Investigation of a Lower-Plate Continental Margin: A Proposal for Drilling in the Great Australian Bight Region by the Ocean Drilling Program

By H.M.J. Stagg & J.B. Willcox

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INVESTIGATION OF A LOWER-PLATE CONTINENTAL MARGIN:

A PROPOSAL FOR DRILLING IN THE GREAT AUSTRALIAN BIGHT REGION BY THE OCEAN DRILLING PROGRAM

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ABSTRACT

The southern margin of Australia, formed by the separation of Australia and Antarctica in the Cretaceous, has long been considered an example of a classic, non-volcanic, passive, rifted margin. In recent times it has been cited as an excellent example of a 'lower plate' margin in the terminology of detachment models of passive margin formation. As the margin has been relatively sediment-starved since breakup, and particularly in the Tertiary, it represents an excellent opportunity to test detachment models via reflection seismic data and drilling.

In this document, we propose that a total of seven holes be drilled by the Ocean Drilling Program in the central Great Australian Bight (GAB). Five of these holes are located close to the previously interpreted continent-ocean boundary (COB), which high-quality seismic data suggest may actually be a metamorphic core complex. The holes have the following basic aims:

1. Test the applicability of detachment tectonics to passive margin formation by drilling through a master detachment to extended lower continental crust;

2. Sample acoustic basement at several sites to characterise the tectonic and magmatic processes that have been influential at high rates of continental extension and/or during early and slow oceanic spreading.

In the event that the interpretation of a metamorphic core complex proves to be incorrect and oceanic crust is encountered, then two additional holes are proposed to:

1. Date the oldest sediments above oceanic crust in the South Australian Abyssal Plain, and hence constrain the currently ill-defined age of onset of spreading between Australia and Antarctica and refine the breakup history of eastern Gondwanaland.

2. Date and characterise the extensional listric faulting that is prominent in possible oceanic crust on the South Australian Abyssal Plain.

As the data on which these sites are proposed is sparse and, in some cases, old, the Australian Geological Survey Organisation (AGSO) proposes to carry out a deep-seismic program in the central GAB that will allow a refined interpretation and consequent up-grading or modification of the proposed sites in 1995/96.

INTRODUCTION

The theories describing the formation of passive continental margins can broadly be considered to have passed through two phases of development in the past quarter-of-a-century. The first phase, which commenced with the widespread acceptance of the principles of plate tectonics in the late 1960s and continued through until at least the late 1970s, was characterised by symmetrical models of uplift and faulting, but only relatively minor amounts of extension (e.g. Falvey, 1974). Extensive analogies were drawn with present-day rift systems (e.g. by Veevers, 1981), leading to models in which concepts such as 'rim basins' and 'extra-arch basins' were developed. The rifting process was considered to be initiated by upwelling of hot mantle which eventually broke through the continental crust, leading to the fragmentation of the continent. The limited availability and quality of reflection seismic data at the time did little to prove or disprove the concept of inherent structural symmetry across a conjugate rifted margin pair.

The second phase of passive margin formation theories commenced in the early 1980s with studies of detachment faulting in the Basin and Range province of the western United States which showed that brittle upper crustal rocks are separated from middle crustal rocks by shallow-dipping mylonite zones (Crittenden et al., 1980; Davis et al., 1980), and simultaneous observations that asymmetry is commonplace across passive margins and within major continental rifts (e.g. Bally, 1981, 1982; Bosworth, 1985). These two lines of study came together in the late 1980s with the development of detachment models to explain the formation of passive continental margins (Lister et al., 1986, 1991; Etheridge et al., 1990).

While detachment faulting is now probably the best-accepted mode of formation of passive margins, it should be noted that these models are based, firstly, on field observations in an extended continental terrane (the Basin and Range province), and secondly, on observations (sometimes tenuous) in reflection seismic data of variable quality. That is, there is relatively little ***direct*** evidence of the applicability of detachment models via sampling or drilling. The importance of verification of detachment models is reflected in the importance given to drilling proposals directed to this end in the Ocean Drilling Program.

The ODP Long Range Plan (ODP, 1990) proposed that ODP drilling should address four major themes, *viz.*:

1. Structure and composition of the crust and upper mantle;
2. Dynamics, kinematics, and deformation of the lithosphere;
3. Fluid circulation in the lithosphere; and
4. Cause and effect of oceanic and climatic variability.

Within these general themes, 15 specific objectives were identified. Objectives 6 and 7, relating to the second theme above, may be summarised from the Long Range Plan as:

Objective 6 - Plate Kinematics: A full understanding of long-term global change requires a knowledge of past plate configurations. Although global displacement histories are fairly well established for the past few tens of millions of years, they are poorly known prior to about 65 million years ago. It is necessary to resolve pre-Cainozoic plate kinematics and plate configurations if we are to place palaeoceanographic and palaeoclimatologic models into a reasonable global context. This resolution requires extensive seismic and magnetic data sets to assess the kinematics and drilling to provide dating.

Objective 7 - Deformation Processes at Divergent Margins: Models of the formation of passive margins can be broadly classified as those that are dependent on pure shear (inherently symmetric rifting) and those that are based on simple shear (inherently asymmetric rifting). Each model has important and different implications for the rheology of crustal rocks, the evolution of sedimentary basins, and the thermal history of the progressively thinned crust. Drilling, in conjunction with high-quality deep-seismic data is obligatory if the relative balance between the different models is to be achieved.

In this document, we tentatively propose a set of drill holes based on existing seismic and drill data that address aspects of both of these ODP objectives. In acknowledging that these sites are preliminary, the Australian Geological Survey Organisation (AGSO) is proposing to conduct further survey work on the southern margin that should allow the sites to be up-graded (Stagg & Willcox, 1995).

