Organisation (AGSO, formerly BMR) acquired 14,200 km of regional (1400 m line spacing) high-resolution aeromagnetic

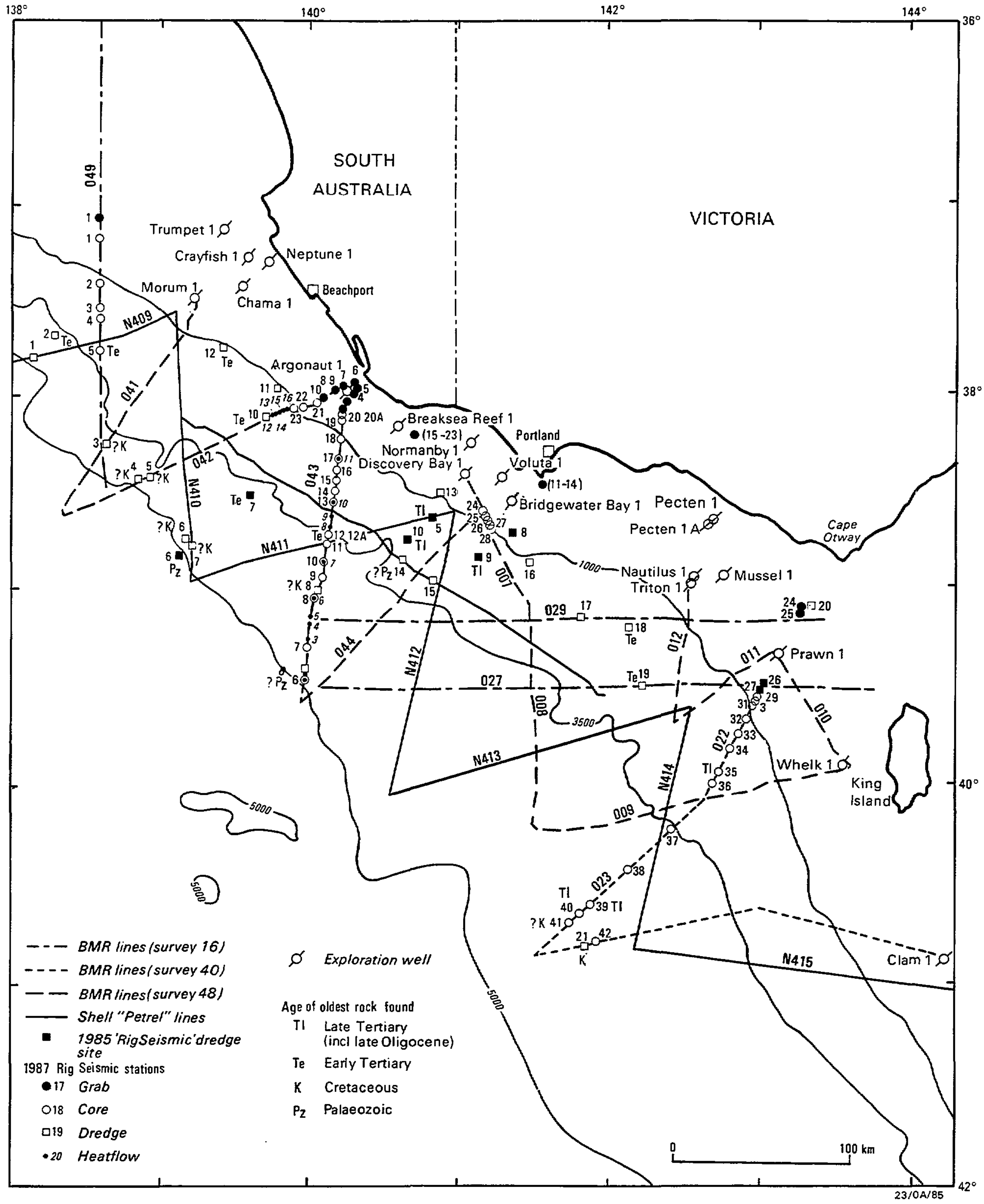

Figure 3: Location map showing existing scientific (non-industry) survey data, core and dredge sample sites in the offshore Otway Basin region (after Exon et al., 1987).

data within the South Australian part of the Otway Basin (Figure 4) (O'Brien et al., 1994a). The survey extended offshore to approximately the 500 m isobath. More recently (May-June, 1994), a further 45,000 km of detailed (500 m line spacing) aeromagnetic data were acquired over the offshore Victorian part of the basin. These magnetic data have provided for the first time, a consistent, regional interpretative framework for the nearshore part of the Otway Basin. Interpretation of these magnetics has allowed:

- accurate mapping of the geometry of the Otway Group rift segments (trend NNE);
- determination of the position and trend of syn- and post-rift faults (strike generally WNW);
- mapping of the distribution of Tertiary volcanics; and,
- determination of detailed basement geometries and depths (noting that the oldest faults strike N-S) (O'Brien, et al., 1994a).

The swath-mapping results from the *l'Atalante* (Exon, Hill et al., 1994) show that offsets in the foot of the slope appear to correspond to north-northeasterly aeromagnetic trends.

MORPHO-TECTONICS AND STRATIGRAPHY

The complex tectonic history of the Otway Basin is reflected in the morpho-tectonics and stratigraphic distribution. Onshore, the basin is composed of a series of predominantly SE-trending Early Cretaceous troughs or half-grabens separated by basement highs (Figure 5). In the western Otway Basin, significant structural features such as the Penola Trough, the Beachport and Kalangadoo Highs, the Padthaway Ridge, and the ENE-trending Robe Trough, Lake Eliza High and Saint Clair Trough are covered by AGSO's 1993 aeromagnetic survey.

Offshore, the basin can be loosely subdivided into three distinct structural provinces, namely the ENE-trending Crayfish Platform in the west with steeply dipping normal faults trending east-west, the centrally-positioned Voluta Trough (western and eastern) with WNW-trending faults, and the Mussel Platform in the east, also with predominantly WNW-trending faults. These structural provinces have existed since

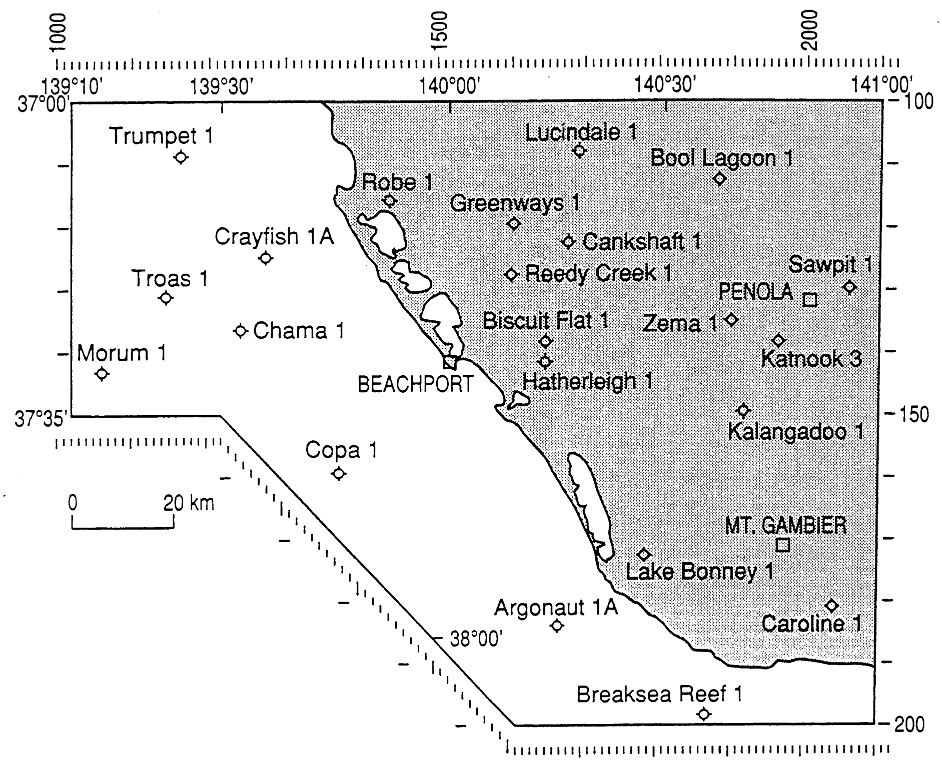

Figure 4: Outline of AGSO's aeromagnetic survey area in the western Otway Basin. The north-south flight line numbers are shown along the northern margin and control-line numbers along the east.

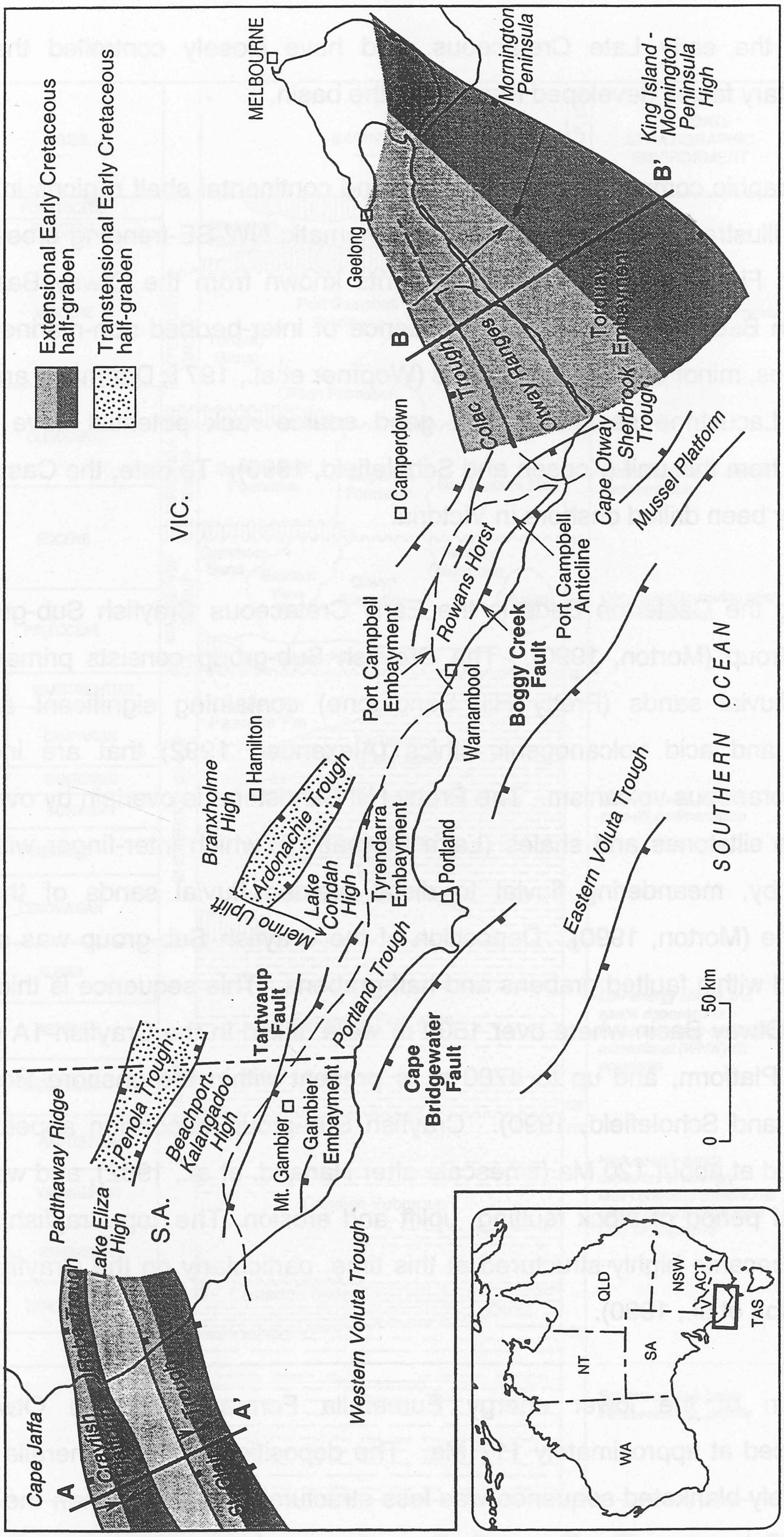

Figure 5: Tectonic elements map of the Otway Basin (from O'Brien et al, 1994a) (modified from Laing et al. (1989).

at least the early Late Cretaceous, and have closely controlled the types of sedimentary facies developed throughout the basin.

A stratigraphic compilation from onshore and continental shelf regions in the Otway Basin is illustrated in Figure 6, while a schematic NW-SE-trending cross-section is shown in Figure 7. The oldest sediments known from the Otway Basin are the Casterton Beds, a latest Jurassic sequence of inter-bedded non-marine siltstones, mudstones, minor coals and volcanics (Wopfner et al., 1971; Dettmann and Douglas, 1976). Lacustrine sediments with good source rock potential have also been reported from this unit (Kopsen and Scholefield, 1990). To date, the Casterton Beds have only been drilled onshore in Victoria.

Overlying the Casterton Beds is the Early Cretaceous Crayfish Sub-group of the Otway Group (Morton, 1990). The Crayfish Sub-group consists primarily of high energy fluvial sands (Pretty Hill Sandstone) containing significant amounts of feldspar and acid volcanogenic lithics (Alexander, 1992) that are indicative of contemporaneous volcanism. The Pretty Hill Sandstone is overlain by overbank and lacustrine siltstones and shales (Laira Formation), which inter-finger with, and are overlain by, meandering fluvial to distal braided fluvial sands of the Katnook Sandstone (Morton, 1990). Deposition of the Crayfish Sub-group was structurally-controlled within faulted grabens and half-grabens. This sequence is thickest in the western Otway Basin where over 1500 m were drilled in the Crayfish-1A well on the Crayfish Platform, and up to 4700 m is present within the onshore Robe Trough (Kopsen and Scholefield, 1990). Crayfish Sub-group deposition appears to have terminated at about 120 Ma (timescale after Harland, et al., 1982), and was followed by a brief period of block faulting, uplift and erosion. The 'top Crayfish Sub-group horizon' became highly structured at this time, particularly on the Crayfish Platform (Williamson et al., 1990).

Deposition of the lower energy Eumeralla Formation of the Otway Group commenced at approximately 117 Ma. The deposition of the Eumeralla Formation as a largely blanketed sequence was less structurally-controlled than the underlying Crayfish Sub-group. The Eumeralla Formation consists predominately of shales and siltstones with minor coals, argillaceous sands and sandstones. These sediments were deposited in low energy flood-plain (low sinuosity stream, lacustrine and back-

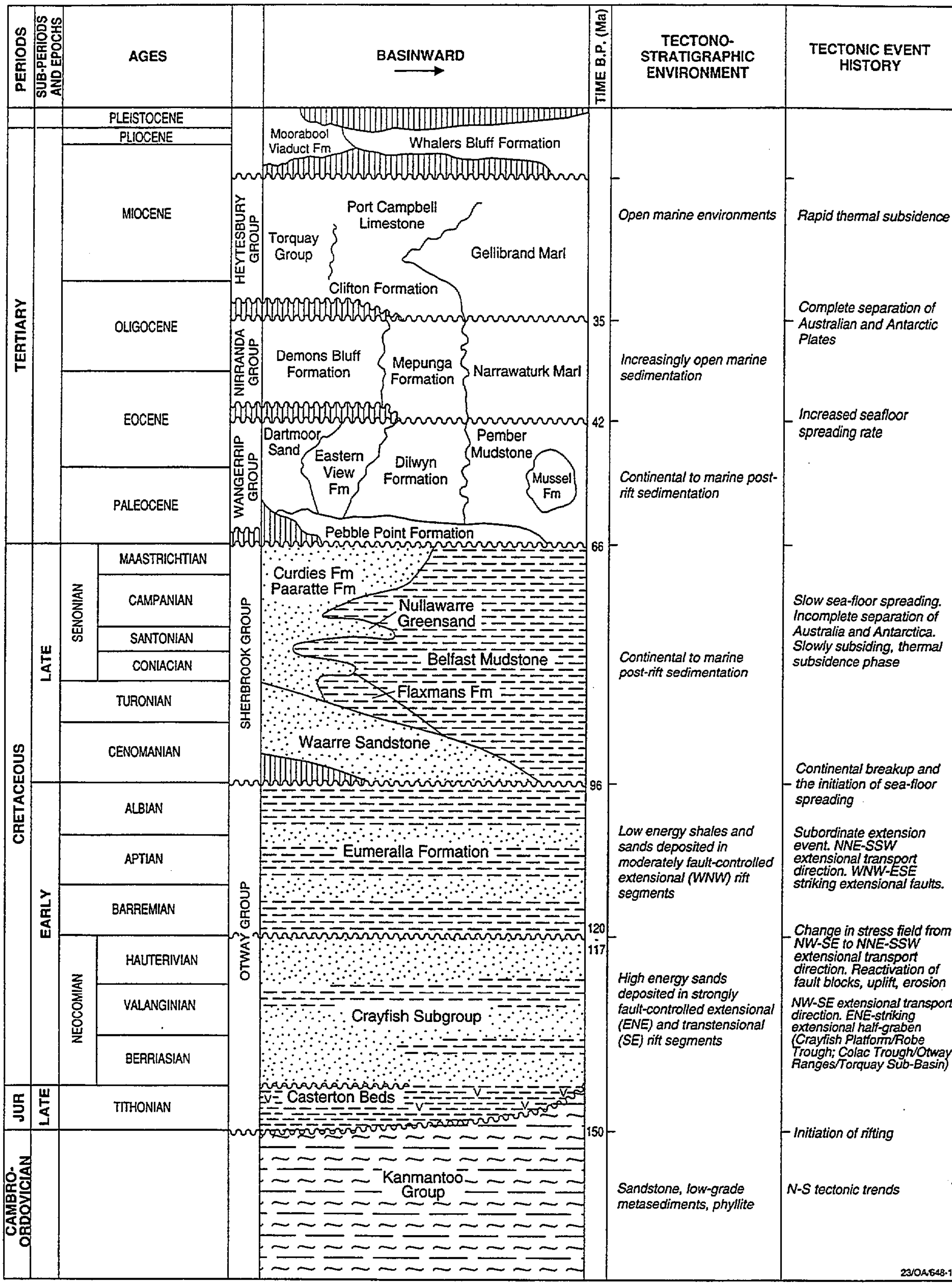

Figure 6: Simplified stratigraphic column for the Otway Basin, shown in relation to the interpreted tectonic event history. (from O'Brien, 1994a; post-Cretaceous history modified from Hinz et al., 1986).