This work will be in three phases. While the first two phases are expected to proceed as part of AGSO's Continental Margins Program, the third phase is contingent upon this proposal receiving a sufficiently high ranking from the ODP thematic panels. The work proposed is:

Phase 1: A deep-seismic survey of the Great Australian Bight (GAB), comprising several margin transects and more detailed work in the central GAB, is currently scheduled to be carried out by the RV *Rig Seismic* in 1995; a summary of this work is included in Appendix 1. Since 1991, AGSO has had considerable success with the deep-seismic tool on Australia's North West Shelf, with the data regularly providing information on basin-forming structures down to 10-12 s TWT. Appendix 2 lists the characteristics of AGSO's deep-seismic recording system. As the southern margin of Australia is well-known as being amenable to the recording of high-quality seismic data, it is expected that the new deep data will be of a high standard and will allow the selection of ODP sites to be refined.

Phase 2: Transcribe a minimum of 2000 km of multichannel seismic reflection data recorded by the Shell research vessel *Petrel* in the Great Australian Bight in early 1973 and process selected lines to stack and migration. While these data are old, the quality is still considered to be excellent and they provide a rare MCS data set on the deep continental margin and abyssal plain.

Phase 3: As a follow-up to the deep-seismic work in 1995, detailed site surveys will be carried out, possibly in conjunction with site surveys required for ODP Proposal 367 (Feary et al., 1994; GAB cool-water carbonates). This work will again use the RV *Rig Seismic*, and will probably use the high-resolution Sodera GI gun-array source.

WHY DRILL AUSTRALIA'S SOUTHERN MARGIN?

The report of the Second Conference on Scientific Ocean Drilling (JOIDES & European Science Foundation, 1987, p 101) established seven basic guidelines for the evaluation of potential margin segments as sites for focused studies of passive margin processes. In brief these guidelines were as follows, with comments relating to the GAB shown in italics:

1. Conjugate margin segments must be accessible for both geophysical and drilling-related studies.
   The conjugate margin to the GAB, offshore Wilkes Land, is well-established and, while access to that margin is limited to the austral summer, a high-quality MCS data set (USA and France) does exist for that margin.

2. Margins must contain substantial thicknesses of pre-rift, syn-rift, and early post-rift sedimentary sequences in order to establish timing and deposition patterns along and across the margins.
   While the deep-water GAB is relatively sediment-starved in both the pre-rift and post-rift sections, the syn-rift and early post-rift sections are up to several kilometres thick and apparently quite complete.

3. Samples of deeper crystalline material (including crust-mantle interface and detachment faults) must be within drill depth capabilities.
   Samples of presumed crystalline material, probably from the lower crust beneath the primary detachment, are frequently within 1 s two-way time (TWT) of the sea-bed and outcrop in places. While the outcrops may be amenable to dredging (although they are of low relief and in water depths of at least 5000 m), dredging is not a practical alternative to drilling since, firstly, the samples are unlikely to be fresh and, secondly, dredge samples will only provide 'spot' samples whereas the drill can provide a continuous section.

4. Typical oceanic crust and a well-defined magnetic lineation pattern must exist adjacent to the margin.
   While there is doubt about the exact definition of the continent-ocean boundary (COB) in the GAB and about the dating of seafloor spreading magnetic lineations due to the early slow spreading between Australia and Antarctica, investigation of this problem by drilling is likely to lead to valuable new ideas and information on the rifting history of Eastern Gondwana.

5. Margins must have either a simple multiple-rift history or a single-rift history, without a complicated post-rift deformation history.
   The separation of Australia and Antarctica was accomplished either as a simple single rift (with the first stage of sea-floor spreading being at a low rate) as has generally been recounted, or perhaps as a dual-stage rift (?with re-rifting of highly-thinned continental crust or old oceanic crust). Post-rifting deformation appears to be almost absent, with the principal structuring at this time being mainly due to adjustments during the post-rift thermal subsidence phase.

6. Regions of moderately thick post-rift sedimentary sections (3-4 km) should be available within the same basin for establishing basin-wide biostratigraphic and palaeoceanographic records needed to provide age calibration and establish the influences of palaeoceanographic processes on the margin sedimentary record. There should be potential "standard-reference section" sites remote from major palaeoceanographic gateways and sites adjacent to those gateways.
   The post-rift section within parts of the GAB is up to several kilometres thick. On the flanks of the palaeo-rift, this section has already been penetrated in several oil industry wells, and the biostratigraphic and palaeoceanographic records are reasonably well-established. Should the existing record be judged inadequate, then there are ample potential sites for further drilling to this end.

7. Margin segments where data are available from either the petroleum industry or past DSDP/ODP exploration should be incorporated where possible. ODP should build on such previous studies, rather than be used as a reconnaissance tool.
   The GAB has been extensively explored by the oil industry down to water depths of about 2000 m, using the MCS technique, and a number of exploration holes have been drilled. A modern high-quality MCS data set was acquired in 1986 by the Australian Bureau of Mineral Resources (BMR; now the Australian Geological Survey Organisation, AGSO). These data sets have been extensively interpreted and the regional geology of the margin is quite well-known (eg Fraser & Tilbury, 1979; Willcox & Stagg, 1990; Stagg et al., 1990; Stagg & Willcox, 1992). That is, future ODP drilling will have an extensive knowledge base on which to build (Appendix 3).

To the question, "Why drill the Australian southern margin, as opposed to an alternative passive margin (e.g. Galicia)?", several responses can be made. In brief, these can be summarised as:

- The rifting history of the margin appears to be relatively simple;
- Crustal-scale structures are well-imaged by the seismic technique, allowing drill information to be placed in structural context;
- A comprehensive data base is available;
- AGSO can make a commitment to the acquisition, processing, and interpretation of high-quality deep-seismic data, an essential adjunct to the slection of appropriate ODP sites.

An obvious criticism of this proposal is that there is no equivalent proposal to drill the conjugate, 'upper plate' Wilkes Land continental margin. This is not currently considered to be an insuperable difficulty since two high-quality MCS data sets (IFP and US Geological Survey) are available for development of ODP proposals on the Antarctic margin. However, we believe that <u>any</u> proposal to drill an interpreted upper plate margin is going to be faced with substantial difficulties in view of the considerable depth of drilling required to adequately test fundamental aspects of the model.

DETACHMENT MODELS FOR PASSIVE MARGIN FORMATION

In this section, we will summarise the main points of the five detachment models that Lister et al. (1986, 1991) proposed to encompass the major classes of detachment geometries; these models also incorporate the effects of distributed pure shear of the crust and mantle beneath the detachment. The five models are shown during continental extension (Fig. 1), and after large extension and continental breakup have occurred (Fig. 2). The models examined by Lister et al. fall into three classes - *viz* lithospheric wedge, stepped detachment (delamination), and detachment with shear. It is important to realise that, with the heterogeneous nature of the lithosphere, no one of these models is 'correct' at the expense of the others.

Lithospheric Wedge (Wernicke) Model

In this model, extension is accomplished along a single throughgoing detachment, soling out at the base of the lithospheric mantle (Wernicke, 1981, 1983, 1985; Fig. 1a). The lower plate is uplifted as it is dragged to the surface from beneath the fracturing upper plate.

Stepped Detachment Models

Lister et al. (1991) referred to these as delamination models since the detachment may run horizontally for considerable distances at mid- or sub-crustal levels (Fig. 1b). This model also incorporates the equivalent of ramps and flats into the detachment geometry, resulting in the development of ramp synclines or ramp basins. The delamination zones are probably the result of variations in strength with depth, particularly at mid-crustal levels and at the crust-mantle boundary, with the zones of higher strength acting as stress guides. The model in Figure 1b shows the case of major horizontal motion along a mid-crustal stress guide. The detachment zone then ramps down through the lower crust before flattening to run horizontally along the crust-mantle boundary.

Detachment Plus Pure Shear Models

The third group of models incorporate detachment faulting with ductile stretching ('pure shear') beneath a mid-crustal shear zone - i.e. within the lower crust and lithospheric mantle. These models (Figs 1c and 1d) result in the horizontal transfer of lithospheric extension across the detachment, leading to lateral separation of the zones of most active extension in the upper crust and the lower crust/mantle. Variation in the amount of lateral separation between the upper and lower extension zones produces radically different results as extension proceeds to breakup, as can be seen in Figures 1c and 1d.

The "stepped detachment with pure shear" models (Fig. 1e) incorporates most aspects of the preceding models.

Passive Margin Architecture

The major consequence of detachment models as applied to the formation of passive margins is that asymmetric structure is predicted on all scales. This asymmetry may be accentuated as extension continues. If the extension culminates in continental breakup, then it follows that conjugate passive margins will display complementary asymmetry and they will have contrasting uplift/subsidence histories.

At the crustal scale, the sense of asymmetry of the conjugate margins is determined by the dip on the master detachment fault during the extension phase. Lister et al. (1986) postulated two classes of continental margin where structures are not dominated by strike-slip faulting. 'Upper plate' margins comprise crust above the detachment zone (right side of Fig. 2), are relatively mildly structured, and exhibit minor subsidence. Faulting tends to be high-angle and syn-rift and post-rift sedimentation tends to be thin. Where igneous underplating of the crust has occurred, passive margin mountains may also develop. 'Lower plate' margins mainly comprise lower crust that lay beneath the master detachment. Upper crustal remnants, if present, are bound by low-angle faults and may be completely foundered, if not entirely stripped off; the detachment model predicts that these upper plate remnants should be separated from the lower plate by a mylonite or shear zone. Both syn-rift and post-rift subsidence and sedimentation are considerable. The geometry of the lower plate margin may become far more complicated if multiple detachments developed during the extension phase.

GEOLOGY OF THE GREAT AUSTRALIAN BIGHT

The southern margin of the Australian continent is a divergent, passive, continental margin extending for some 4000 km from the Perth Basin and Naturaliste Plateau off southwest Australia to the Sorrel Basin off the west coast of Tasmania (Fig. 3). The margin formed during the protracted period of extension and rifting that led to the separation of Australia and Antarctica at some time in the Cretaceous. The basins of this rift system (referred to as the 'Southern Rift System' by Stagg et al., 1990) include, from west to east, the Bremer, Great Australian Bight (consisting of the Eyre, Ceduna, and Recherche Sub-basins), Duntroon, Otway, and Sorrel Basins. The margin has long been considered a classic example of a rifted margin (e.g. Sproll & Dietz, 1969; Smith & Hallam, 1970; von der Borch et al., 1970; Griffiths, 1971) and has recently been used to illustrate the concepts of detachment models for continental margin formation (Etheridge et al., 1990).

The principal features of the Great Australian Bight (GAB) Basin, at the centre of the rift (and focus of this drilling proposal) are as follows (Fig. 4) -

1. **A broad continental shelf** generally underlain by shallow Precambrian basement.

2. **The Eyre Terrace,** lying at water depths of 200-2000 m on the western side of the GAB. The Eyre Terrace is underlain by the Eyre Sub-basin, consisting of two main ENE-trending half-grabens themselves fragmented by associated smaller faults. The sub-basin contains up to 5000 m of ?Jurassic-Tertiary sediments dated at the exploration well Jerboa-1 in the centre of the sub-basin (Bein & Taylor, 1981; Stagg et al., 1990; Blevin, 1991). The sub-

basin is bounded to the north, west, and south by shallow Precambrian basement and merges with the main sediment accumulation of the GAB Basin to the east. With its position high on the continental slope, low extension (~20%), and minimal subsidence, the Eyre Sub-basin has been interpreted as a 'perched' extensional basin developed near the main rift-bounding fault by Etheridge et al. (1990).