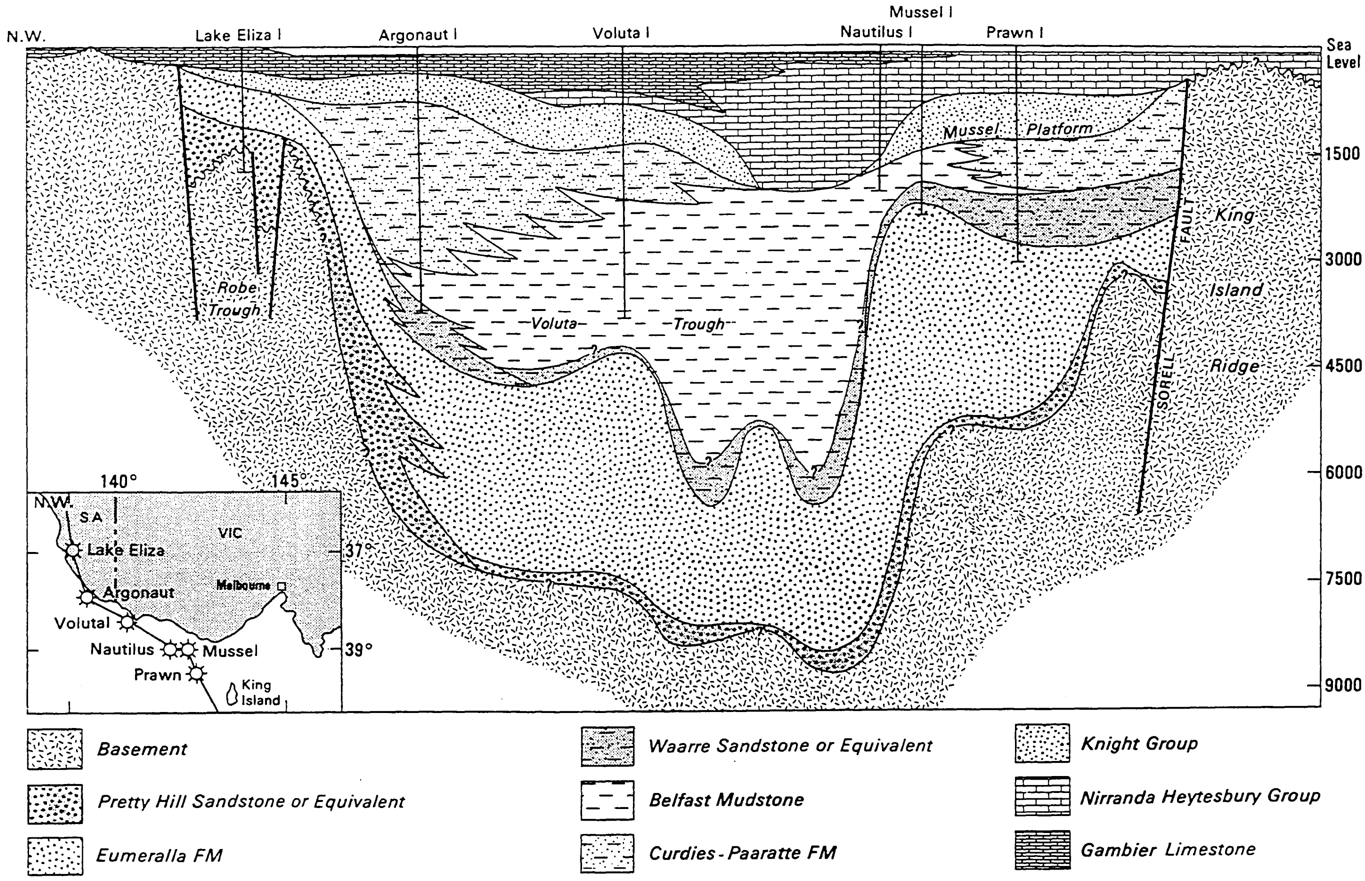

Figure 7: Schematic cross-section across the Otway Basin (modified from Williamson et al., 1987).

swamp) environments (Morton, 1990). A significant amount of volcanogenic detritus has been described in the Eumeralla Formation (Robertson, 1966). Early Cretaceous sedimentation was terminated by a mid-Cretaceous period of block faulting, differential uplift, and erosion between 100 and 95 Ma, which may have been related to continental breakup and the initiation of seafloor spreading, or alternatively to continental stretching. Offshore, the basin became subdivided into a series of slowly subsiding platforms (Crayfish and Mussel Platforms) and rapidly subsiding troughs (western and eastern Voluta Trough). Deposition of the overlying Late Cretaceous Sherbrook Group commenced in the Cenomanian. The margin continued to subside throughout the Tertiary, eventually leading to widespread carbonate deposition. After fast seafloor-spreading commenced at 42 Ma, the margin collapsed by rotation, with the shallow-water Oligocene unconformity being present and unfaulted to the continental slope (Heggie et al., 1988).

Tertiary volcanic rocks, which can provide a significant source of magnetic anomalies, are present in two distinct horizons in the Otway Basin (Megallaa, 1986). The Older Volcanics erupted in the Paleocene whereas, in the Neogene, extensive volcanic eruptions of basalts in central and western Victoria constituted the Newer Volcanics. Thicknesses of up to 200 m have been observed for the Newer Volcanics within the present study area.

MODELS OF BASIN DEVELOPMENT

The architecture of the southern continental margin of Australia is dominated by the Mesozoic 'Southern Rift System' which extends for over 4000 km from Broken Ridge in the west to the South Tasman Rise in the southeast. This rift system was formed in the latest Jurassic to earliest Cretaceous during a period of NW-SE-oriented extension associated with the fragmentation of Gondwana (Willcox, 1990; Willcox and Stagg, 1990; Stagg et al., 1990). In most places the system underlies the continental slope, where it has physiographic expression in such margin features as the Eyre, Ceduna and Beachport Terraces, and the South Tasman Rise. However, in some areas, most notably south of the Eyre Terrace and off the Otway and Sorell Basins of west Tasmania, it appears to give rise to an abnormally wide (*ca.* 200 km) lower continental slope/continental rise at nearly abyssal depths (4000-5000 m).

Traditionally, the Bassian Rift, of which the Otway Basin is one part, is considered to have developed during NNE-SSW lithospheric extension, largely during the Early Cretaceous (Veevers et al., 1991; Etheridge et al., 1985, 1987; Perincek et al., 1994) (Figure 8). This extension led to the development of a linked array of WNW-ESE-oriented, shallow-dipping, normal extensional faults and orthogonal, steeply-dipping, transfer or accommodation faults. In this model, the tectonic evolution proceeded smoothly from rift initiation to active rifting, to sea-floor spreading and associated post-rift subsidence.

The Bassian Rift appears to be a splay off the 'Southern Rift System' of Willcox and Stagg (1990). Further afield, Late Jurassic to Early Cretaceous NW-SE extension formed extensional basins in the Great Australian Bight (Stagg and Willcox, 1992), and also the Gippsland Basin as an extensional feature (Willcox et al., 1992; Colwell and Willcox, 1993), as well as strike-slip basins on the western Tasmanian margin (Moore et al., 1992). Looking at the Bassian Rift as a whole (Gippsland, Bass and Otway Basins), Willcox et al. (op. cit.) proposed that the early history of the Otway Basin was dominated by extension in the same sense as the other parts of the rift, namely by NW-SE extension (Figure 9). It is possible that there was an early phase of Australian-Antarctic seafloor spreading in the Neocomian, at least off the western part of Australia's southern margin (Stagg and Willcox, 1992).

Williamson et al. (1990) proposed two stages of rifting in the Otway Basin. In the model of Williamson et al. (op. cit), the initial rift stage extended from 140 to 120 Ma, and resulted in an offshore rift that included the present-day Crayfish Platform. This platform is characterised by steeply dipping, E/W to ENE-trending normal faults. The second stage of rifting occurred at around 95 Ma, prior to seafloor spreading, with faults trending ESE and SE, with maximum extension near oceanic crust. Williamson et al. (1989) interpreted the crustal structure of the magnetic quiet zone outboard of the Otway Basin to consist of relatively thin, faulted and extended continental crust. The upper and lower crust were interpreted to have extended separately by listric but approximately subplanar faulting, and planar normal faulting, respectively, during a final mid-Cretaceous extensional phase prior to sea floor spreading. (Williamson et al., 1989) (Figure 10). This model is used to explain the discrepancy that occurs between the observed crustal thickness (7 km) and the fault geometries which cannot account for a crustal thinning of less than 25 km thickness.

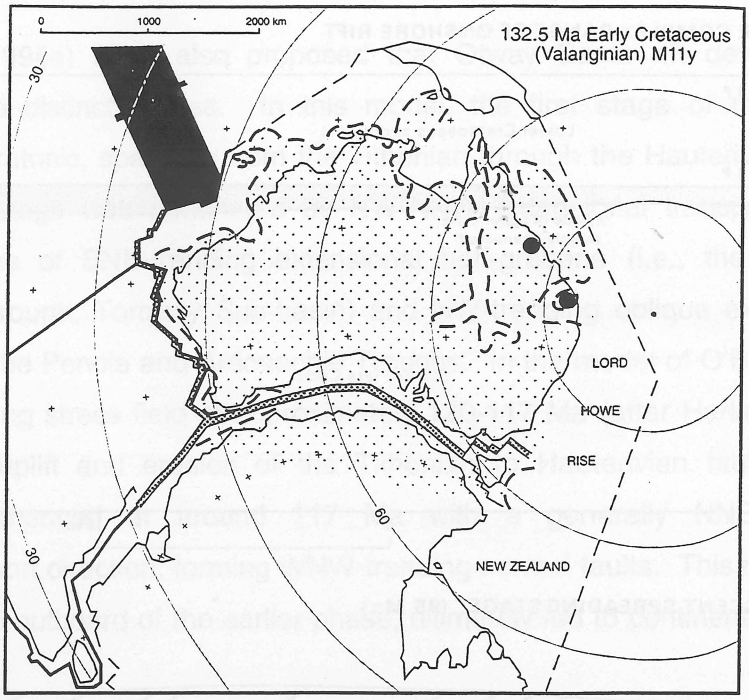

Figure 8: Reconstruction of East Gondwanaland at 132.5 Ma (M11y, Valanginian (Veevers, et al., 1991), showing the onset of NE-SW oriented rifting between Australian and Antarctic plates.

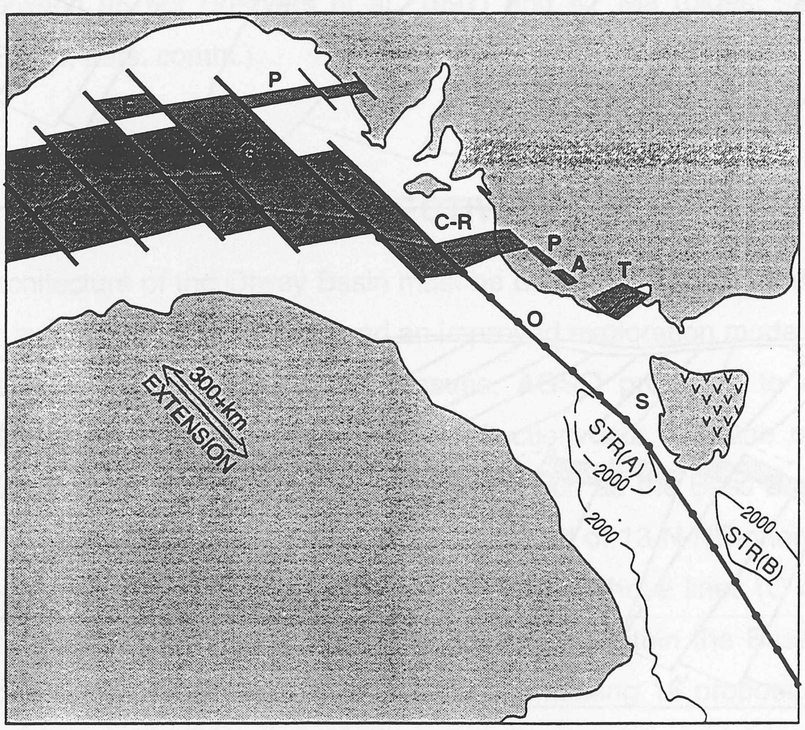

Figure 9: Plate reconstruction of the southern Australian margin for the Late Jurassic to Early Cretaceous (150-120 Ma; Tithonian to Hauterivian). Within the Otway Basin, the Crayfish Platform-Robe Trough (C-R) and the Torquay Sub-basin (T) represent almost purely extensional half-grabens, whereas the Penola Trough (P) and perhaps the Ardonachie Trough (A) represent strike-slip/oblique extensional features. Dotted line shows the position of the eventual COB (from O'Brien, et al., 1994a; modified from Willcox and Stagg, 1990).

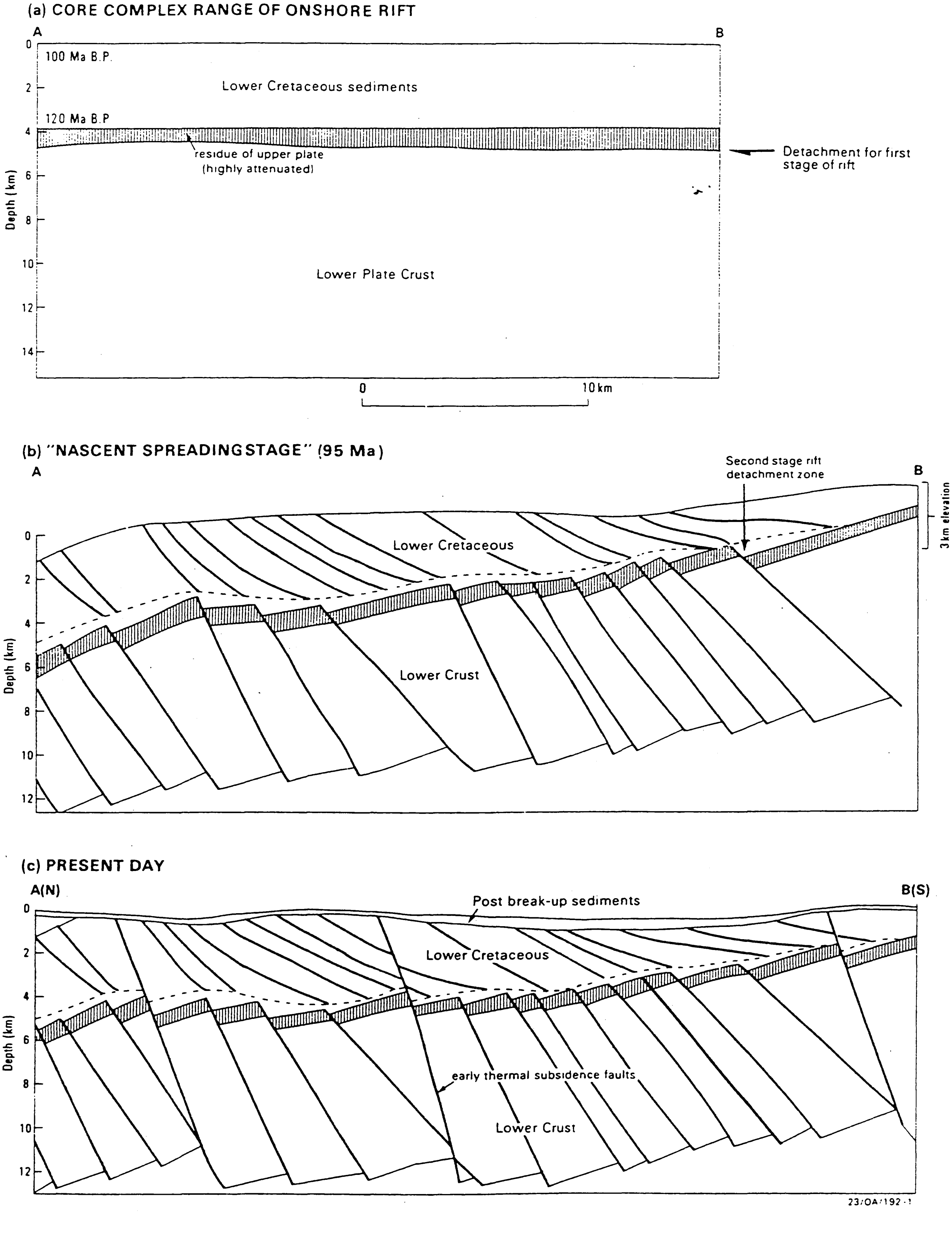

Figure 10: Model for the development of the crustal structure in the magnetic quiet zone of the Otway Basin as secondary rifting of an earlier first stage onshore rift formed by pure and/or simple shear (Williamson et al., 1989).

O'Brien et al. (1994a) have also proposed that Otway Basin rift development proceeded in two distinct stages. In this model, the first stage of rifting was essentially intra-cratonic, spanning from the Tithonian through the Hauterivian (150-120 Ma). This stage was dominated by NW-NNW extensional transport which produced a series of ENE-trending extensional half-grabens (i.e., the Crayfish Platform, Robe Trough, Torquay Sub-basin) and NW-trending oblique extensional features such as the Penola and Ardonachie Troughs. In the model of O'Brien et al. (1994a), a changing stress field at approximately 120-117 Ma (after Harland et al., 1982) produced uplift and erosion of the Tithonian to Hauterivian fault blocks. Extension recommenced at around 117 Ma with a generally NNE-trending extensional transport direction, forming WNW-trending normal faults. This rift phase, which was located outboard of the earlier phase, ultimately led to continental margin formation.

Irrespective of uncertainties surrounding the early rift tectonics, final continental break-up (i.e., the initiation of north-south seafloor spreading) commenced off the Otway Basin between 96 Ma (Veevers et al, 1991) and 42 Ma (oldest magnetic lineations, J.Y. Royer, pers. comm.).

PROGRAM OBJECTIVES

The structural architecture of the Otway Basin must be determined before the widely differing tectonic models can be assessed and an improved exploration model for the Otway Basin developed. To address these issues, AGSO proposed to acquire approximately 5,600 km of deep crustal seismic reflection data over the offshore Otway Basin, as well as linking key structural elements such as the Bass Basin and COB. The original proposal for AGSO Survey 137 consisted of 13 N-NE-oriented dip lines and five E-SE-oriented strike lines (Figure 11). Two of these lines (O and P), comprising 600 km of proposed data acquisition, fell largely within the Bass Basin and were regarded as low-priority acquisition. Of the remaining 16 proposed lines, 11 lines comprising 3,465 km of data acquisition were given a high-to-highest priority ranking (nine dip lines and two strike lines) (see Appendix 2 of O'Brien et al., 1994b). A limited program of seismic refraction data acquisition at selected onshore stations was also planned and should provide important information on crustal velocities for key lines.