3. **The Ceduna Terrace** lies at water depths of 200-2500 m on the eastern side of the GAB and is underlain by the main depocentre of the GAB Basin, the Ceduna Sub-basin. While basement cannot be imaged beneath the sub-basin, interpretation of magnetic basement depths indicates that in excess of 10 km of sediments has accumulated since the Late Jurassic (dated by the exploration well Potoroo-1, on the northern flank). To the north and northeast, the Ceduna Sub-basin is bounded by the shallow Precambrian basement of the Gawler Block, while to the southwest and south it abuts the flat-lying sediments of the continental rise. The great thickness of sediments contained in the Ceduna Sub-basin preclude any definite interpretation of its placement in a continental margin detachment model.

4. **A broad continental rise**, coinciding with a magnetic quiet zone (MQZ) and underlain by a considerable thickness of relatively unstructured sediments, known as the Recherche Sub-basin. This sub-basin is interpreted to be floored by highly-extended remnants of upper plate (i.e. continental crust) and 6-8 km of ?Jurassic and younger sediments. The sub-basin is bounded to the north by shallow Precambrian basement beneath the continental slope, to the northeast by the major sediment 'pod' of the Ceduna Sub-basin, and to the south by shallow rugged basement that has typically been interpreted as oceanic crust.

Stratigraphy

Knowledge of the stratigraphy of the Great Australian Bight comes from the drilling of 5 petroleum exploration wells on the continental margin. Unfortunately, all these wells were drilled high on the margin, necessitating extrapolation over distances of the order of several hundred kilometres in order to interpret the stratigraphy in deep water. The stratigraphy of the central GAB is best summarised by reference to the exploration well Jerboa-1, drilled high on the flank of the rift in 1981 (Fig. 5).

In the well, the basal section above Precambrian basement consists of 410 m of Berriasian to lowest Valanginian non-marine sediments. The earliest sediments are poorly-sorted sandstones interpreted to be derived locally from basement outcrop soon after basin initiation and, as such, they have a syn-rift relationship to the basement. The remainder of the sequence consists of sandstones with interbedded siltstones and shales deposited in lacustrine and fluvial environments. With the location of Jerboa-1 on the crest of a tilted fault block, it appears that the oldest sediments in the Eyre Sub-basin were not sampled and we believe it likely that sedimentation commenced in the Middle or Late Jurassic.

The basal section is unconformably overlain by thick, lower Valanginian to Barremian, dark grey to dark brown shales with rare interbeds of siltstone deposited in a fresh or brackish-water lacustrine environment.

After a 15 Ma hiatus, the earliest marine influence is recorded in the middle Albian when a thin, shaley, prograding unit was deposited unconformably across the Barremian shales. After a further hiatus of 3 Ma in the Late Albian, marine sedimentation resumed in the Cenomanian with the deposition of a further 452 m of interbedded shales, claystones, and sandstones in an environment interpreted as near-shore.

At Jerboa-1, the Turonian to Lower Eocene section is absent, representing a gap in the sedimentary record covering approximately 40 Ma. Major unconformities spanning all or part of this time period appear to be present throughout much of the GAB. Although parts of this section may be preserved in the structurally lower parts of the basin, it is evident that a major erosional event, possibly combined with lengthy periods of non-deposition, affected the region. Sedimentation re-commenced with the deposition of a 28 m thick section of Hampton Sandstone in the latest Early Eocene. These sands were rapidly succeeded by calcilutite and marlstone of the Eocene-Oligocene Wilson Bluff Limestone and poorly consolidated, open-marine, prograding carbonates which comprise the remaining 335 m of section at Jerboa-1.

Seismic Interpretation of the Central GAB

In this section interpretations of portions of key seismic lines in the western and central GAB are presented. The westernmost lines, BMR line 65-6 and Shell *Petrel* line N405, traverse the Eyre and Recherche Sub-basins (underlying the Eyre Terrace and continental rise, respectively), while the central GAB line (BMR line 65-14) extends from the outer margin of the Ceduna Sub-basin (underlying the Ceduna Terrace) across the continental rise to the edge of the South Australian Abyssal Plain in the central GAB (Fig. 4).

Lister et al. (1986) have applied detachment models originally developed for the formation of metamorphic core complexes to the formation of passive continental margins. In their model they predict the existence of complementary 'upper plate' and 'lower plate' passive margins after breakup, with breakup probably taking place close to the culmination in the bowed-up lower plate (the 'outer high', analogous to a metamorphic core complex), since that is where the crust is thinnest.

The central GAB is interpreted to have formed when the 'lower plate' Australian margin was pulled out from beneath the 'upper plate' Antarctic margin (Etheridge et al., 1990; Fig. 6). Highly extended remnants of the upper plate occur beneath the Magnetic Quiet Zone (MQZ) and the Ceduna Terrace on the Australian margin. The total amount of pre-breakup extension has been estimated as 360 km (Veevers & Eittreim, 1988) and 280 km (Etheridge et al., 1990), and is assumed here to be about 300 km. The azimuth of pre-breakup extension, usually assumed by early workers to be N-S, has most recently been interpreted by Willcox & Stagg (1990) to be approximately NW-SE from the ?Middle Jurassic to the Neocomian, on the basis of seismic, magnetic, and gravity mapping of basin-forming structures in the central and western GAB.

Lines 65-6 & N.405

BMR Line 65-6 (Fig. 7) extends southeastwards from the Eyre Sub-basin to the broad continental rise in the western GAB and illustrates the structure and stratigraphy of this area. The primary structural and sedimentary features observed on this line include:

- A 'perched' extensional basin, the Eyre Sub-basin, containing syn-rift and post-rift sediments; extension is about 20%, and a detachment is predicted at about 15 km depth (Etheridge et al., 1990). The sedimentary fill, which is up to 5000 m thick in places, has been dated by the Jerboa-1 exploration well. This fill includes a syn-rift section of ?Upper Jurassic to lower Valanginian sediments, and a post-rift section that includes non-marine sediments of lower Valanginian-Barremian and marine sediments of Albian-Cenomanian age, overlain by prograding Tertiary sands and carbonates.

- Upper crustal tilt-blocks beneath the continental rise appear progressively more strongly rotated southwards, until on the lower continental rise they are completely foundered or have been stripped off. Extension has been computed as at least 200% (Etheridge et al., 1990), and basement has subsided to depths of at least 10 km (compared with 2-5 km in the Eyre Sub-basin).

- A very flat, strong seismic reflector (Horizon ND) can be identified throughout the deep-water GAB (Stagg & Willcox, 1988). This horizon is a major decollement beneath the upper continental rise which marks a major change in the seismic stratigraphy. Ties of horizon ND to the exploration wells Jerboa-1 and Potoroo-1 (on the northern flank of the Ceduna Sub-basin) rely largely on a well-defined character correlation that date it as early Neocomian (?early Valanginian).

- A lower sedimentary section beneath the continental rise ('basement' to horizon ND) which is at least 3000 m thick in places and is seismically featureless (possibly indurated), except at the base of the continental slope where it has some syn-rift relationships.

- A sedimentary section above horizon ND that is typically 2.5 s two-way time (twt; >3500 m) thick beneath the continental rise, and is probably of Valanginian to Maastrichtian age. Apart from the syn-sedimentary faulting beneath the upper continental rise, the section is essentially flat and unstructured throughout most of the deep-water GAB, and has the appearance of a post-rift thermal sag section. This section contains prominent sedimentary structures that include Barremian-Albian slumps and nappe structures beneath the upper continental rise and western Ceduna Terrace, and a major Cenomanian- Maastrichtian delta beneath the southwest Ceduna Terrace.

- After a major hiatus and/or period of erosion in the Late Cretaceous and earliest Tertiary, a thin veneer of Tertiary carbonates was deposited, principally on the Eyre and Ceduna Terraces.

Figure 8 is a portion of Shell *Petrel* Line N.405 (Location in Fig 4), beyond the southern end of line 65-6, in which ND can be seen to onlap a basement hummock which Veevers (1986, fig. 3) has interpreted to be characteristic of the COB south of Australia. Seismic character correlation across this hummock, to the south, indicates that horizon ND overlies ~0.5 s twt (>500 m) of flat-lying sediment above Veevers' interpreted oceanic basement. Consequently, if the identification of oceanic basement, the dating of ND as Valanginian, and the continuation of ND to the south end of line N.405 be correct, then oceanic crust in the western GAB is far older than the previously interpreted Cenomanian age.

Line 65-14

The portion of north-south BMR line 65-14 illustrated in Figure 9 traverses the continental rise south of the Ceduna Terrace in the eastern GAB. The position of the "COB", as identified from magnetic data by Veevers et al. (1990) is shown at the top of the section; this again corresponds to a basement 'hummock' in the seismic data. A stacked seismic section with no migration shows a highly-diffracting basement surface south of the COB, that could easily be identified as 'typical' oceanic crust. However, migration of the seismic data (Fig. 10) radically alters this interpretation, and it becomes evident that there is extensive listric faulting and apparent syn-rift sedimentation *within* previously interpreted oceanic basement for at least 80 km south of the "COB".

The seismic data interpreted in Figure 9 display many of the characteristics of a 'metamorphic core complex', bounded above by a major detachment fault as illustrated. South-dipping faults to the north may sole out on a master detachment surface that shoals across the top of the interpreted complex. The south-dipping listric faults within what was previously interpreted as basement may also sole out on this detachment as it deepens to the south of the complex. Alternatively, the entire basement complex may consist of old oceanic crust that was re-rifted prior to the emplacement of new oceanic crust in the Cretaceous.

RECONSTRUCTIONS AND SPREADING HISTORY

Magnetic lineations in the Southern Ocean were first identified and mapped by Weissel & Hayes (1972) on the basis of data recorded on the USNS *Eltanin*. They concluded that the oldest magnetic anomaly that could be identified was Anomaly 22, and that breakup between Australia and Antarctica occurred at about 55 Ma, in the Early Eocene. In addition to the basic lineation pattern, Weissel & Hayes also identified several large scale anomalous magnetic or morphologic features that are apparently fundamental to margin formation, yet are difficult to explain. These features include -

1. The *Australia-Antarctic Discordance*, a region of subdued, yet confused magnetic anomalies and deeper than expected crust, astride the Southeast Indian Ridge south of the western side of the GAB (see also Weissel & Hayes, 1974). Following a cooperative airborne magnetic survey of the area by the US Navy and the RAAF, Vogt et al. (1983) were able to map the magnetic anomalies in detail. Veevers (1982) concluded that the discordance was part of a major morphological depression that extends from southern Australia to Wilkes Land, Antarctica, and was caused by downward convection in the lithosphere. This notion has been extended by Crawford et al. (1989) in a proposal for ODP drilling, in which it is suggested that the Australia-Antarctic Discordance is the

surface expression of the boundary between major mantle convection cells underlying the Pacific and Indian Oceans.

2. The *Diamantina Zone* (formerly known as the Diamantina Fracture Zone), a latitudinal band of very rough topography south of southwest Australia. The Diamantina Zone is most pronounced west of 125°E, where it appears to take the form of a series of ENE-striking *en echelon* ridges with southeasterly offsets, whilst to the east it gradually becomes buried by sediments. The eastward extent of the Diamantina Zone is ill-defined.