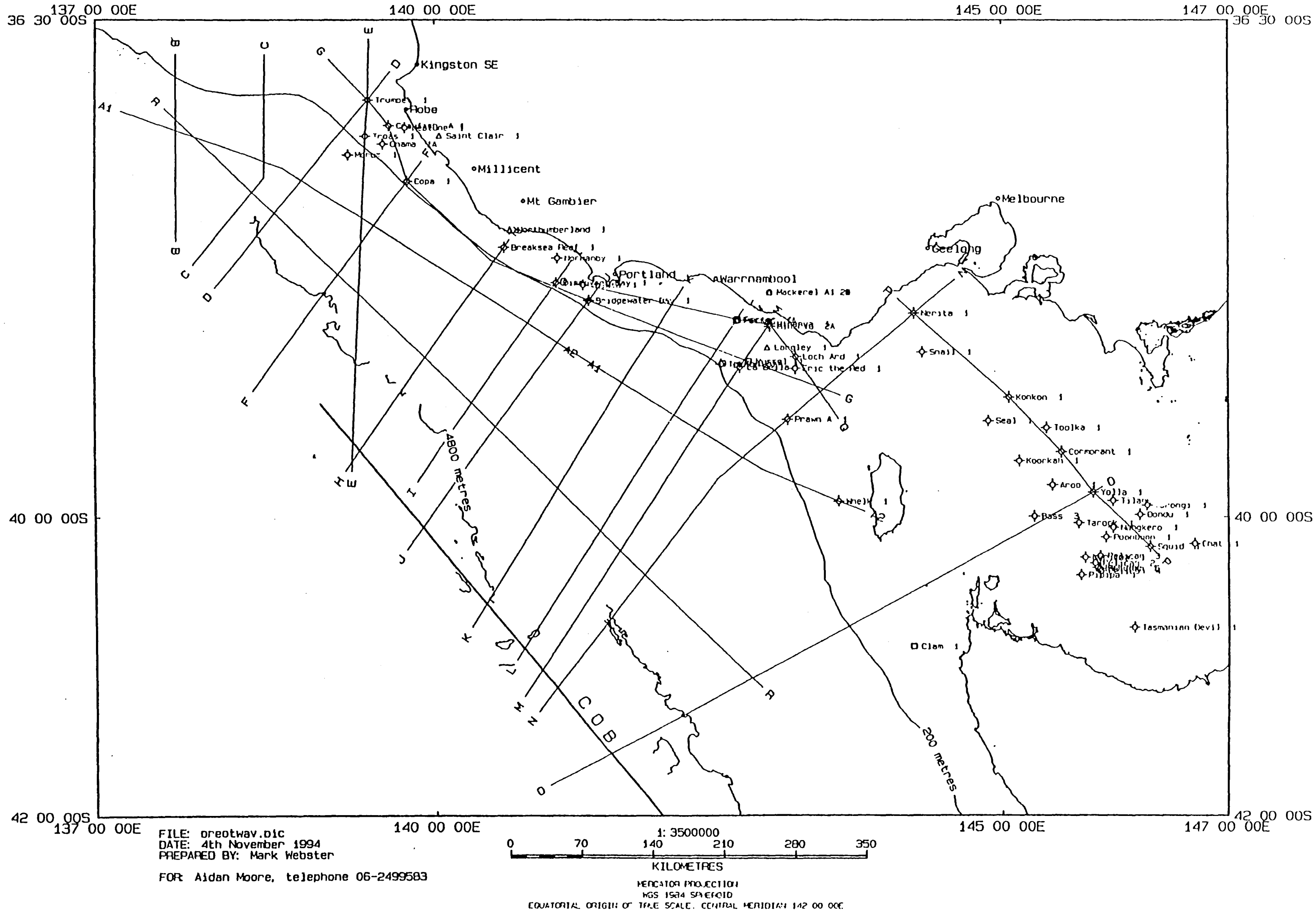

Figure 11: Pre-survey 137 map showing the proposed locations of seismic transects, well locations and bathymetry (O'Brien et al., 1994b).

The data acquisition program of Survey 137 addressed the following specific program objectives:

- To determine the under-pinning structural architecture and ages of the entire basin from the shelf to the lower continental slope, including the Crayfish Platform-Robe Trough, the Voluta Trough, the Mussel Platform and the Torquay Sub-Basin, as well as establishing the nature of the linkages between these elements, and with oceanic crust. The characterisation and contrasting of the underpinning structural architecture of the ENE-trending Crayfish Platform/Robe Trough and Torquay Sub-Basin versus the NNW-trending Voluta Trough may allow the relative merits of the above models to be determined, as well as allowing the interpretation of the aeromagnetic data to be much better constrained.

- To image the linkages between the Otway Basin and the flanking Bass Basin to the east and the Kanmantoo High to the west. Understanding these linkages will help to determine the large scale extensional processes which led to the development of the Otway Basin as part of the larger Bassian Rift System, and its relationship to the Southern Rift System to the west and the Sorrell Basin to the south.

- To characterise the manner in which the large-scale rift elements (e.g., accommodation/relay zones, basement fractures, etc) have controlled structuring in the overlying section through geologic time.

- To characterise the extensional transport direction (ETD) from the Tithonian to the Hauterivian (Crayfish Sub-Group deposition), determining the tectonic driving mechanism for the Hauterivian Unconformity (Top Crayfish Sub-Group time), and characterising the ETD from the Barremian to Albian (Eumeralla Formation time).

- AGSO's new aeromagnetic data in the offshore Victorian part of the basin have delineated major NE-trending structural boundaries on the shelf. These features define the boundaries of the eastern and western Voluta Troughs, which have been interpreted as "accommodation zones". Obsevations from GEOSAT imagery and swath-mapping suggest these features continue to the COB. In the framework of Etheridge et al. (1985, 1987) and Perincek et al. (1994), these accommodation zones would be long-lived (Tithonian to Albian), and potentially bracket deep Tithonian to Hauterivian source rock depocentres. In the framework of O'Brien et al. (1994a), however, the Tithonian to Hauterivian sediments would be thin to absent (as this represents the intra-cratonic phase of basin evolution), and the accommodation zones would effectively be shorter-lived (Barremian to Albian).

- To determine the offshore distribution of sediments of Crayfish Sub-Group age. In the model of O'Brien et al. (1994a), these sediments would be absent under the Mussel Platform and Voluta Trough because the intra-cratonic rift phase was largely restricted to the present-day onshore areas. As the basal Crayfish Sub-group sediments are potential oil-prone source rocks, and, if present, would be in the oil window over the eastern Mussel Platform, their presence or absence offshore has important exploration implications.

- To provide a fundamental framework within which to interpret the extensive data set of conventional seismic reflection data which has recently been acquired over the shelf and onshore areas of the basin, in order to examine spatial and temporal changes in the geological development across this complex basin.

SURVEY PARAMETERS AND ACQUISITION DETAILS

Data Acquired

Data collected on Survey 137 comprise:

- Deep seismic reflection data, 48 fold (shots fired every 50 m at a ship speed of 4.5 to 5.0 knots), 16 second record length acquired with a 4800 m active length streamer and dual tuned airgun arrays (20 sleeve-guns of 5 litres total capacity).
- Magnetic data on approximately 80% of seismic and transit lines.
- Bathymetry on all lines.
- Gravity data during Phase 2 of the survey.

Execution of the Seismic Program

The proposed (pre-survey) locations of the seismic transects and navigation waypoints are shown in Figure 11 and summarised in Appendix 8c. The post-survey locations of the seismic lines recorded and the waypoints used during Survey 137 are presented in Appendices 8a and 8b, with acquisition parameters outlined in Appendices 6 and 7. A number of deviations to the original survey proposal (O'Brien et al, 1994b) were required in response to two influential factors (see ***Summary of Data Acquisition***): 1) the need to avoid sub-surface buoys and craypots to minimise potential damage to the seismic cable; and, 2) to accommodate extensions to the southern terminations of transects to ensure that the continental-oceanic boundary (COB) had been crossed.

A chase boat, the MV *Perfect Lady*, was contracted to clear craypots from a 200 m wide swath of the continental shelf in water depths of less than 200 metres. The *Rig Seismic* was also required to undertake the inshore segments of the transects during daylight hours so as not to interfere with fishing operations (which are undertaken at night). A procedure was established whereby the *Rig Seismic* rendezvoused with the chase boat at the shelf edge (>200 m water depth) at daybreak (approximately 0500 hr). By this time, the 200 m swath had generally been cleared of visible obstructions and the chase boat accompanied the *Rig Seismic* across the shelf to ensure safe passage. The chase boat was frequently required to move poorly-marked or unflagged sub-surface buoys which were only visible during the daylight hours. At the inshore terminus of the transect, the seismic cable was retrieved, and the vessel undertook a broad turn to exit the area along the same cleared track. This procedure meant that several of the lines (Lines 137/200, 137/300 and 137/400) were shot in two different directions (generally the inshore segment to the north, and the deep water segment to the south). The inshore segments of seismic lines acquired in the most heavily fished area between Kingston (South Australia) and Portland (Victoria) had to be terminated early (i.e., before the preplotted EOL waypoint) due to snagged craypots which caused excessive noise and/or tension on the seismic cable (Lines 137/200, 137/300, 137/401, 137/ 700 and 137/1200). A proposed strike line (137/502) extending along the inshore shelf from Troas-1 to Voluta-1 had to be repositioned to the shelf edge due to potential cable damage. A detailed record of course deviations and waypoint changes are summarised in the ***Cruise Narrative*** and ***Seismic Data Recorded*** sections of this report.

In addition, the priority assigned to transect acquisition (O'Brien, et al., 1994b) had to be balanced with prevailing sea conditions in order to maximise the amount of data collected, and to minimise transit time and the impact of the southwesterly swell on data quality. Overall, all the highest-to-high priority lines (O'Brien et al., 1994b) were acquired during Phases 1 and 2 of the cruise, with the exception of the deep water part of Line K (line 137/1300). An additional line in deep water was added mid-way through Phase 1 (Line "X", 137/800) to test observations of a transitional COB. Data quality is most likely to be affected by poor weather conditions and a moderate southwesterly swell which persisted during approximately 80% of the survey time. Due to the structural nature of the Otway Basin (and hence the orientation of the seismic lines), the NE-trending dip lines were aligned parallel to the dominant swell direction from the southwest, while W-NW-trending strike lines were affected by swell across the beam.

Cruise Narrative - Survey 137, Phase 1

Phase 1 of Survey 137 commenced in Portland on 26 November 1994 and finished in Melbourne (Port Phillip Bay) on 21 December 1994. Cable deployment commenced west of King Island on 29 November and acquisition of Line 137/100 was began at 2133 hr on 30 November. A total of 2,524.85 km of data was recorded on nine lines during Phase 1. The following is a summary of the main events during Phase 1 of Survey 137.

dates indicated are local, ie. Eastern Australia Time.

26 November	sailed from Portland; transit to proposed eastern terminus of Line 137/100 west of King Island; cruise briefing.
27 November	transit; equipment trials (gun bundles, gun controller box).
28 November	transit; equipment trials (gun bundles, gun controller box); safety meeting.
29 November	transit; equipment trials (gun bundles, gun controller box, and dynamic positioning device required for vibrocoring onsubsequent cruise); begin deployment of GPS-equipped tailbuoy and cable.
30 November	Cable deployment; SOL 137/100, data recorded from 1021hr to 1112hr in moderate to rough sea conditions; data out of specifications; transect abandoned; partial cable retrieval; cable redeployed; restart SOL 137/100 at 2133hr; Whelk-1 wellhead.

1 December	Continue 137/100; doglegs at 0557hr (SP1659) and 2250hr (SP 4821), no line changes.
2 December	Continue 137/100.
3 December	Continue 137/100; dogleg at SP 10374; EOL waypoint modified to extend line by 15nm to west; EOL 137/100; transit; data acquisition on line 137/200 delayed due to poor sea conditions; SOL 137/200 at 43.762nm along preplotted line.
4 December	Continue 137/200; rendezvous with chase boat MV *Perfect Lady* at daybreak on shelf margin; craypot snagged on cable at 0930hr (SP 1978, Bird 22) causing increased noise levels on several channels and cable tension; Trumpet-1 wellhead; second craypot snagged on cable; course change to avoid craypot; third craypot snagged (SP2497, Bird 20); magnetometer damaged at 1241hr during retrieval in shallowing waters; magnetometer inoperable; early termination of line due to shallowing of the cable and increased noise levels; EOL137/100; cable retrieval; retrace cleared transect to back into deeper water; begin cable redeployment.
5 December	Cable deployment; loop and position for SOL 137/300 approximately 5 km south of shelf edge at daybreak; SOL 137/300 at 0509hr; Troas-1 wellhead; Trumpet-1 wellhead; course deviation to avoid craypots; EOL 137/300 before preplotted EOL; cable retrieval; retrace cleared transect back into deeper water; transit to SOL 137/301.
6 December	Cable deployment; SOL 137/301.
7 December	Continue 137/301; moderate noise level on several channels possibly due to leakage from shark bites; southern terminus of 137/301 extended 2.2 km beyond original waypoint; EOL 137/301; begin cable retrieval; weather conditions deteriorate; begin loop waiting for improvement.
8 December	Cable repair and deployment; SOL 137/400; excessive noise outside of specifications due to sea conditions; Line 137/400 abandoned. Begin loop waiting for improvement in weather.
9 December	Restart of SOL 137/400 at position 40nm north of original waypoint due to swell conditions; Line 137/400 terminated at 2203hr at shelf edge (ship cannot cross into craypot areas outside daylight hours) EOL 137/400; begin loop waiting to start 137/401 at daybreak.
10 December	SOL 137/401; Breaksea Reef-1 wellhead; two dead channels due to ?shark bites; EOL 137/401; transit to SOL 137/500. Line 137/500 began 2.4 nm west of original waypoint; SOL 137/500;
11 December	Continue 137/500; Pecten-1 wellhead; EOL 137/500 at dogleg

at Minerva-1 wellhead; gun retrieval, repair, and redeployment on loop; SOL 137/501 at Minerva-1 wellhead; Loch Ard-1 wellhead; EOL 137/501; cable retrieval; transit to SOL 137/600.

12 December	Transit; cable deployment; testing of magnetometer replacement; SOL 137/600; magnetometer functioning well.
13 December	Continue 137/600; Line 137/600 terminated early due to medical emergency; EOL 137/600; cable and gun retrieval; begin transit to Portland at 1522hr to evacuate personnel (medical emergency).
14 December	Medical evacuation; replacement personnel transferred to ship; alter cruise plan to minimise transit time; begin acquisition of proposed line west of Portland; replace cable sections and connectors during deployment; SOL 137/700; feather angle (FA) is -21° at SP 100; FCSP 129 at FA -14°; magnetometer replacement continues to function well; Bridgewater Bay-1 wellhead; no problems in shelf area with craypots.
15 December	Continue 137/700.
16 December	Southern terminus of Line 137/700 was extended southward by 10 nm; EOL 137/700; transit to 137/402; SOL 137/402; Line aborted due to incorrectly entered waypoint; begin loop to restart line; restart SOL 137/402.
17 December	Continue 137/402 to tiepoint with 137/400; EOL 137/402; an additional line (Line "X") was added to the acquisition program following discussions between the on-board AGSO Scientific Representative and (shore-based) Project Leader; transit to 137/800 (Line "X"); SOL 137/800.
18 December	EOL 137/800; transit; SOL 137/601.
19 December	EOL 137/601; transit; SOL 137/900.
20 December	Continue 137/900; LaBella-1 wellhead; Minerva-1 wellhead; EOL 137/900; cable retrieval; begin transit to Melbourne (Port Phillip Bay).
21 December	Transit; at dock in Melbourne at 1435hr. End of Survey 137, Phase 1.
22 December	Shipboard work; AGSO personnel return to Canberra;

Cruise Narrative - Survey 137, Phase 2

Seismic data acquisition commenced on Phase 2 of Survey 137 on 14 January 1995. The survey was completed on 22 January, with the ship returning to Melbourne (Port

Phillip Bay) on 23 January. A total of 940.05 km of seismic reflection data was collected on eight lines (including the completion of four existing lines from Phase 1 and three new lines), with a daily average of 117.5 km (based on 8 days of acquisition). The following is a summary of the main events during Phase 2 of Survey 137.

dates indicated are local, ie. Eastern Australia Time.

13 January	Transit to SOL 137/1100; on-board equipment preparations.
14 January	Transit; SOL 137/1100.
15 January	Continue 137/1100; EOL (southern terminus) was extended by 11 nm beyond original waypoint; EOL 137/1100; transit; SOL 137/101.
16 January	Continue 137/101; transit; SOL 137/201; EOL 137/201; transit to SOL 137/801.
17 January	SOL 137/801; EOL 137/801; fire-drill; transit; SOL 137/1200.
18 January	Continue 137/1200; Copa-1 wellhead; line 137/1200 was deviated because of shark nets and terminated 6 nm early due to craypots on transect; cable retrieved with damage from craypots and shark bites (5 sections damaged); transit to SOL 137/502.
19 January	SOL 137/502; high-tides and prevailing winds submerged marker buoys on craypots making them undetectable; chase boat was unable to clear transect; the line was repositioned from a shallow "along-shelf" transect to a deeper water location, roughly following the 200m isobath; the proposed well ties on this transect were not made due to repositioning.
20 January	Continue 137/502; craypot hooked at 0312hr (Bird 16); second craypot hooked at 0948hr (Bird 1); dogleg; course deviation at 1243hr and 1328hr to avoid craypots; the seismic cable surfaced at 1459hr with seas rising; line 137/502 aborted at 1706hr when cable could not be controlled at any depths; begin loop to overshoot/complete line 137/502; cable retrieval, birds replaced, craypots removed, cable rebalanced with extra weight.
21 January	Transit to resume 137/502; the attempt to reshoot line was aborted at 0305hr when cable surfaced again; transit to new position to try and re-shoot line in the opposite direction (i.e., from east to west); craypot hooked (Bird 5) and line aborted at 0927hr; transit to reshoot line in original direction (i.e., west to east); waypoints for 137/503 were adjusted with Point 1 in line with 0.3 nm off line distance of the LCSP of 137/502; Point 2

	was back on original 137/501 with no off-line distance; Point 3 was the original EOL waypoint; the "lead-in" was adjusted to a low tow position (1300hr), and cable taken down to 18m depth and slowly brought up to 13m; craypots hooked on Birds 5 and 16; EOL 137/503; transit.
22 January	Transit; SOL waypoint for 137/1300 moved 4 nm to the east to avoid heavily craypotted area; high noise levels due to sea conditions; EOL 137/1300; terminated early due to time restrictions; cable and guns retrieved; transit to Melbourne.
23 January	Transit; ship in dock at Melbourne (Port Phillip Bay) at 1600hr; End of Survey 137, Phase 2.

Seismic Data Recorded

A total of 13 seismic lines were recorded during Phases 1 and 2 of Survey 137 (Figure 2). These lines total 3464.90 km and tie nine exploration wells located in inshore area of the basin. A brief description of the location of each line is presented below. Seismic line information is summarised in Appendix 10 and a listing of tape numbers for each seismic line is given in Appendix 11. The phases of survey acquisition are noted as follows: Phase 1 = (P1), and Phase 2 = (P2).

Line 137/100: (Cruise Proposal Lines A^1 and A^2)

Strike line (with dogleg) extending along the outer continental slope from the western margin of King Island to the predicted western margin of the Otway Basin. Ties Whelk-1 and lines 137/200, 137/300, 137/400 (401), 137/700, 137/900, 137/1100, 137/1200, 137/1300. Recorded in two segments in two directions: 137/100 (P1) (east to west) and 137/101 (P2) (west to east). Total line length: 621.85 km.

Line 137/200: (Cruise Proposal Line D)

Northeast-trending dip line from inner shelf to COB. Ties Trumpet-1 and lines 137/100, 137/200, 137/300 and 137/801. Recorded in two segments: 137/200 (P1) and 137/201 (P2). Inshore segment of line terminated before preplotted EOL due to the craypots on seismic cable. Southern segment of line recorded in rising seas with possible swell noise. Total line length: 210.15 km.

Line 137/300: (Cruise Proposal Line E)

North-trending dip line from inner-shelf to COB. Ties Troas-1, Trumpet-1 and lines 137/100, 137/200, 137/402, 137/502, 137/800 and 137/1200. Recorded in two segments in two directions: 137/300 (P1) (south to north) and 137/301 (P1) (north to south). Inshore segment of line terminated early due to craypots on seismic cable. Southern terminus of line extended beyond original EOL waypoint by 2.5 nm. Total line length: 352.00 km.

Line 137/400: (Cruise Proposal Line H)

Northeast-trending dip line from inner shelf to COB. Ties Breaksea Reef-1 and lines 137/100, 137/301, 137/502 and 137/800. Recorded in three segments: 137/400 (P1), 137/402 (P1) and 137/403 (P3). Total line length: 232.25 km.

Line 137/500: (Cruise Proposal Lines G and Q)

Northwest to southeast-trending strike line along the inner continental shelf. Ties Voluta-1, Pecten-1A, Discovery Bay-1, Minerva-1, Loch Ard-1 and lines 137/200, 137/300, 137/401, 137/700, 137/900, 137/1200 and 137/1300. Recorded in four segments: 137/500 (P1), 137/501 (P1), 137/502 (P2), 137/503 (P2). Segments 137/500 and 501 were recorded without incident. The acquisition of segments 137/502 and 503 was extremely problematic due to the weather conditions and the density of craypots set offshore between Robe and Mt. Gambier, South Australia. Segments 502 and 503 were repositioned from the original waypoints to follow 200 m isobath. Seismic cable surfaced on two occasions and craypots were hooked at several points along cable. Possible problems with excessive cable noise. Total line length: 478.95 km.