3. A broad *Magnetic Quiet Zone* (MQZ) bound landward by a prominent *Magnetic Trough* (MT), extending along the southern margin of Australia from the west of the continent (where it is relatively disturbed) to the eastern side of the GAB where it encompasses the oldest magnetic anomalies. The crust beneath the MQZ has variously been interpreted as continental (Falvey, 1974; Boeuf & Doust, 1975; Deighton et al., 1976) or as a hybrid "rift-valley" crust (Talwani et al., 1979).

In a major re-interpretation of the oldest part of the magnetic anomaly series, Cande & Mutter (1982) suggested that the anomalies originally identified as 19-22 could be better modeled as Anomalies 20-34, with spreading during this period being at a very slow 'half-rate' (~4.5 mm/yr); spreading since approximately 44 Ma has taken place at more normal spreading rates. Cande & Mutter estimated that breakup of Australia and Antarctica took place at some time in the interval 110-90 Ma. This revised anomaly identification, which is now quite widely accepted, accounts for the roughness of the Diamantina Zone (attributed to the slow spreading), the previous difficulties in identifying the older magnetic anomalies, and the period of rapid basin subsidence prior to 90 Ma on the southern margin of Australia (Falvey & Mutter, 1981).

Veevers (1986, 1988) refined the estimate of breakup age to 96 +/-4 Ma (Cenomanian-Turonian) by proposing that Cande & Mutter's Anomaly 34 is, in fact, the continent-ocean boundary (COB) edge-effect anomaly and by extrapolating the 4.5 mm/yr spreading rate.

While Cenomanian breakup is currently quite widely accepted, work by Stagg & Willcox (1992) points to a number of problems that remain to be resolved, both with the breakup age and also with other aspects of the seafloor spreading history. Stagg & Willcox concluded that:

- interpretation of seismic data from the continent-ocean boundary (COB) demonstrated that it is likely that the oldest interpreted oceanic crust is overlain by several hundred metres of sediment that is no younger than Valanginian (*ca* 125 Ma); that is, the emplacement of the first oceanic crust between Australia and Antarctica must have occurred at least 30 Ma prior to the proposed Cenomanian breakup;

- that breakup between Greater India and Western Australia and between Australia and Antarctica may well have been contemporaneous; and

- that previously identified oceanic crust may actually be either extensively thinned continental crust (a metamorphic 'core complex'), interfingered slivers of oceanic and continental crust, or re-rifted oceanic crust from a previous phase of restricted sea-floor spreading.

SCIENTIFIC PROBLEMS TO BE ADDRESSED

Deformation Processes at Divergent Margins - Testing Detachment Models

- Test the applicability of detachment tectonics to passive margin formation by drilling through a master detachment into the lower crust;
- Sample acoustic basement at several sites to characterise the tectonic and magmatic processes that have been influential at high rates of continental extension and/or during early/slow oceanic spreading;

Plate Kinematics - Eastern Gondwanaland Breakup

- What was the history of the early separation of Australia and Antarctica (particularly the period 150-90 Ma) and what are the implications for synchronous Australia-Greater India and Australia-Antarctica rifting versus piecemeal breakup?

PROPOSED DRILLING SITES AND DRILLING STRATEGY

The problems outlined above can be addressed by a suite of judiciously placed ODP sites along the Southern Margin and in the Southern Ocean. Although complementary sites could be located on the conjugate margin, particularly Wilkes Land, its expected 'upper plate' characteristics are likely to place basin-forming structures beyond the reach of ODP drilling.

The proposed drilling sites are listed in Appendix 4 and Site Summary forms are included in Appendix 5.

Figure 11 shows the strategy to be used in drilling the holes. Two of these holes will only be drilled in the event that the previous identification of the location of the COB is correct. In this case, sites GAB02A and GAB05A will provide valuable information on the age of separation of Australia and Antarctica and on the processes involved and age of rifting of old oceanic crust, respectively.

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APPENDIX 1: EXECUTIVE SUMMARY FROM AGSO CRUISE PROPOSAL FOR DEEP-SEISMIC TRANSECTS IN THE GREAT AUSTRALIAN BIGHT
(after Stagg & Willcox, 1995)

The southern margin of Australia has long been considered an example of a classic passive rifted continental margin. In recent times, it has been cited as an example of a 'lower plate' margin in the terminology describing detachment models of passive margin formation. However, despite extensive study by both industry and government since the early 1970s, some fundamental aspects of the structure and geological history of the margin remain speculative.

It is proposed here to use the AGSO research vessel *Rig Seismic* to acquire 4087 km of deep-seismic data (16 s record length) in the central Great Australian Bight (GAB) and across the continental margin south of Western Australia. The survey has three principal objectives:

1. To enhance understanding of the tectonic evolution / event history of the southern margin to encourage successful petroleum exploration.

2. To provide the necessary framework data in support of a proposal submitted to the Ocean Drilling Program (ODP) for drilling in the GAB; and

3. To provide data in the GAB that support Australia's claim to a Legal Continental Shelf beyond the 200 n.m. Exclusive Economic Zone (EEZ) as defined under the 1982 UN Convention on the Law of the Sea (UNCLOS).

The specific scientific aims of the work include:

- Definition of the deep crustal structure of the region and the mode of margin formation across a number of key transects. In particular, to image the key detachment surfaces which are believed to have controlled the extensional processes. Interpretation of the deep structures will be enhanced by the availability of seismic refraction data recorded by Lamont-Doherty Geological Observatory in 1976.

- Determination of the location and structural setting of the continent-ocean boundary. In places, stratified tilt-blocks that lie oceanwards of the magnetically determined COB suggest that either the COB identification is incorrect, old oceanic crust has been re-rifted, or the seismic data are imaging an amalgam of oceanic crust and continental slivers.

- Determination of the structure and origin of the enigmatic Diamantina Zone, west of the GAB, and its relationship, if any, to the change in seafloor spreading rate at 44 Ma. Is the crust to the north oceanic, or is it highly extended continental?

The data to be acquired can be considered in two distinct sets (Fig. 12):

Margin Transects (2494 km)
Four margin 'dip' transects are proposed, with each transect extending from unextended continental craton out to oceanic crust well to the south of the currently interpreted continent-ocean boundary (COB). These transects are oriented NNW-SSE, coincident with the probable original extension azimuth, and commence in the margin segments containing the Bremer Basin (570 km), Recherche Sub-basin (581 km), Eyre Sub-basin (637 km), and Ceduna Sub-basin (706 km). These data are necessary to our understanding of the tectonic framework and structural origins of the southern margin and provide a basis for the selection of the most appropriate ODP sites.

Law of the Sea (1593 km)
Under the 1982 UNCLOS, Australia can lay claim to an area of Legal Continental Shelf beyond the EEZ southwest of the Ceduna Terrace in the central GAB of approximately 25 000 km^2. For this area to be adequately defined, a total of seven NNE-SSW oriented lines are required, with the lines ranging in length from 88 to 260 km. An orthogonal tie line is also proposed, linking the LOS data set internally, and tieing the Eyre and Ceduna Transects described above. As the area covered by this part of the survey is also a priority area for the proposed ODP drilling, these data will satisfy both of the survey objectives.

While there are no serious time constraints on the acquisition and interpretation of the LOS data (before November 16, 2004), the ODP time constraints are critical. If a revised drilling proposal is to be submitted in time to be considered by early 1996, then the data must be acquired, processed, and interpreted by late 1995. If it is assumed that the processing, interpretation, and proposal writing require a total of six months, then it is essential that the seismic data be acquired before mid-1995. However, as weather conditions in the Southern Ocean can deteriorate severely during the winter months, it obviously makes good sense to carry out the survey as early as possible, and preferably no later than the autumn.

APPENDIX 2: AGSO DEEP-SEISMIC ACQUISITION RECORDING PARAMETERS

Since early 1990, the Australian Geological Survey Organisation has been acquiring deep-seismic data in southeast Australia (Gippsland Basin) and in a systematic program along the North West Shelf. These data are providing new insights into basin-forming mechanisms on the continental margin through the capacity to image original basement fabrics and structures. It is anticipated that in 1995/96 a program of deep-seismic acquisition will be instituted on Australia's southern margin. This program will use the same acquisition parameters as have been used on the North West Shelf; these parameters include:

Seismic Cable Configuration:

active streamer length	4800 m
group length	25 m
no. channels	192

Seismic Source

Airgun array capacity	49.2 litres (3000 cu in)
Airgun pressure	1800 psi
Shot interval	50 m

Fold

Standard	4800%

Recording Parameters

Record length	16 s
Sample interval	2 msec

APPENDIX 3: AVAILABILITY OF GEOSCIENCE DATA IN THE GREAT AUSTRALIAN BIGHT

Reflection Seismic Data

The reflection seismic data base available across the continental margin and deep ocean in the central GAB is extensive, though highly variable in quality. The principal data sets of value comprise:

Eltanin: From 1969-72, the Lamont-Doherty Geological Observatory (LDGO) recorded approximately 190000 km of magnetic, gravity, and low-power seismic data during a major southern hemisphere research project. South of Australia, a number of widely spaced N-S profiles were recorded between the Australian and Antarctic continental margins. In much of the deep ocean, these data remain the only geophysical information available.

Continental Margin Survey: During 1972, as part of it's Australia-wide regional survey of the continental margin, the Bureau of Mineral Resources recorded a series of generally N-S and E-W trending seismic, gravity, and magnetic profiles throughout the GAB. While the seismic data are only fair quality, the lines cross the entire margin from continental shelf to the edge of the abyssal plain.

Petrel: During 1972-73, Shell Development Pty Ltd carried out a reconnaissance seismic survey of much of the continental margin of Australia with the R/V *Petrel*. Approximately 2000 km of these data are in the area encompassed by this proposal. The 24-channel data from this survey, though largely unprocessed, are of consistently good quality and provide valuable information linking the continental shelf to the abyssal plain. AGSO is currently (late 1994) transcribing the original field tapes from this survey, and intends to selectively process relevant lines.

Shell Development Australia: In the period 1966-76, Shell held exploration leases over the Ceduna Terrace and adjacent continental shelf. During this time, they recorded approximately 25000 km of multichannel data of fair to good quality. However, these data are limited to water depths of less than about 2000 m, and hence are of limited value in any deep-water drilling proposal.

Vema: In 1976, the LDGO's R/V *Vema* recorded shallow seismic reflection, deep-crustal seismic refraction probes, and gravity and magnetic data along profiles across the continental margin between southwest Australia and the Ceduna Terrace. While the reflection seismic data are of limited value, velocities and depths derived from the refraction data are valuable in crustal modelling.

Esso: From 1979-82, Esso Australia recorded a total of 4071 km of high-quality multichannel seismic data across the Eyre Sub-basin and adjacent areas on the continental shelf and upper slope. Although these data do not extend into deep water, they allow detailed mapping of the Eyre Sub-basin and thereby provide valuable additional information in development of tectonic models for the GAB.

BMR Survey 65: In late 1986, the Bureau of Mineral Resources recorded approximately 3500 km of high-quality, 24-fold multichannel seismic data on a series of regional lines in the central GAB. These lines link the Eyre and Ceduna Terraces with the continantal rise and northern edge of the abyssal plain, and are invaluable in developing models of margin formation, and as a basis for ODP drilling.

Japan National Oil Corporation: In 1990, JNOC acquired 5300 km of MCS data over the Eyre Sub-basin and adjacent continental shelf and slope. These data are of high quality and resolution, and have been used as the basis for site selection for ODP Proposal 367 (GAB cool-water carbonates; Feary et al., 1994).