Line 137/600: (Cruise Proposal Line N)

Northeast-trending dip line from inner shelf, across eastern basin margin to COB. No well or line ties to other 137 survey data. Line recorded in two segments: 137/600 (P1) and 137/601 (P1). It is recommended that the northern terminus of line 137/600 be extended to tie line 137/501, if additional Otway Basin deep-seismic work in undertaken in future. Total line length: 236.50 km.

Line 137/700: (Cruise Proposal Line J)

Northeast-trending dip line from inner shelf to COB. Ties Bridgewater Bay-1 and lines 137/100, 137/500 and 137/800. Line recorded in one segment (P1). Southern terminus of line extended by 10 nm. Total line length: 263.90 km.

Line 137/800 and 801: (Line "X" added during Phase 1 of acquisition)

Northwest-trending strike line on outer continental slope. Line 137/800 ties lines 137/301, 137/402 and 137/700. Line 137/801 ties lines 137/201 and 137/1200. Line recorded in two segments: 137/800 (P1) and 137/801 (P2). Total line length: 260.0 km.

Line 137/900: (Cruise Proposal Line M)

Northeast-trending dip line from inner shelf to COB. Ties LaBella-1, Minerva-1 wells and lines 137/100, 137/500 and 137/501. Recorded in one segment (P1). Total line length: 353.90 km.

Line 137/1000: (Overshoot of Line 137/200 using 4 x 4 GI gun array)

Line acquired for technical purposes only.

Line 137/1100: (Cruise Proposal Line B)

North-trending dip line across the western margin of the basin. Ties line 137/101. Recorded in one segment (P2). Southern terminus of line extended for 11 nm beyond original waypoint. Total line length: 170.55 km.

Line 137/1200: (Cruise Proposal Line F)

Northeast-trending dip line from inner shelf to COB. Ties Copa-1 and lines 137/100, 137/300, 137/502 and 137/801. Deviation to original waypoint because of shark nets. Northern terminus of line terminated 6 nm before EOL waypoint due to craypots on seismic cable. Total line length: 210.45

Line 137/1300: (Cruise Proposal Line K)

Northeast-trending dip line from inner shelf to COB. Ties lines 137/100 and 137/500. Line moved 4 nm east of original waypoints due to craypots. Southern terminus of line aborted due to time restraints (i.e., southernmost 225 km of line abandoned, line did not cross COB). It is recommended that the southern terminus of Line 137/1300 be extended to the COB, if additional deep seismic data is acquired in the Otway Basin in future. Total line length: 79.50 km.

SUMMARY OF EQUIPMENT AND SYSTEMS REPORTS

(a condensed and edited version of internal AGSO post-survey technical report by
K. Webber (Ship Manager, Phase 1), G. Cassim (Ship Manager, Phase 2),
and AGSO Shipboard Parties (Phases 1 and 2)

Navigation/Geophysical (non-seismic) Data Acquisition System (DAS)

The geophysical/navigation data acquisition (DAS) ran without serious problems for the duration of Survey 137, Phases 1 and 2. Minor problems were encountered with the Navigation Dat tapes during the first half of Phase 1. The tapes had excessive time jumps and could not be compared with disk data as the program was unable to resynchronise the two after the time jumps. Minor problems were also experienced with the Vax when doing backups of the DAS-137 file. After rebooting, the backups were completed successfully. Raw GPS data were logged at Melbourne for this survey as Adelaide has no facility for logging to optical disk.

Navigation

Differential GPS was available at all times except when constrained by equipment and/or satellite problems, of which there were very few during this survey. Periods of Dead Reckoning were brief and created no problems.

GPS/dGPS (Racal System)

The prime navigation systems for Survey 137 consisted of two differential Global Positioning Systems (dGPS), Multifix (V1.3) (primary) and Multifix (V2.06j) (secondary) supplied by RACAL Survey Ltd. Updated software installed on the system encountered only minor problems during the survey. A tertiary navigation system was provided by Magnavox dual-axis sonar doppler velocity log and IR gyro-compass. This system is only intended to provide dead-reckoning navigation during periods of a few minutes when full differential coverage may be lost for technical reasons.

Dead Reckoning

The majority of the survey was run in deep water without bottom lock on the sonar dopplers. In these conditions, the SD dead reckoning systems were ineffective and were fortunately rarely required. A system change to manual DR was required on only one occasion.

Sonar Dopplers and Gyro-compasses

The sonar doppler and various gyro-compasses provided dead-reckoned navigation for the brief periods when GPS/dGPS coverage was not available. The sonar doppler had difficulty tracking in deeper water, but performed well in shallow water. The gryo-compasses performed without problem. The bridge gyro-compass was not functioning at the start of Phase 2 and was run from the IR gyro-compass.

Magnetics

The magnetometer was deployed during the early part of the survey on lines 137/100 and 137/200. The initial magnetometer was lost on a submerged object in shallowing water on line 137/200. There were no readily available spare parts (magnetometer head) to repair the equipment. Technicians required 9 days to assemble required spare parts. The repaired magnetometer performed well, with noise levels typically 6nT.

Gravity

The gravity meter was inoperable at the time of survey departure from Portland on 26 November 1994. The meter was partially dismantled and on-board spares were used in an unsuccessful attempt to repair the equipment. A preliminary assessment suggested that the gyrometer was faulty. The meter was manually caged for the duration of Phase 1 of the survey. During the break between Phases 1 and 2, the gravity meter was repaired and gravity data was collected during Phase 2 of the survey.

Bathymetry

Bathymetric data were collected during the entire survey without major acquisition problems using 12 kHz and 3.5 kHz echo sounders. The 12 kHz echo sounder displayed values 4000 m too high on two occasions during Phase 1. This problem was repeated on Phase 2, but was tracked down to a loose connector plug between the echo sounder and the multiplexor box. The 3.5 kHz echo sounder failed between Survey 146 and the start of Survey 137, Phase 2. Both echo sounders appear to be unreliable in shallow water. AGSO's Operations personnel have been alerted to this concern. Water depths of 30 to 5000 m were encountered. Data quality was variable.

Seismic Aquisition System

Amplifiers and Phoenix A-D converter

The Phoenix/Amplifiers performed well during Phase 1 of Survey 137, requiring neglible work except maintaining the Instrument Room temperatures within specifications. The Phoenix failed to power-up during systems testing at the start of Phase 2. The contacts were cleaned and some joints resoldered. The system worked well, with a check in Amplifier test mode recording RMS noise of 30uv and DC offset of 50 uv.

Tape Drives

The MUSIC MUB0 tape drive performed reliably during the survey, although a unusual noise (?fan) was detected intermittently. There were no problems with jammed or faulty tapes. The serial numbers of tapes are continuing to be logged.

Seismic Cable

The seismic streamer configuration (Appendix 7) consisted of armoured tow leader (80-110 m deployed), tension cell, 3 x 50 m stretch sections, 48 x 100 m active sections (192 x 25 m active groups), a single 50 m stretch section, and a tailbuoy at the end of a 150 m rope. Twenty-five remotely controlled cable levellers (birds), each with a depth transducer, were deployed along the streamer to provide depth control. The streamer was first deployed on 28 November 1994 and reconfigured to 25 m group intervals. Lead on the streamer from the previous survey was removed, and the streamer was re-ballasted for the colder waters of the Southern Ocean. A few cable levellers reported depths properly, but were inaccurate for the wing angle. It was found that the locating pin for the wings was not properly aligned. Frequent shark bites on the seismic cable caused water to ingress into the streamer section causing noisy channels. The streamer appeared to be too buoyant during Phase 2 of the survey causing the cable to rise when swell height increased. A faulty tension cell at the head of the streamer meant that much of Phase 2 had to be shot without tension meter readings.

Tailbuoy

The tailbuoy operated well during Phase 1 of the survey. On 14 December, a new Cortran Radar Transponder was installed. This device made the tailbuoy visible in choppy and heavy seas. During Phase 2 of the survey, the tailbuoy batteries were not properly charged due to the propellers getting caught up in craypot ropes and floats. Consequently, the tailbuoy was not operational during 90% of Phase 2.

Mechanical

Seismic Source

The seismic source for Survey 137 was provided by two arrays of sleeve guns, towed at depths of 10 to 13 metres. The arrays consisted of sixteen 150 cubic inch sleeve guns in each array. During seismic recording, 10 guns were fired from each array with the airguns grouped in clusters of 4, 3, 2 and 1 gun(s)at a nominal pressure of 1800 psi. New mini bundles were installed on the sleeve guns prior to the start of Survey 137 and performed well, except for the fracturing of welds of the bundle clamps after the first line (Line 137/100). The use of GI gun connectors for connecting the gun depth transducers to the firing lines has hastened the replacement of faulty transducers. Only seven depth transducers were used during the survey due to one of the depth display meters in the instrument room being out of service.

Gun Controller

The new gun controller in conjunction with the mini bundles performed very well. Gun timing errors were typically around 2.5%, and enabled a 55 hour line (137/100) to be shot without loops. At the start of Phase 1, the controller and gun sensor pulse were tested, with only minimal adjustments required to the controller gain settings.

Compressors

High pressure air at 2000 psi was supplied by running four air compressors at 1700/1800 rpm with two compressors on stand-by. All units operated satisfactorily requiring only minor maintenance.

PRELIMINARY SCIENTIFIC RESULTS

The greater part of Survey 137 is located in deep water, with an estimated 80 to 90% of the survey shot in water depths exceeding 1000 meters. Over much of this area, particularly in water depths greater than 4000 m, the shipboard seismic monitors indicate that the sea bed consists of low-relief volcanic mounds and highly-rotated continental blocks covered by a thin drape of pelagic sediment. Consequently, some generalised observations can be made concerning the morphology of the lower continental slope and abyssal plan, and the transition from continental to oceanic crust. In the continental shelf areas (<200 m water depth), much of the 3-second record which is monitored during acquisition is obscured by sea bottom multiples.

Continental Shelf and the Basin Margins

The monitor records across the continental shelf typically show a series of narrow, seaward-stepping fault blocks that are bounded by high-angle, southward-dipping faults. The fault blocks consist of northward-dipping, parallel-bedded sediment of presumably Early to Late Cretaceous age. This type of structure comprises the main drilling target for companies exploring for hydrocarbons in the Otway Basin. Fault blocks underlying the shelf show a moderate degree of truncation. A post-structuring wedge of prograding sediment can be seen to downlap onto the fault blocks on the outer continental shelf (Figure 12). These prograding sediments are overlain by a thicker sequence of parallel-bedded sediments that are presumed to be Cainozoic (largely Neogene) carbonates. Many of the high-angle faults bounding the Late Cretaceous fault blocks appear to have been reactivated, with significant offsets frequently extending upwards to the present sea bed. Two 1987 BMR surveys measured the concentration and molecular compositions of gases contained in cores from the offshore Otway Basin. Anomalous concentrations of thermogenic hydrocarbons were found at nine localities (Heggie et al, 1988; Heggie et al, 1991; Heggie and O'Brien, 1988; O'Brien and Heggie, 1989). These concentrations were interpreted as probable gas seeps and generally lie above faults that appear to reach seafloor.

The northern boundary of the Otway Basin immediately east of Robe (South Australia) can be well-defined from the available industry seismic grid and aeromagnetic data. This boundary loses definition to the west where data coverage is poor. Survey 137 seismic lines 137/101, 137/200, 137/300 and 137/1100 were positioned to help define this boundary. The onboard monitor record from seismic line 137/300 (Figure 13) shows the steep (?faulted) outer boundary of the basementblock (at < 1.0 s TWT depth) northeast of Trumpet-1, and the progressive onlap of sediment onto this feature. The onlapping sequence is truncated and overlain by a flat-lying, unstructured sequence of ?Late Cretaceous to Cainozoic carbonates. The seismic monitor records of line 137/101 indicate that this transect did not cross the western margin of the basin (ie, did not cross into an area of shallow basement similar to lines 137/200, 137/300 and 137/1100). However, a

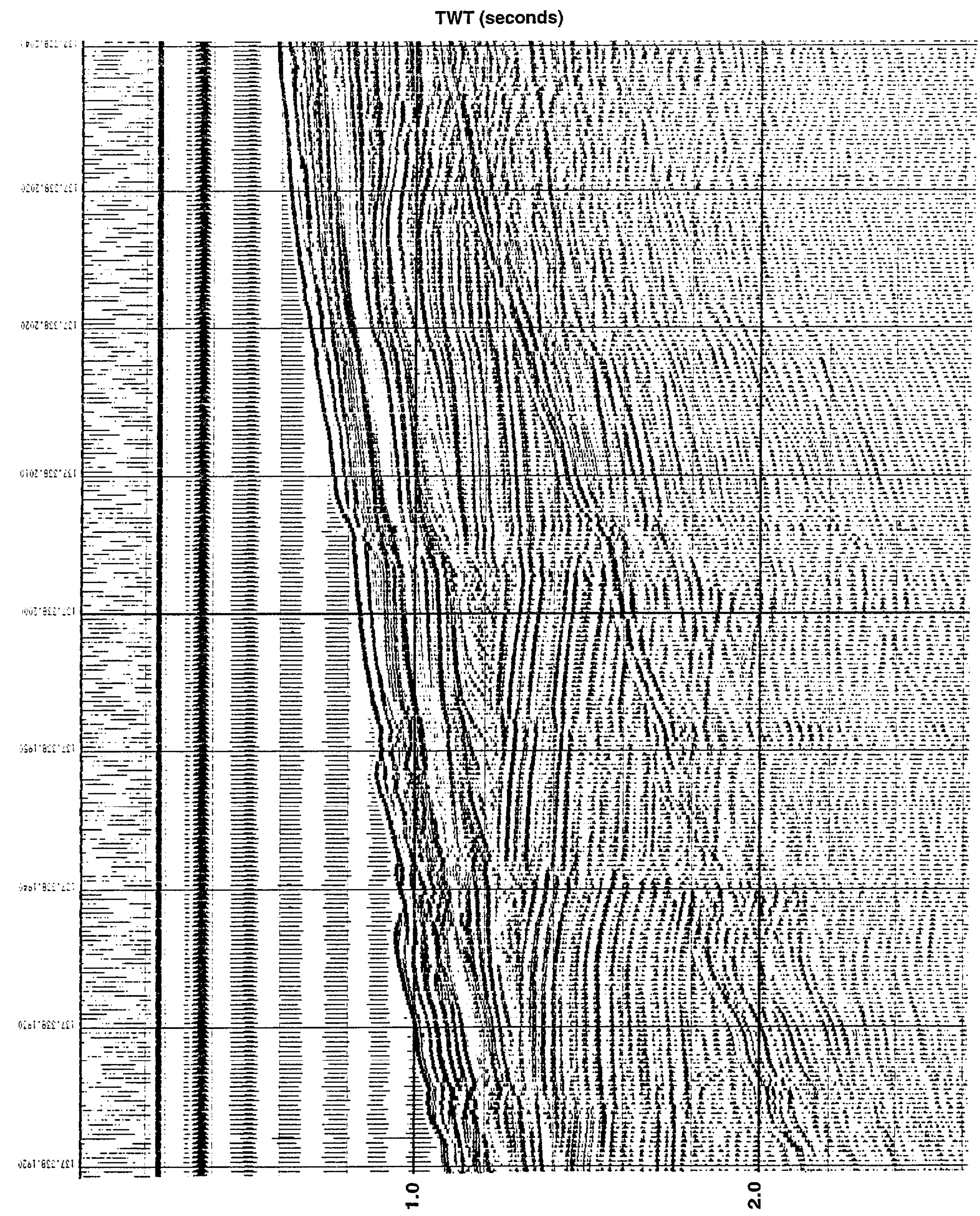

Figure 12: Seismic monitor record (line 137/300), showing fault blocks of Early to Late Cretaceous age overlain by a prograding wedge of Cretaceous to Cainozoic sediment.

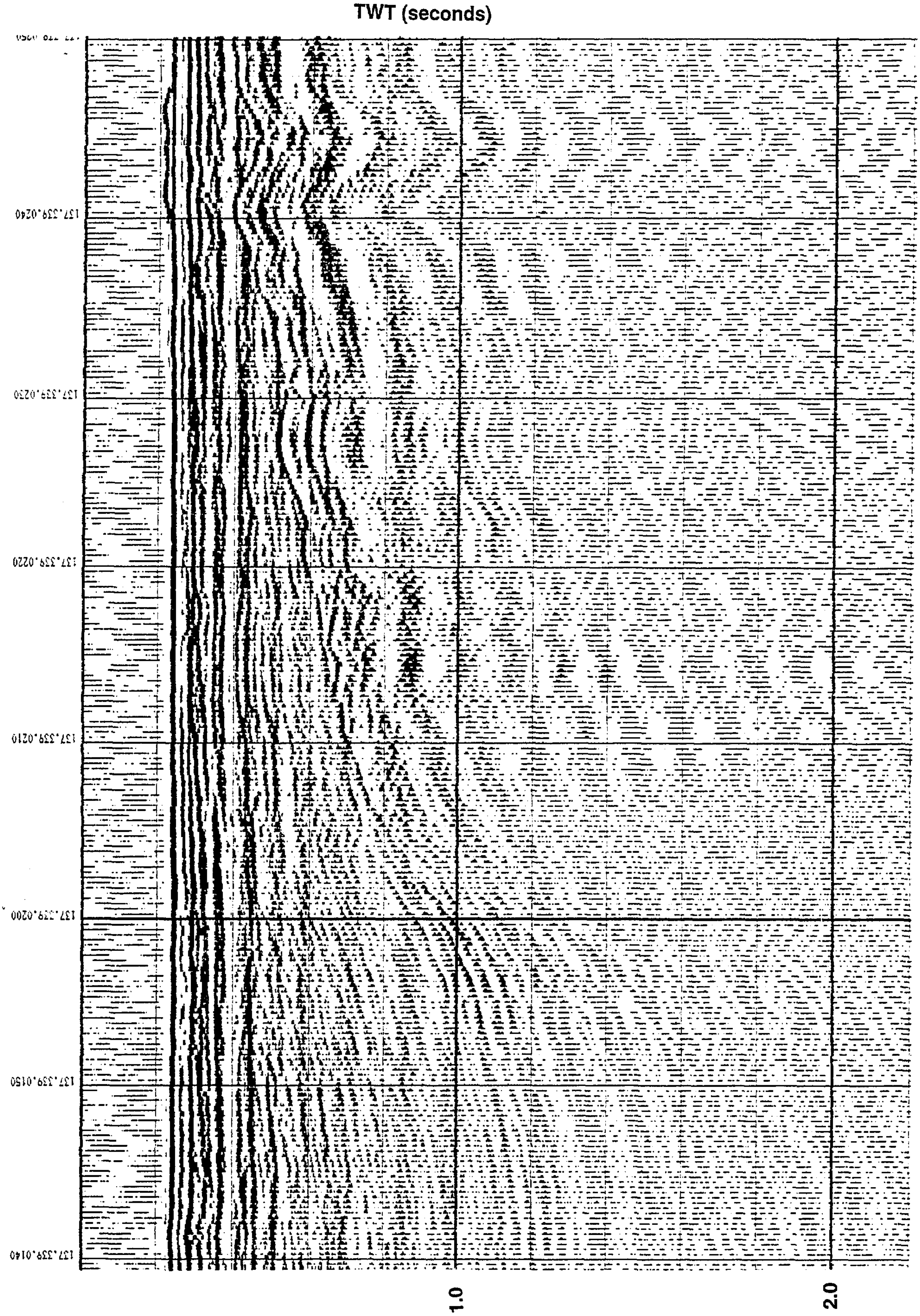

Figure 13: Seismic monitor record (line 137/300), showing the ?faulted northern margin of the Otway Basin (east of Robe) and the onlapping relationship of the overlying Cretaceous sediment.

broad shelf-edge canyon located at SP5550 (Line 137/101) has downcut into the surrounding shelf to a depth of some 1.5s TWT (approximately 2250m of relief based on an average velocity of 1500 m^{-1} for sea water) (Figure 14). The location of submarine canyons of this magnitude may controlled by underlying (?transfer) faults which cut the shelf margin.

To the east, line 137/501 which ties the Minerva-1 and Loch Ard-1 wells, also does not appear to have crossed a major bounding fault (ie, the basin margin fault) on the eastern edge of the Otway Basin. This eastern margin of the basin is defined by a northwest-trending basement ridge known as the Bassian Rise. The monitor records show a gradual thinning of sediment in an easterly direction and a possible shallowing horizon which may correlate to basement (Figure 15). In addition, the records show intermittent zones of high-velocity, some of which appear to outcrop at the sea bed. The origin of these zones cannot be determined from the monitor records, but are likely to be areas underlain by high velocity carbonates or igneous/metamorphic rock (basement).

The Continent-Ocean Boundary (COB)

As stated in the program objectives, the southern termination of each transect was intended to cross the COB. A predetermined location of this boundary was derived from interpreted GEOSAT data (Figure 16). The GEOSAT data suggests that the COB is a well-defined, linear (although somewhat arcuate) boundary with progressive southerly offsets along a series of N-NE aligned transform faults. This trend is shown on Figure 17 from Veevers (1988), who interpreted a series of ridge jumps based on magnetic lineation patterns off the Otway and West Tasmania Basins. Veevers also identified a series of fracture zones (FZ) which terminate at the COB in the region south of the Otway Basin (Spencer FZ, George V FZ, St Vincent FZ, Gambier FZ and Tasman FZ). A plot of Veever's (1988) proposed fracture zones indicates that, if present, these proposed offsets should have been crossed during the acquisition of Survey 137 data.

The seismic monitor records over this region commonly show a transition from S-SE-dipping continental fault blocks, many of which are difficult to define because of the high-degree of rotation, to outcropping volcanic mounds (Lines 137/201, 137/301, 137/402, 137/800, and 137/1200). This zone of transition appears to occur over

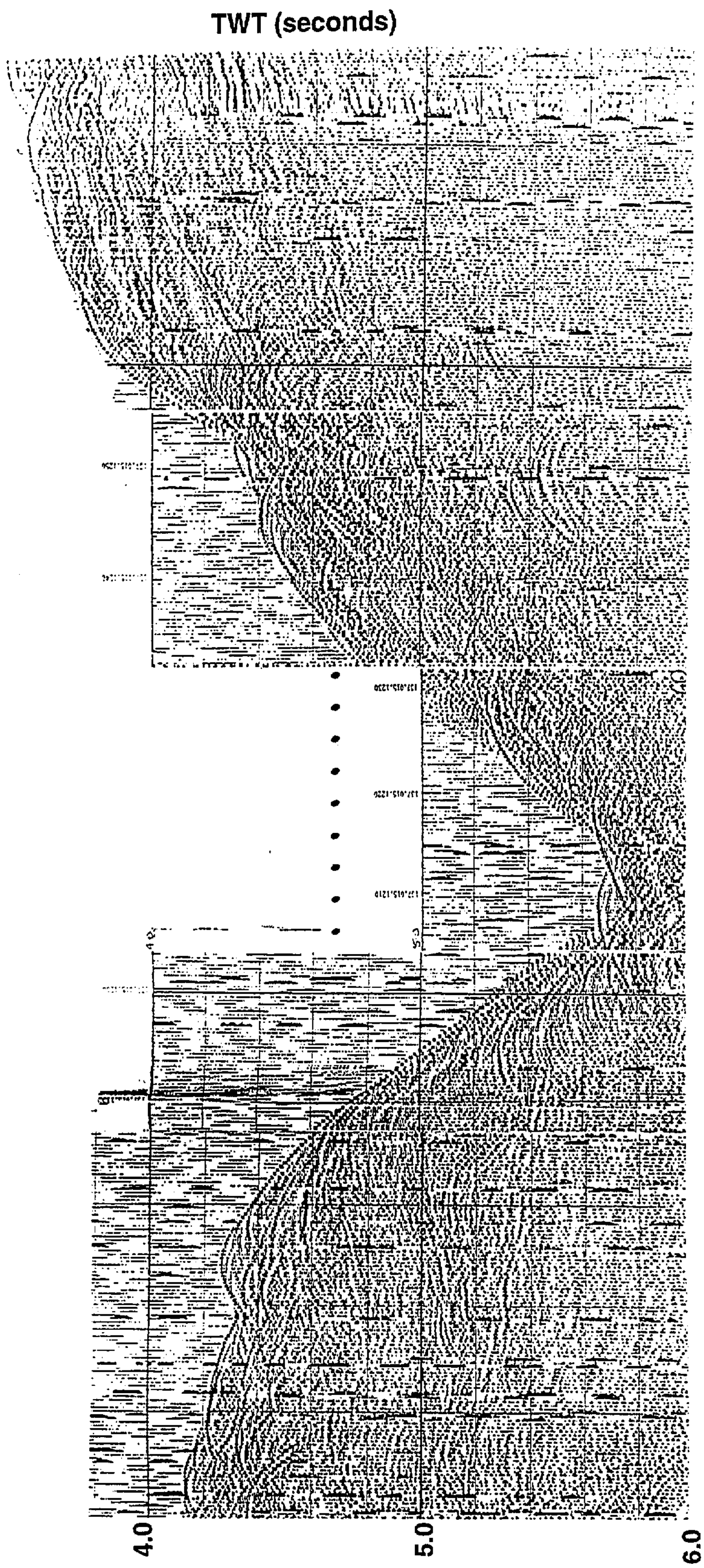

Figure 14: Seismic monitor record (line 137/101), showing a shelf-edge canyon cut to a depth of 2250 m below the surrounding shelf. The location and development of this canyon may be controlled by an underlying fault.

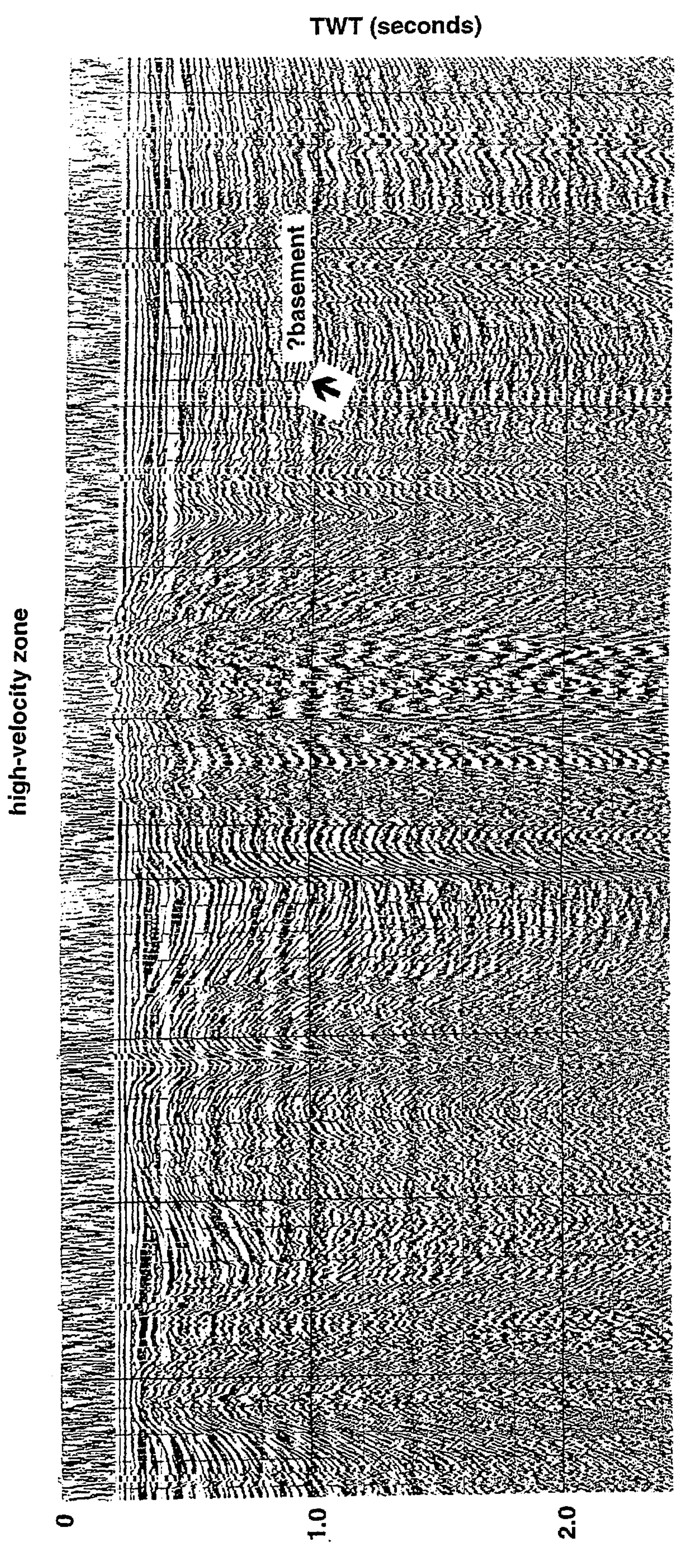

Figure 15: Seismic monitor record (line 137/501), showing the ?shallowing of possible basement horizon towards the eastern basin margin, along with several high-velocity zones.

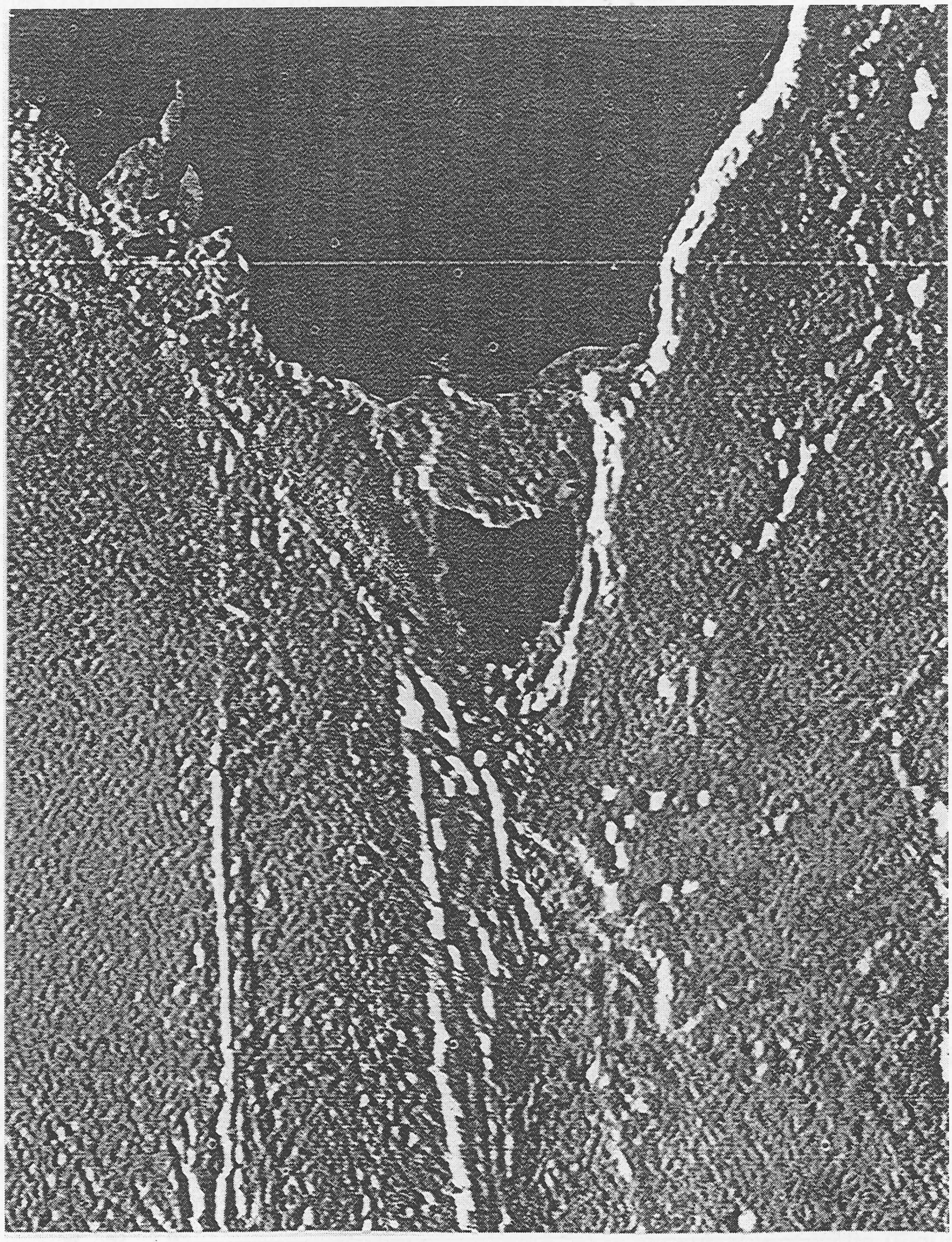

Figure 16: GEOSAT image of southeastern Australia showing the arcuate zone which is proposed to be the COB south of the Otway Basin. Also note the prominent N-NNE-trending fracture zones which appear to terminate at this boundary.

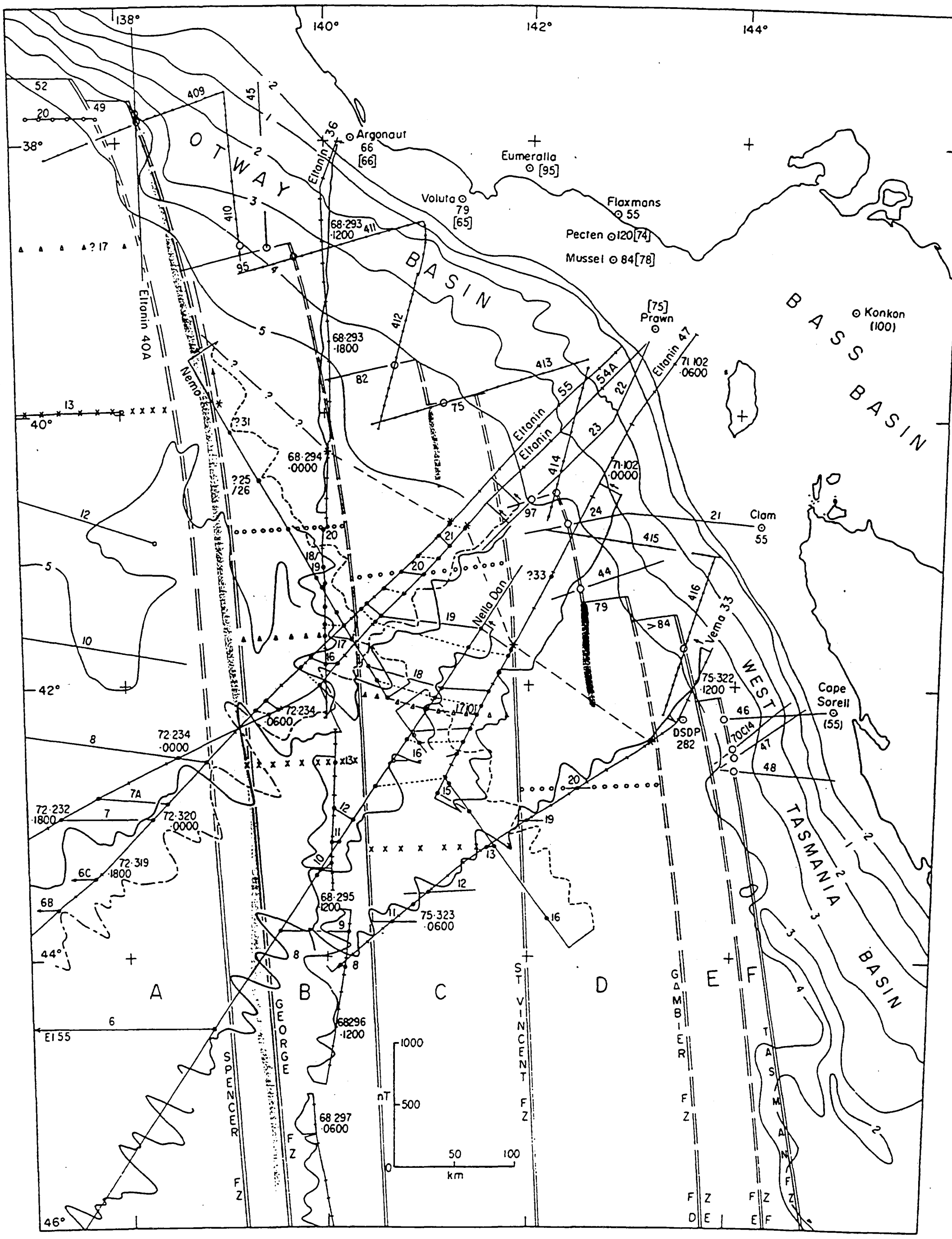

Figure 17: Map of the offshore Otway and Bass Basins showing the Shell *Petrel* seismic transects (400-series lines), magnetic profiles from the *Vema* and *Eltranin* surveys, and the interpreted positions of fracture zones (Veevers, 1988) which are delineated as A to F.

distances of between 40 to 100 km. In these instances, a precise COB is difficult to define, and has been picked for the purpose of this summary as a "point beyond which continental fault blocks are no longer clearly evident". On other transects such as lines 137/600, 137/700, 137/900 and 137/1100, the COB appears to be relatively distinct and well-defined. Variations in the apparent definition of the COB on the monitor records may simply be a function of the degree of obliquity at which the boundary is crossed. With the exception of lines 137/301 and 137/402, and 137/601 and 137/900, the spacing between seismic lines is too great to determine the true strike of the COB.

In the eastern survey area, lines 137/601 and 137/900 are semi-parallel transects positioned approximately 20 to 30 km apart, yet the COB has an apparent offset of around 70 kilometres (Figure 18). This offset may correspond to the eastern edge of the St. Vincent Fracture Zone (SVFZ) as defined by Veevers (1988), although the trend appears to be more northerly rather than northeasterly as proposed. The COB offset as interpreted from lines 137/402 and 137/700, may correlate to the George V Fracture Zone of Veevers (1988).

The complexity of the transition zone to the COB appears to be most evident on lines 137/201, 137/301, 137/402 and 137/801. On monitor records, the zone consists of masses of diffractions which are taken to be volcanic in nature, while more angular and seismically-transparent features are interpreted to be continental fault blocks. It must be noted again that preliminary observations discussed here are based on single-channel monitor records. The morphologic criteria used to differentiate these features will undoubtedly become more apparent on the processed seismic data, most likely as diffractions on stacked reflection data and possibly as discrete angular features on migrated data. Magnetics and seismic refraction data will be critical is differentiating these features on the processed dataset.

On line 137/402, a series of seaward-dipping, highly-rotated continental blocks appears to have been extended along low-angle, possibly sub-planar faults (Figure 19). Large extrusive mounds of volcanic material are also common, with the largest mound encountered on the survey having relief of some 700+ m above the sea floor. Three sequences can be defined within the sediments that are ponded between the fault blocks and volcanic mounds. The lowermost sequence comprises a basal infill

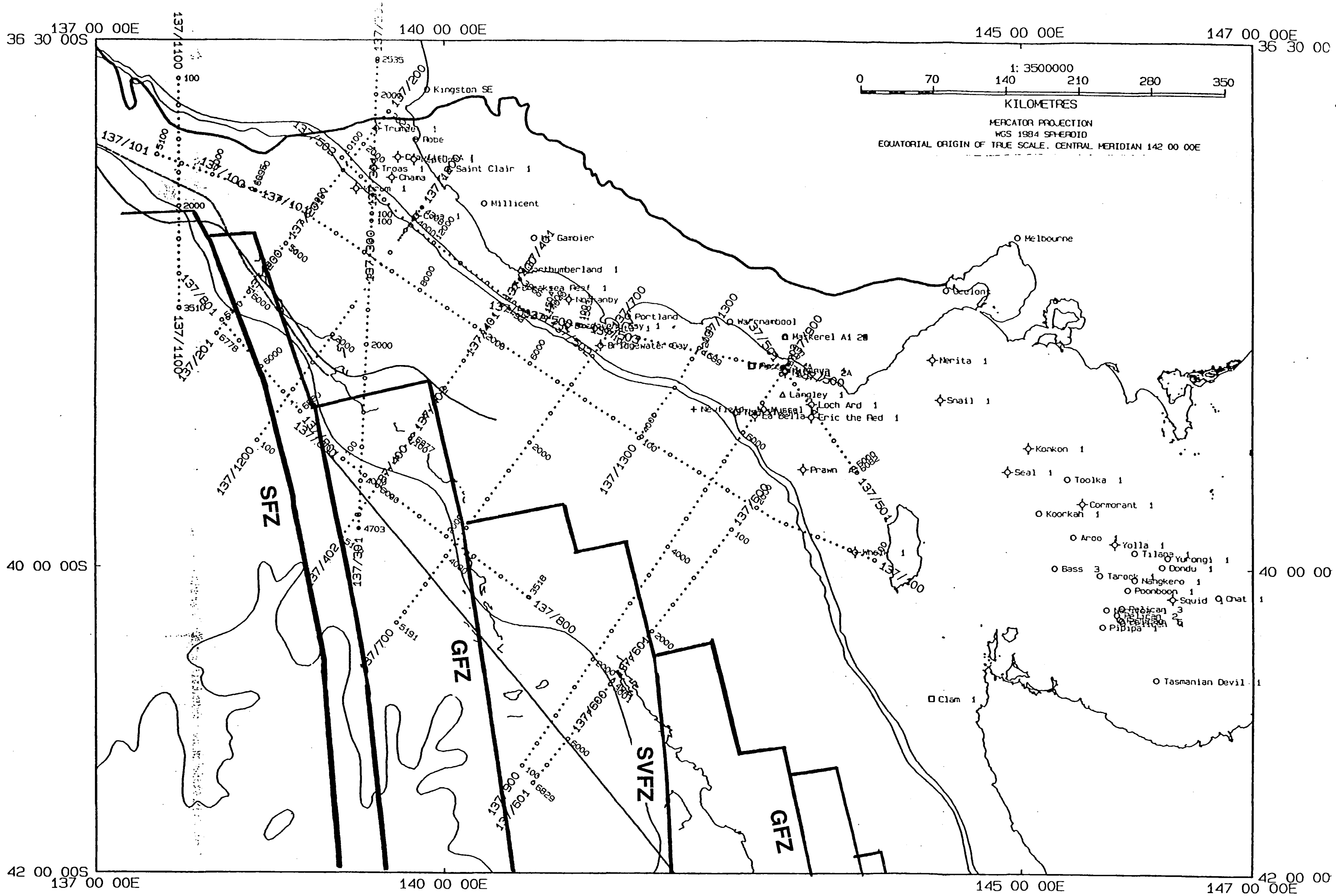

Figure 18: Map of Survey 137 seismic lines, the COB as defined from GEOSAT, and the location of fractures zones as proposed by Veevers (1988)

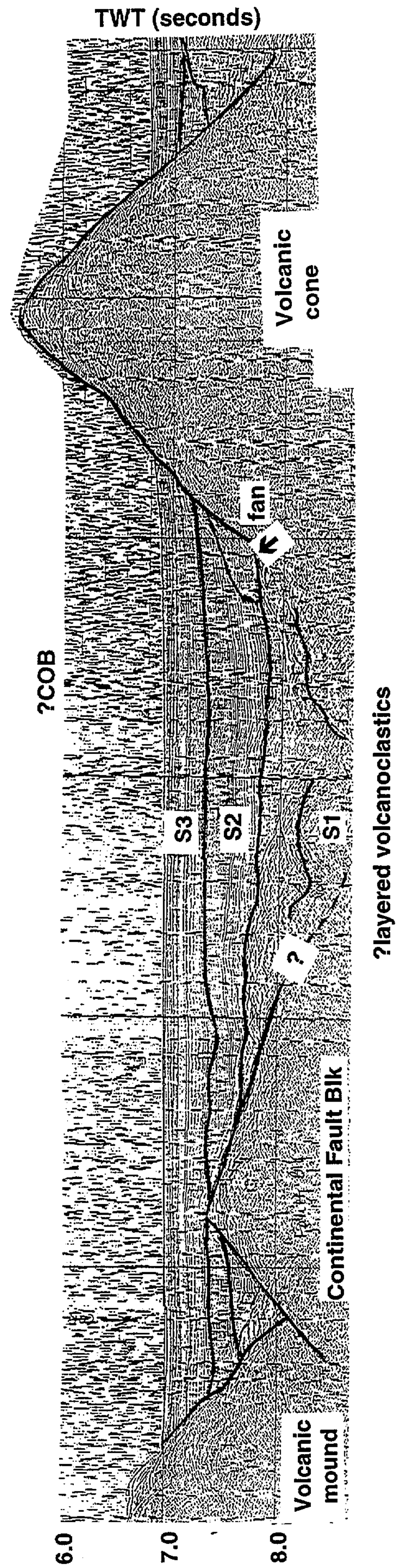

Figure 19: Seismic monitor record (line 137/402) showing interpreted continental fault blocks, volcanic mounds (cone), ponded sediments, and the proposed COB location.

section of interlayered sediment and possible volcanics (possibly flows). The overlying sequence appears to be a late infill phase of sedimentation which thickens into the main ponded areas and thins to onlap the surrounding structures. This sequence includes a series of possible fans which extend from the margins of the adjacent volcanic mound. An upper sequence of flat-lying unstructured sediment is interpreted to be latest Cretaceous to Cainozoic carbonates and/or pelagic ooze.

The occurrence of volcanics associated with the continental fault blocks suggests that the flows/mounds are localised along fault planes. The apparent complexity seen on monitor records of line 137/402 may suggest that this transect is aligned parallel to a possible transform fault, however only the integration of all geophysical and geological datasets will provide conclusive evidence.

The interpreted COB on transect 137/1100 was the only instance where the boundary coincided with the interpreted monitor section. In this instance, the COB lies only 50 km from the northern basin margin. The observed offset between the COB as defined on lines 137/1100 and 137/101 may coincide to the Spencer Fracture Zone as proposed by Veevers (1988). When the eastern edge of this fracture zone is projected in a northerly direction, it appears to align with the deep shelf margin canyon described earlier on line 137/101.

A preliminary plot of the COB as picked on the single channel data during Survey 137 suggests that COB is a WNW-to-NW trending boundary that is separated along NNE-to-NNW offsets (Figure 20). The final determination of this zone, along with the relationship between the COB, proposed fracture systems (Veevers, 1988) and the GEOSAT data will await processing of the deep seismic data.

ACKNOWLEDGEMENTS

The Masters, M. Gusterson (Phase 1), B. Hardinge (Phase 2), and the AMSA crew of the RV *Rig Seismic*, along with AGSO's ship managers K. Webber (Phase 1) and G. Cassim (Phase 2) and technical staff are thanked for their help and close cooperation during the execution of Survey 137. Their expert skills and demonstrated professionalism under often difficult circumstances made a vital contribution to the successful completion of the scientific program. The crew of the chase boat MV *Perfect Lady* and the representatives of various fishing cooperatives along the Victorian and South Australian coast are gratefully acknowledged for their flexibility and mobility during the coordination of this survey.

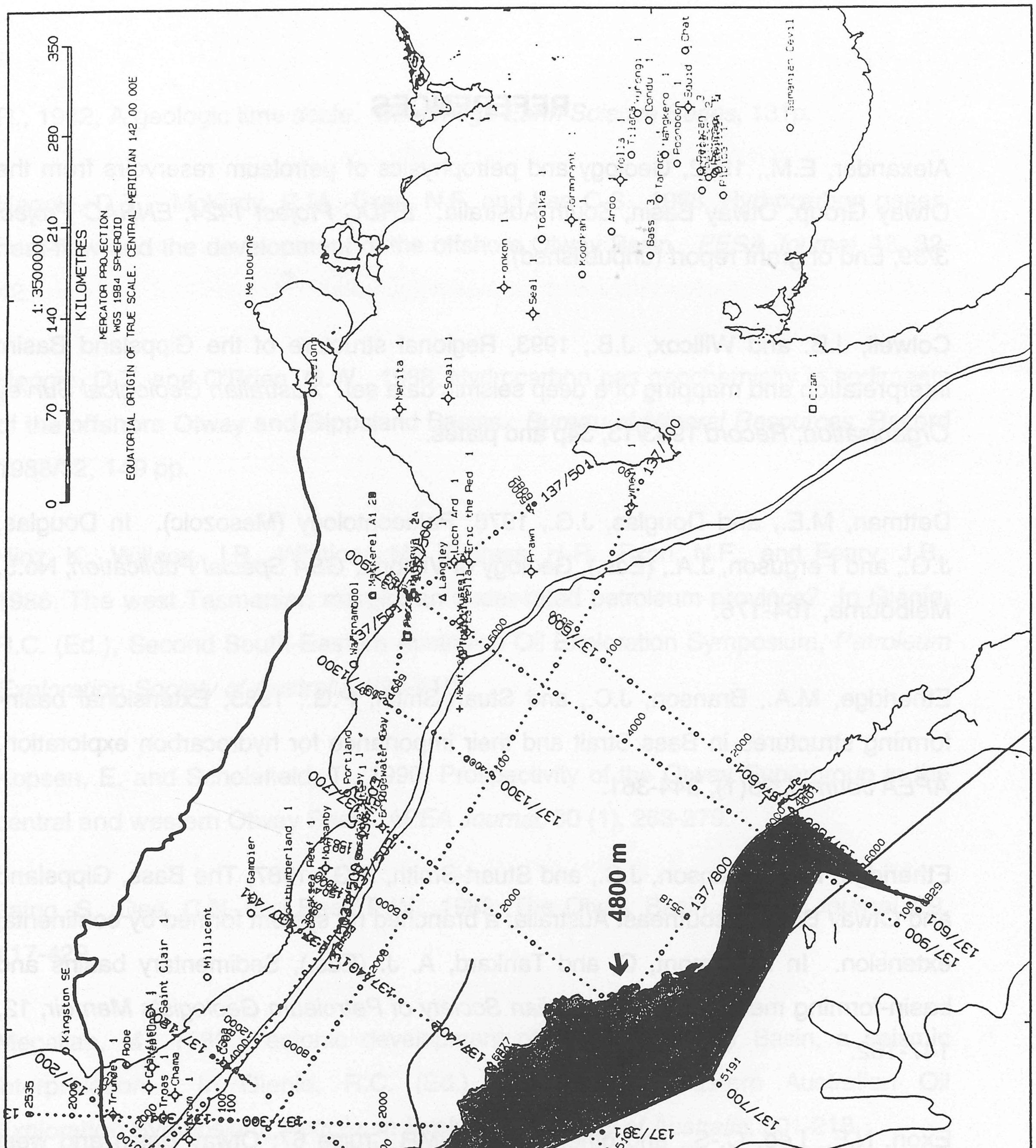

Figure 20: Preliminary plot of the COB as derived from single channel monitor records on-board the RV *Rig Seismic*. The area lying between the 4800 m bathymetric contour and the proposed COB approximates the location of the transition zone from continental-to-oceanic crust.

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APPENDIX 1: LISTING OF AGSO (BMR) AND NON-INDUSTRY SCIENTIFIC SURVEYS IN THE OFFSHORE OTWAY BASIN

Year	Organisation - Survey	Ship	Data Collected	Source and Recording
1971	Shell International Petroleum Mij. (Netherlands)	*Petrel*	seismic	airgun,48-channel 24 fold,digital
1982	BMR, Survey 40 (Australia)	*Lady Vilma*	reflection seismic (225 km)	airgun,96 channel, 24 and 48 fold, digital
1985	BMR, Survey 48 (Australia)	*Rig Seismic*	reflection seismic (1470 km), dredge samples	airgun, 48 channel, 21-24 fold, digital
1987	BMR, Survey 67 (Australia)	*Rig Seismic*	grab, core, dredge samples, heatflow	---
1994	AGSO Survey 125 (Australia)	*l'Atalante*	swath-mapping	---

APPENDIX 2: ORGANISATIONS CONSULTED DURING SURVEY PLANNING PHASE

During preparation of this cruise proposal, the following exploration companies and organisations were contacted to provide input.

- Ampol Exploration Ltd
- BHP Petroleum Pty Ltd
- Bridge Oil Ltd
- Cultus Petroleum Pty Ltd
- Gas And Fuel Resources
- Santos Ltd
- Sagasco Resources Pty Ltd
- Geological Survey Of Victoria
- South Australian Mines And Energy
- Victorian Institute of Earth and Planetary Sciences (VIEPS)

APPENDIX 3: RESEARCH VESSEL *RIG SEISMIC*

R.V. *Rig Seismic* is a seismic research vessel with dynamic positioning capability, chartered and equipped by AGSO to carry out the Continental Margins Program. The ship was built in Norway in 1982 and arrived in Australia to be fitted out for geoscientific research in October, 1984. It is registered in Newcastle, New South Wales, and is operated for AGSO by the Australian Maritime Safety Authority.

Gross Registered Tonnage:		1545 tonnes
Length, overall:		72.5 metres
Breadth:		13.8 metres
Draft:		6.0 metres
Engines:	Main: Norma KVMB-12	2640 H.P./825 r.p.m.
	Aux: 3 x Caterpillar	564 H.P./ 482 KVA
	1 x Mercedes	78 H.P./56 KVA
	Shaft generator:	AVK 1000 KVA, 440 V/60 Hz
	Side thrusters:	2 forward, 1 aft, each 600 H.P.
Helicopter deck:		20 metres diameter
Accommodation:		39 single cabins and hospital

APPENDIX 4: SCIENTIFIC EQUIPMENT USED DURING SURVEY 137, PHASES 1 AND 2

- FJORD Instruments seismic receiving array: 25 m group length, 192 channels, 4800 m active streamer length.
- Syntron RCL-3 cable levellers; individual remote control and depth readout.
- Haliburton Geophysical Service 32 x 150 cubic inch airguns in two 16-gun arrays; normal operating array is 2 x 10 guns, giving a total of 3000 cubic inches normal operating array volume.
- Air compressor system: 6 x A-300 Price compressors, each providing 300 scfm at 2000 psi (62 litres/min at 14 Mpa)
- Digital seismic acquisition system designed and built by AGSO; 16-bit floating point, SEG-Y output on cartridge tape.
- Raytheon echo-sounders: 3.5 KHz (2 kW) 16-transducer sub-bottom profiler, and 12 KHz (2 kW) precision echo-sounder.
- Geometrics G801/803 magnetometer/gradiometer.
- Bodenseewerk Geosystem KSS-31 marine gravity meter (inoperable during Phase 1 of Survey 137).

NAVIGATION EQUIPMENT

- Primary Navigation: Racal Multifix Version 1.3 Differential GPS system, reference stations used: Melbourne, Adelaide, and Sydney.
- Secondary Navigation: Racal 2 Multifix Version 2.0 Differential GPS system, reference stations used: Melbourne, Adelaide, and Sydney.
- Tertiary Navigation: Magnavox MX 610D / Sperry Mk 37 Gyrocompass.
- Additional equipment: Raytheon DSN 450 dual axis doppler sonar, Magnavox MX 100 GPS.

APPENDIX 5A: SHIPBOARD PARTY - SURVEY 137, PHASE 1

AGSO REPRESENTATIVES

K. Webber	Ship Manager
J. Blevin	Client Representative
M. Alcock	Quality Control Scientist (26 Nov to 14 Dec)
H. Miller	Quality Control Scientist (14 Dec to 22 Dec)
T. Hunter	Science Technical Officer
T. McNamara	Science Technical Officer
J. Ryan	Science Technical Officer
H. Reynolds	Science Technical Officer
S. Ridgway	Science Technical Officer
M. Timms	Electronics Technical Officer
C. Saroch	Electronics Technical Officer
M. James	Mechanical Technical Officer
B. Dickinson	Mechanical Technical Officer
A. Radley	Mechanical Technical Officer
S. Milnes	Mechanical Technical Officer
A. Hinds	Mechanical Technical Officer

AMSA Crew

M. Gusterson	Master
J. Weeks	1st Mate
D. Watson	2nd Mate
P. Pitiglio	Chief Engineer
J. Scott	1st Engineer
I. McCulloch	Electrician
M. Stapleton	Integrated Ratings
J. Frazer	Integrated Ratings
T. Dale	Integrated Ratings
M. Hagner	Integrated Ratings
K. Beu	Chief Cook
T. Strange	Cook
S. Staveley	Catering Attendent
B. Goerner	Catering Attendent

APPENDIX 5B: SHIPBOARD PARTY - SURVEY 137, PHASE 2

AGSO REPRESENTATIVES

G. Cassim	Ship Manager
M. Fellows	Client Representative
D. Maidment	Observer/Client Representative
M. de Deuge	Quality Control Scientist
J. Bedford	Science Technical Officer
T. McNamara	Science Technical Officer
S. Laidlaw	Science Technical Officer
P. Hyde	Science Technical Officer
F. Stradwick	Science Technical Officer
J. Reid	Science Technical Officer
G. Atkinson	Science Technical Officer
C. Saroch	Electronics Technical Officer
N. Ford	Electronics Technical Officer
S. Wiggins	Mechanical Technical Officer
A. Hislop	Mechanical Technical Officer
A. Hogan	Mechanical Technical Officer
G. Burns	Mechanical Technical Officer
S. Rucinski	Mechanical Technical Officer

AMSA Crew

B. Hardinge	Master
R. Thomas	Chief Engineer
D. Orgill	1st Mate
P. Robinson	2nd Mate
R. Heaton	1st Engineer
B. Dickman	Electrician
B. Noble	Integrated Ratings
D. Kane	Integrated Ratings
J. Sabatino	Integrated Ratings
P. Hutchinson	Integrated Ratings
G. Conley	Chief Cook
A. King	Cook
A. Clark	Catering Attendent
C. Blackman	Catering Attendent

APPENDIX 6: SEISMIC ACQUISITION PARAMETERS, SURVEY 137

Seismic Cable Configuration

Standard	length	4800 m
	group length	25 m
	no. channels	192

Seismic Source

sleeve gun capacity	50 litres (3000 cu in)
airgun pressure	1800 psi (normal)
	1600 psi (minimum)
shot interval	50 m
shot rate	19.4 s @ 5 knots
	21.6 s @ 4.5 knots

Recording Parameters

Fold	4800%
Record length	16 s
Sample interval	2 ms

APPENDIX 7: SEISMIC ACQUISITION GEOMETRY, SURVEY 137, PHASES 1 AND 2

The following diagram are extracts from an AGSO Survey 137 Operations Report.

A.	Recording Geometry:	line sequence 001 (Line 137/100)
B.	Recording Geometry:	line sequences 002 to 021 (Phase 1)
C.	Recording Geometry:	line sequences 022 to 023 (Phase 2)
D.	Streamer Geometry:	line sequences 001 to 023 (Phases 1 and 2)
E.	Source Geometry:	line sequences 001 to 023 (Phases 1 and 2)

AGSO

AGSO Marine

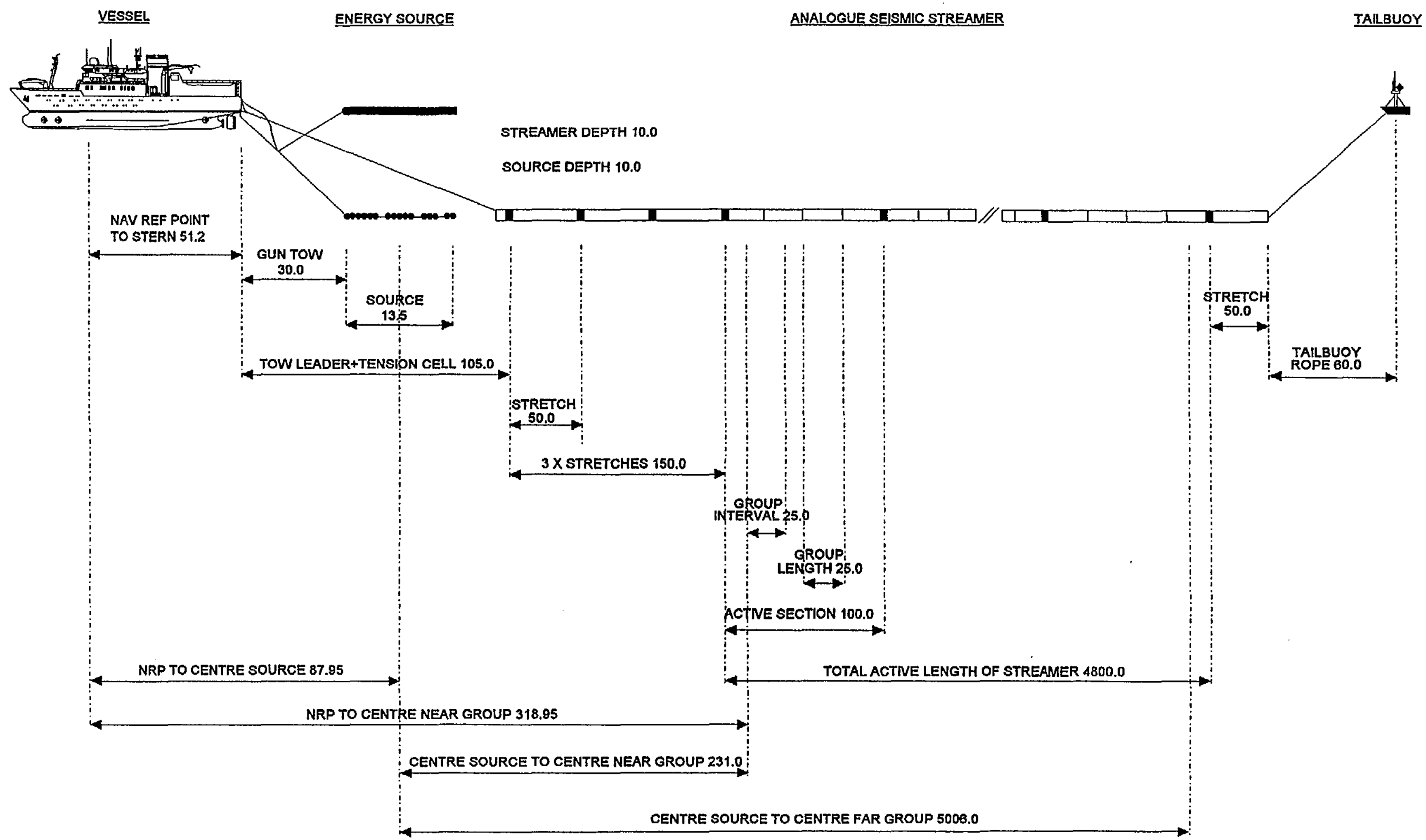
R/V Rig Seismic

Recording Geometry

Drawing valid for line sequence 001

Cruise 137

Otway Basin



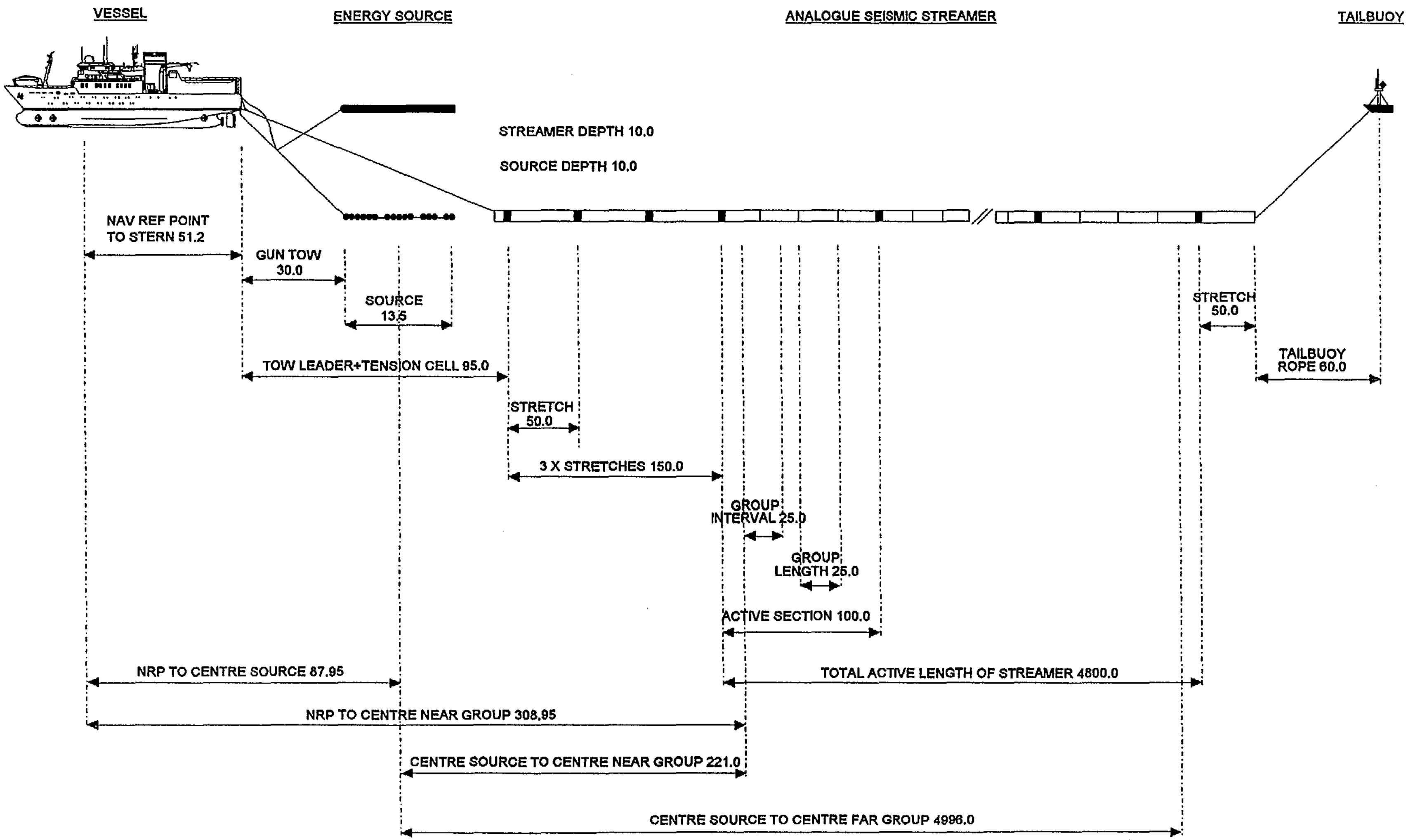
AGSO

AGSO Marine
R/V Rig Seismic

Recording Geometry

Drawing valid for line sequences 002 - 021

Cruise 137
Otway Basin

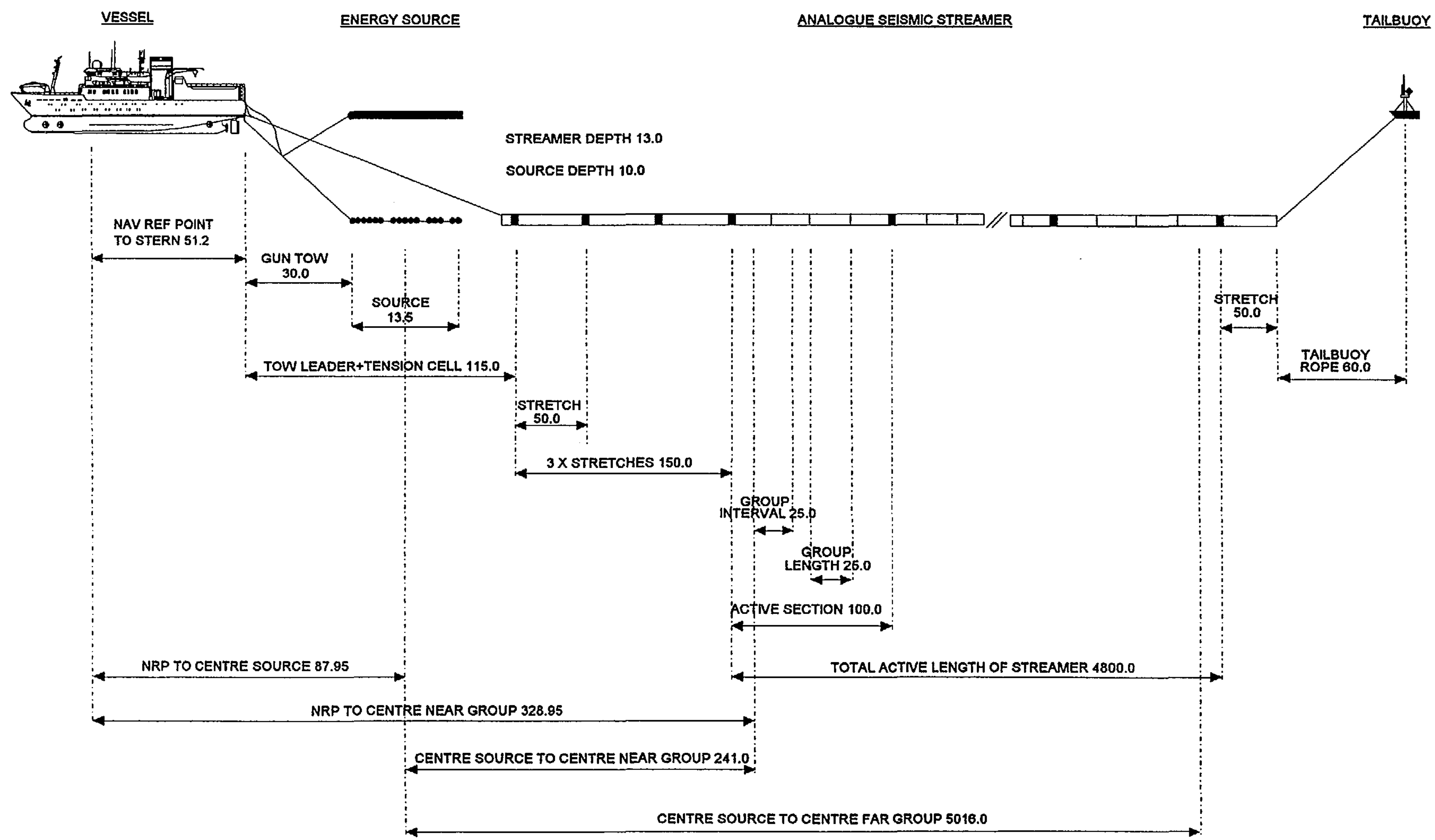


AGSO Marine
R/V Rig Seismic

Recording Geometry

Drawing valid for line sequences 022 - 023

Cruise 137
Otway Basin



AGSO
AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

AGSO Marine
R/V Rig Seismic

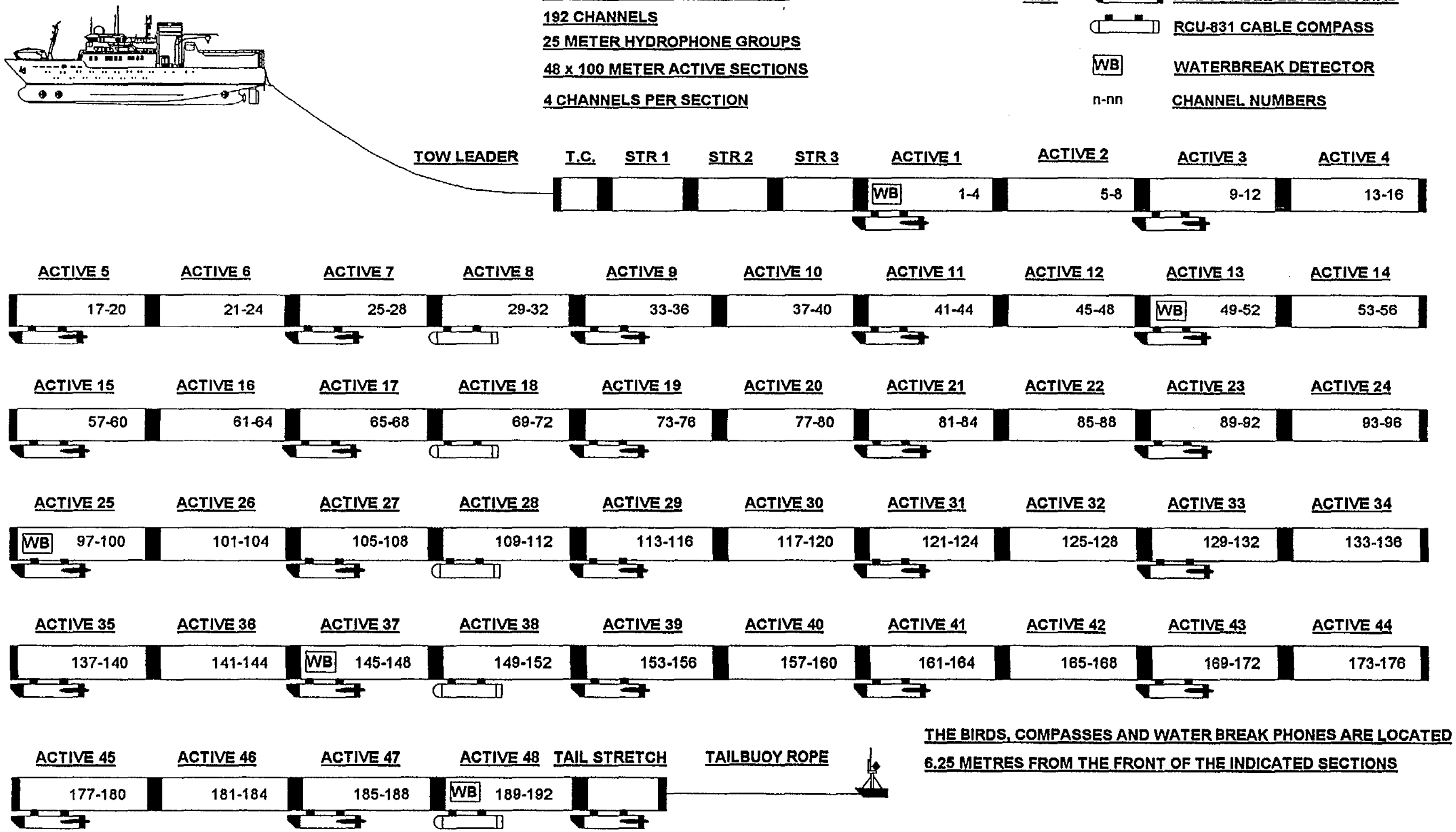
Streamer Geometry

Drawing valid for line sequences 001 - 023

Cruise 137
Otway Basin

4800 METER ACTIVE STREAMER
192 CHANNELS
25 METER HYDROPHONE GROUPS
48 x 100 METER ACTIVE SECTIONS
4 CHANNELS PER SECTION

KEY:
RCL-3 CABLE LEVELLER BIRD
RCU-831 CABLE COMPASS
WB WATERBREAK DETECTOR
n-nn CHANNEL NUMBERS



THE BIRDS, COMPASSES AND WATER BREAK PHONES ARE LOCATED 6.25 METRES FROM THE FRONT OF THE INDICATED SECTIONS

AGSO

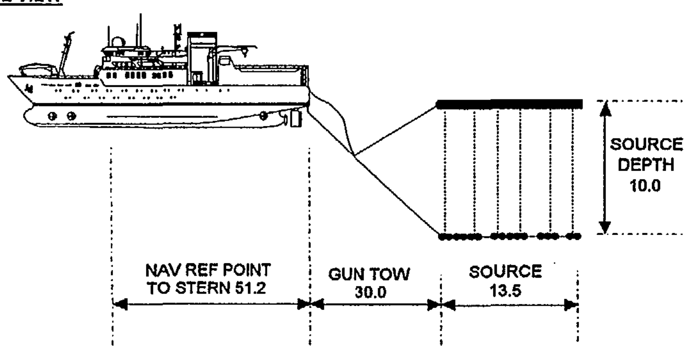
AGSO Marine
R/V Rig Seismic

Source Geometry

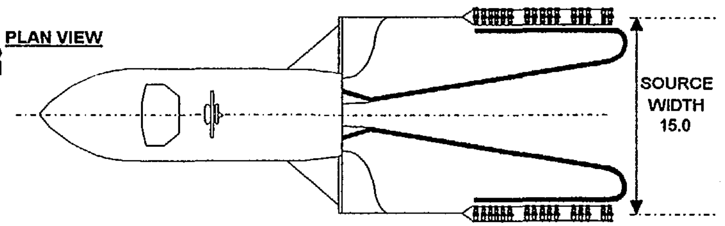
Drawing valid for line sequences 001 - 023

Cruise 137
Otway Basin

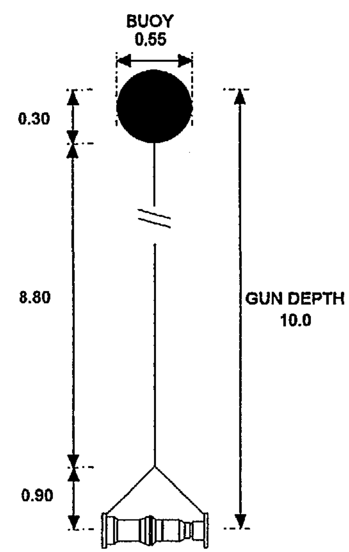
SIDE VIEW



PLAN VIEW



FRONTAL VIEW



ENERGY SOURCE ARRAY DETAILS

3000 CUBIC INCH SLEEVE GUN SOURCE ARRAY

2 SUB-ARRAYS

32 GUNS IN TOTAL

16 GUNS PER SUB-ARRAY (10 ACTIVE - 6 SPARE)

150 CUBIC INCHES PER GUN AT NOMINAL 1800 PSI

4 HYDROPHONES AND 4 DEPTH TRANSDUCERS PER SUB-ARRAY

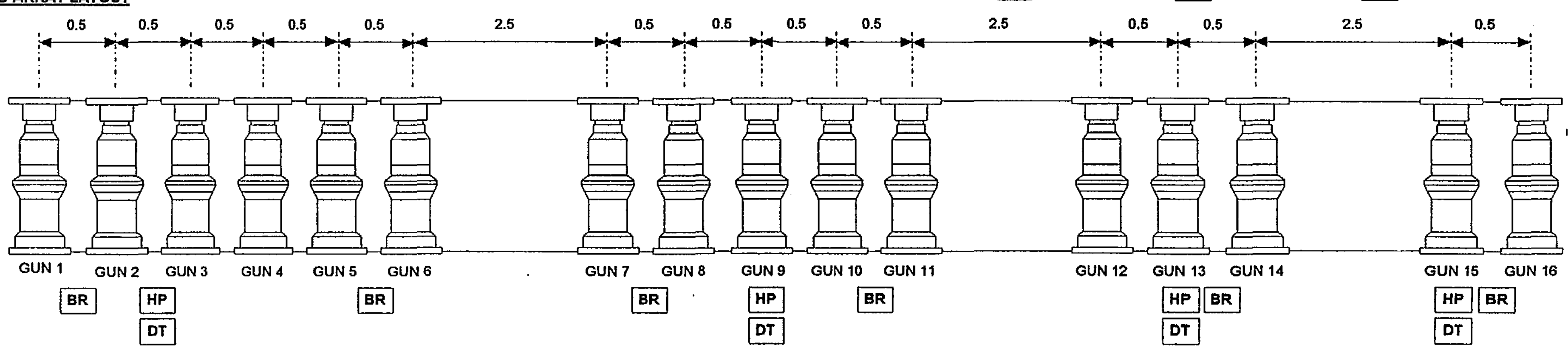
ALL SUB-ARRAY GUNS ARE SUSPENDED FROM ONE SAUSAGE BUOY

GUNS ARE HUNG IN THE WATER HORIZONTALLY

KEY

BR BUOY ROPE HP HYDROPHONE DT DEPTH TRANSDUCER

SUB-ARRAY LAYOUT

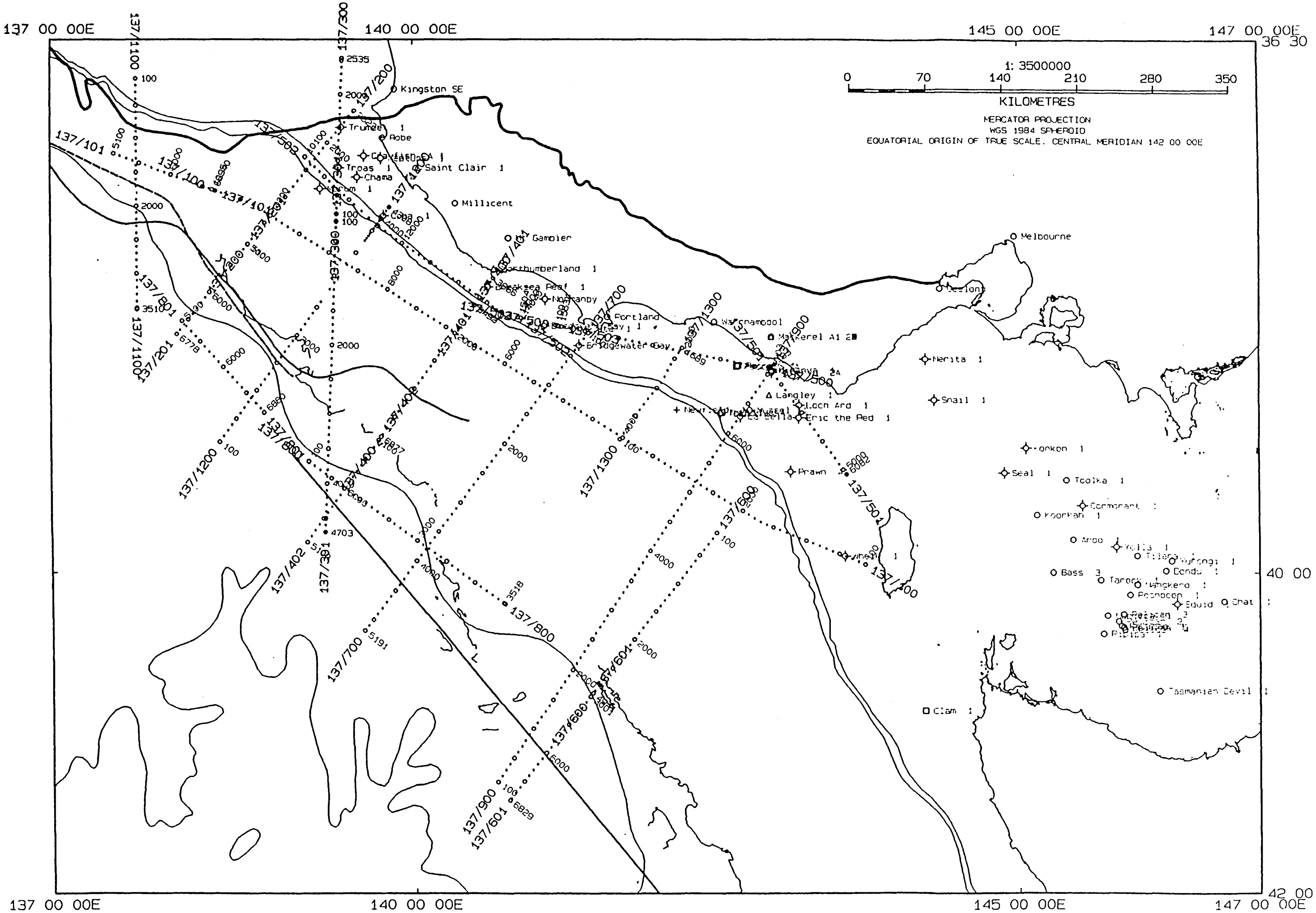


APPENDIX 8A: WAYPOINTS USED FOR SURVEY 137, PHASES 1 AND 2

Line No.	Survey Phase	Pre-Survey Reference	Line Positions	Latitude deg/min S	Longitude deg/min E
137/100	1	A	SOL	39 57.057	143 43.676
	1	A	EOL	37 30.468	138 20.873
137/101	2	A	SOL	36 16.266	137 31.683
	2	A	EOL	37 30.935	138 22.496
137/200	1	D	SOL	37 52.474	138 38.289
	1	D	EOL	36 58.919	138 31.233
137/201	2	D	SOL	37 52.358	138 38.401
	2	D	EOL	38 27.913	138 02.728
137/300	1	E	SOL	37 43.450	139 22.359
	1	E	EOL	36 37.684	139 25.355
137/301	1	E	SOL	37 40.452	139 22.515
	1	E	EOL	39 44.744	139 16.081
137/400	1	H	SOL	39 09.316	139 42.811
	1	H	EOL	38 16.535	140 30.450
137/401	1	H	SOL	38 17.859	140 29.261
	1	H	EOL	38 06.036	140 39.748
137/402	1	H	SOL	39 48.534	139 07.004
	1	H	EOL	39 07.989	139 44.011
137/500	1	Q	SOL	38 24.606	141 11.478
	1	Q	EOL	38 42.336	142 59.333
137/501	1	Q	SOL	38 40.837	142 56.004
	1	Q	EOL	38 22.317	142 34.694
137/502	2	Q	SOL	37 17.751	139 06.999
	2	Q	EOL	38 21.457	140 53.307
137/503	2	Q	SOL	38 21.391	140 53.356
	2	Q	EOL	38 24.929	141 13.209
37/600	1	N	SOL	39 45.002	142 29.970
	1	N	EOL	40 46.580	141 26.673
137/700	1	J	SOL	38 27.473	141 26.600
	1	J	EOL	40 22.306	139 35.917
137/800	1	X	SOL	39 17.501	139 07.999
	1	X	EOL	40 12.013	140 44.574
137/801	2	X	SOL	38 22.718	138 05.316
	2	X	EOL	38 58.813	138 45.883

Line No.	Survey Phase	Pre-Survey Reference	Line Positions	Latitude deg/min S	Longitude deg/min E
137/900	1	M	SOL	41 18.647	140 40.579
	1	M	EOL	38 39.837	142 59.049
137/1100	2	B	SOL	36 45.778	137 42.782
	2	B	EOL	38 17.944	137 43.135
137/1200	2	F	SOL	39 10.003	138 24.006
	2	F	EOL	37 37.764	139 48.544
137/1300	2	K	SOL	39 08.800	141 42.201
	2	K	EOL	38 33.353	142 13.197

APPENDIX 8B: LOCATION MAP OF SEISMIC TRANSECTS, SURVEY 137, PHASES 1 AND 2



APPENDIX 8C: PRE-SURVEY WAYPOINTS (Appendix I of O'Brien et al., 1994)

Line	WP	Comments	Latitude DDMMSS	Longitude DDMMSS	Name
A1	1	SOL	385640.4S	1411912.9E	
A1	2	DOGLEG	373542.8S	1383943.2E	
A1	3	EOL	371058.3S	1371322.7E	
A2	1	SOL	385640.0S	1411913.0E	
A2	2	DOGLEG	394117.7S	1425305.6E	
A2	3	WHELK-1	395352.5S	1433325.8E	
A2	4	EOL	395752.7S	1434726.2E	
B	1	SOL	364546.7S	1374247.2E	
B	2	EOL	380640.1S	1374305.6E	
C	1	SOL	364546.2S	1383013.9E	
C	2	DOGLEG	373956.7S	1382951.6E	
C	3	EOL	381700.7S	1375158.0E	
D	1	SOL	365305.8S	1393645.8E	
D	2	TRUMPET-1	370542.1S	1392447.3E	
D	3	EOL	382648.9S	1380350.1E	
E	1	SOL	363904.5S	1392519.3E	
E	2	TRUMPET-1	370542.1S	1392447.3E	
E	3	TROAS-1	372156.5S	1392327.2E	
E	4	EOL	394200.0S	1391613.9E	
F	1	SOL	373236.5S	1395308.3E	
F	2	COPA-1	374113.0S	1394527.0E	
F	3	EOL	391000.0S	1382400.0E	
G	1	SOL	364742.5S	1390426.3E	
G	2	TRUMPET-1	370542.1S	1392447.3E	
G	3	CRAYFISH A-1	371717.0S	1393555.0E	
G	4	COPA-1	374113.0S	1394527.0E	
G	5	DOGLEG	381500.0S	1403000.0E	
G	6	BRIDGEWATER BAY-1	383220.7S	1412152.8E	
G	7	MUSSEL-1	385746.0S	1424621.7E	
G	8	EOL	391133.3S	1433435.9E	
H	1	SOL	380613.8S	1403935.0E	
H	2	BREAKSEA REEF-1	380925.7S	1403649.3E	
H	3	EOL	394200.0S	1391300.0E	
I	1	SOL	381450.6S	1411310.6E	
I	2	DISCOVERY BAY-1	382437.6S	1410426.0E	

I	3	EOL	394620.2S	1395046.3E
J	1	SOL	382548.0S	1412813.2E
J	2	BRIDGEWATER BAY-1	383220.7S	1412152.8E
J	3	EOL	401300.0S	1394500.0E
K	1	SOL	382630.7S	1421216.6E
K	2	EOL	404403.3S	1401859.3E
L	1	SOL	383601.1S	1424346.6E
L	2	PECTEN-1A	384041.0S	1423956.0E
L	3	EOL	405712.0S	1404227.8E
M	1	SOL	383949.8S	1425903.6E
M	2	MINERVA-1	384206.9S	1425717.3E
M	3	LA BELLA-1	390008.9S	1424147.9E
M	4	EOL	411200.0E	1404630.0E
N	1	SOL	382301.7S	1443513.8E
N	2	NERITA-1	383737.8S	1441349.6E
N	3	PRAWN A-1	392119.4S	1430646.8E
N	4	DOGLEG	394500.0S	1422958.0E
N	5	EOL	411800.0S	1405400.0E
O	1	SOL	394803.4S	1455324.0E
O	2	YOLLA-1	395013.5S	1454825.3E
O	3	EOL	412543.2S	1415409.3E
P	1	SOL	383122.7S	1440435.8E
P	2	NERITA-1	383737.8S	1441349.6E
P	3	KONKON-1	391214.2S	1450344.5E
P	4	CORMORANT-1	393417.4S	1453140.4E
P	5	YOLLA-1	395013.5S	1454825.3E
P	6	SQUID-1	401148.1S	1461832.3E
P	7	EOL	401530.0S	1462330.0E
Q	1	SOL	382502.8S	1411428.8E
Q	2	VOLUTA-1	382541.4S	1411852.4E
Q	3	PECTEN-1	384019.0S	1424042.0E
Q	4	MINERVA-1	384206.9S	1425717.3E
Q	5	LOCH ARD-1	385549.4S	1431100.1E
Q	6	EOL	392110.9S	1433340.3E
R	1	SOL	370945.1S	1373647.6E
R	2	EOL	410831.4S	1425229.6E

APPENDIX 9: EXPLORATION WELLS TIED BY SURVEY 137

Line No.	Well	Operator	Year	Total Depth	Status
137/500	Pecten-1A	Shell Development	1967	2850 m	minor gas
137/501	Loch Ard-1	BHP Petroleum	1993	1397 m	minor gas
137/500 137/900	Minerva-1	BHP Petroleum	1993	2425 m	gas discovery
137/100	Whelk-1	Esso Expl. & Prod.	1970	1420 m	dry
137/300	Troas-1	BHP Petroleum	1993	1430 m	gas and minor condensate
137/200 137/300	Trumpet-1	Esso Expl. & Prod.	1973	2245 m	dry
137/400	Breaksea Reef-1	Ultramar Aust. Ltd.	1984	4468 m	minor gas
137/500	Voluta-1	Shell Dev (Aust.) P/L	1968	3974 m	minor gas
137/700	Bridgewater Bay-1	Phillips Australia	1983	4200 m	minor gas
137/900	La Bella-1	BHP Petroleum	1993	2735 m	dry

APPENDIX 10: SURVEY 137 SEISMIC LINE SUMMARY, PHASES 1 AND 2

Line No.	Pre-Survey Ref	Date (SOL)	Start Time	End Time	Start		Stop		FSP	LSP	Length (km)
			Julian dddhhmm	Julian dddhhmm	Latitude deg/minS	Longitude deg/minE	Latitude deg/minS	Longitude deg/minE			
137/100	A	30-11-94	334:1033	336:1828	39 57.057	143 43.676	37 30.468	138 20.873	100	10940	542.05
137/101	A	15-1-95	015:0946	015:1831	36 16.266	137 31.683	37 30.935	138 22.496	5100	6695	79.80
137/200	D	3-12-94	337:1223	338:0023	37 52.474	138 38.289	36 58.919	139 31.233	100	2623	126.20
137/201	D	16-1-95	016:0012	016:0900	37 52.358	138 38.401	38 27.913	138 02.728	5100	6778	83.95
137/300	E	5-12-94	338:1811	339:0645	37 43.450	139 22.359	36 37.684	139 25.355	100	2535	121.80
137/301	E	6-12-94	339:1942	340:1922	37 40.452	139 22.515	39 44.744	139 16.081	100	4703	230.20
137/400	H	9-12-94	342:2226	343:1103	39 09.316	139 42.811	38 16.535	140 30.450	100	2492	119.65
137/401	H	10-12-94	343:1924	343:2228	38 17.859	140 29.261	38 06.036	140 39.748	3432	3966	23.70
137/402	H	16-12-94	350:0551	350:1641	39 48.534	139 07.004	39 07.989	139 44.011	5100	6938	88.90
137/500	Q	10-12-94	344:0609	344:2249	38 24.606	141 11.478	38 42.336	142 59.333	100	3303	160.20
137/501	Q	11-12-94	345:0130	345:1113	38 40.837	142 56.004	39 22.317	143 34.694	4183	6082	92.00
137/502	Q	19-1-95	019:0238	020:0330	37 17.751	139 06.999	38 21.457	140 53.307	10100	14040	197.05
137/503	Q	21-1-95	021:0516	021:0917	38 21.391	140 53.356	38 24.929	141 13.209	15041	15634	29.70
137/600	N	12-12-94	346:0744	346:2321	39 45.002	142 29.970	40 46.580	141 26.673	100	3001	145.10
137/601	N	18-12-94	352:0529	352:1606	40 45.306	141 27.995	41 25.374	140 46.282	4941	6829	91.40
137/700	J	14-12-94	348:0744	349:1415	38 27.473	141 26.600	40 22.306	139 35.917	100	5406	263.90
137/800	X	17-12-94	351:0045	351:1922	39 17.501	139 07.999	40 12.013	140 44.574	100	3518	170.95
137/801	X	16-1-95	016:1316	016:2315	38 22.718	138 05.316	38 58.813	138 45.883	5100	6880	89.05
137/900	M	19-12-94	352:1839	354:0748	41 18.647	140 40.579	38 39.837	142 59.049	100	7177	353.90
137/1100	B	14-1-95	014:0114	014:1930	36 45.778	137 42.782	38 17.944	137 43.135	100	3510	170.55
137/1200	F	17-1-95	017:0540	018:0434	39 10.003	138 24.006	37 37.764	139 48.544	100	4308	210.45
137/1300	K	21-1-95	021:2055	021:0540	39 08.800	141 42.201	38 33.353	142 13.197	100	1689	79.50

APPENDIX 11: SEISMIC TAPE LISTING, PHASES 1 AND 2

Line No.	Survey Phase	FSP	FCSP	LSP	LCSP	First Tape	Last Tape
137/100	1	100	100	10940	10940	137/001	137/168
137/101	2	5100	5100	6695	6695	137/918	137/943
137/200	1	100	100	2623	2623	137/169	137/208
137/201	2	5100	5100	6778	6778	137/944	137/970
137/300	1	100	100	2535	2535	137/209	137/246
137/301	1	100	100	4703	4703	137/247	137/318
137/400	1	100	100	2492	2492	137/319	137/356
137/401	1	3432	3493	3966	3966	137/357	137/365
137/402	1	5100	5100	6938	6877	137/574	137/603
137/500	1	100	100	3303	3303	137/366	137/415
137/501	1	4183	4243	6082	6082	137/416	137/445
137/502	2	10100	10100	14407	14040	137/1066	137/1132
137/503	2	14980	15041	15634	15634	137/1133	137/1144
137/600	1	100	100	3001	3001	137/446	137/491
137/601	1	4941	5002	6829	6829	137/658	137/687
137/700	1	100	129	5406	5406	137/492	137/573
137/800	1	100	100	3518	3518	137/604	137/657
137/801	2	5100	5100	6880	6880	137/971	137/999
137/900	1	100	100	7177	7177	137/688	137/797
137/1100	2	100	100	3510	3510	137/864	137/917
137/1200	2	100	100	4308	4308	137/1000	137/1065
137/1300	2	100	100	1689	1689	137/1145	137/1170

FSP = First Shot Point FCSP = First Chargeable Shot Point
LSP = Last Shot Point LCSP = Late Chargeable Shot Point

Note: Line 137/1000 was a overshot of Line 137/200 using a 4 x 4 G.I. gun array. This line was acquired for technical purposes and is not included in this listing of survey tapes.

APPENDIX 12: PROCESSING PARAMETERS FOR SURVEY 137 SEISMIC DATA

- Resample to 4 ms
- Static correction for gun delay
- Gain correction
- F-K filter
- Wavelet processing - decon using Tanner's exponential method
- NMO velocity analysis every 4 km
- F-K demultiple
- Radon demultiple - Tau-Q rejection used to attenuate multiples
- DMO-NMO every 2 km
- Static correction for gun and cable depths
- Decon after stack
- Migration
- Bandpass filter
- Scaling
- Trace mix