Refraction Seismic Data

A relatively comprehensive refraction seismic data set was acquired by Lamont-Doherty Geological Observatory in 1976 (Talwani et al., 1979). These data were recorded from sonobuoys using airgun and/or explosives as source. Sixteen stations were recorded in the central GAB, with nine of these recording Mantle velocities.

Drill Data

Well:	Echidna-1
Basin:	Duntroon
Year:	1972
TD:	3823 m

Well:	Platypus-1
Basin:	Duntroon
Year:	1972
TD:	3881 m

Well:	Potoroo-1
Basin:	Ceduna Sub-basin
Year:	1975
TD:	2923 m

Well:	Jerboa-1
Basin:	Eyre Sub-basin
Year:	1980
TD:	2537.5 m

Well:	Duntroon-1
Basin:	Duntroon
Year:	1986
TD:	3515.6 m

Well:	Borda-1
Basin:	Duntroon
Year:	1993
TD:	N/A

Well:	Greenly-1
Basin:	Duntroon
Year:	1993
TD:	N/A

Well:	Vivonne-1
Basin:	Duntroon
Year:	1993
TD:	N/A

APPENDIX 4: PROPOSED DRILLING SITES AND DRILLING PROGRAM

Detaile descriptions of the proposed southern margin ODP sites are contained on the following pages.

Site GAB01A

Description: Site GAB01A (Figs 13-15) lies on top of an outcropping basement hummock that has previously been interpreted as the expression of the COB between extended continental crust and the first-formed oceanic crust between Australia and Antarctica. Interpretation of seismic data in the GAB suggests that the hummock may actually be exposed lower continental crust and that the true COB lies some distance to the south. As there is negligible sediment cover, this hole provides a rapid first test as to the validity of these conflicting interpretations. Should the site turn out to be oceanic, then it will sample the crust produced at the initial separation of Australia and Antarctica; this crust was produced at an extremely slow spreading rate.

Location: 35° 31.8' S, 127° 10.3' E
Water Depth: 5250 m
Sediment thickness: negligible
Seismic coverage: Shell *Petrel* line N.405, SP 440

Objectives:

1. Sample a basement high, outcropping at seabed. Previously interpreted as the continent-ocean boundary, interpretation of this feature elsewhere indicates it may be exposed lower plate (continental crust).

Proposed drilling program:
RCB drilling through thin sediment cover, penetrating a significant section of the basement (approximately 200 metres) interpreted as lower continental crust.

Logging & downhole operations:
Standard strings (geophysical, geochemical, and FMS).

Rocks anticipated:
Basement (continental or oceanic), possibly with a thin skin of pelagic ooze.

Pollution prevention & safety:
Basment site only.

Site GAB02A

Description: This site (Figs 13-15) will only be drilled if site GAB01A turns out to be oceanic. The intention here is to sample and date the oldest sediments overlying the oceanic crust that was first emplaced between Australia and Antarctica, thus providing an indisputable date for this separation. The current interpretation and dating of magnetic anomalies during the original slow A-A spreading is tenuous and in contradiction with the interpretation of the continental margin stratigraphy.

Location: 35° 38.3' S 127° 10.0' E
Water Depth: 5400 m
Sediment thickness: 1500 m
Seismic coverage: Shell *Petrel* line N.405, SP 200

Objectives:
This hole will only be drilled if site GAB01A turns out to be oceanic crust.

1. Date the oldest sediments overlying first-emplaced oceanic crust formed during separation of Australia and Antarctica.

Proposed drilling program:
RCB drilling through sedimentary section and into fresh basement.

Logging & downhole operations:
Standard strings (geophysical, geochemical, and FMS).

Rocks anticipated:
Abyssal plain tubidites and pelagic sediments; oceanic crust.

Pollution prevention & safety:
1500 m of abyssal sediments overlying oceanic crust, considered to have negligible hydrocarbon prospectivity.

Site GAB03A

Description: This site is situated oceanwards of the generally interpreted location of the COB in the central GAB on a broad basement complex (Figs 13, 16, 17, 18). High-quality seismic data show that the 'oceanic crust' has been subjected to extension and listric faulting. Our current interpretation is that the basement complex represents a metamorphic core complex and therefore comprises lower continental crust beneath a primary continental margin forming detachment. This site presents a rapid first test of these conflicting interpretations. While it is possible that this detachment may be drilled through, it is more likely that the original detachment surface has been destroyed by later-stage faulting and erosion. Should the complex prove to be oceanic, then the site will sample early slow-spreading oceanic crust that has been extensively faulted.

Location:	35° 49.3' S 130° 30.4' E
Water Depth:	5550 m
Sediment thickness:	600 m
Seismic coverage:	AGSO line 65-14P2, Julian time 310.2330

Objectives:
1. Sample lower continental crust below a detachment in an interpreted metamorphic core complex.
2. Drill through a primary detachment surface.
3. Determine early sedimentation history.

Proposed drilling program:
RCB drilling through approximately 600 metres of sedimentary section with 100-200 metre penetration of the underlying lower continental crust.

Logging & downhole operations:
Standard strings (geophysical, geochemical, and FMS).

Rocks anticipated:
Possible abyssal plain turbidites and pelagic sediments; claystone, siltstone, fine sandstone; lower continental crust or, less likely, oceanic crust.

Pollution prevention & safety:
Thin sedimentary section (600 m) overlying basement.

Site GAB04A

Description: This site is situated at the landward edge of the interpreted metamorphic core complex sampled at site GAB03A (Figs 13, 16, 17, 19). While the interpretation of the existing data is somewhat equivocal, we expect to sample a sedimentary section deposited at the time of uplift of the core complex - i.e. the site will provide information on the uplift/subsidence history. There is also the possibility of drilling through a primary detachment into lower continental crust. In the event that site GAB03A turns out to be slow-spreading oceanic crust, then this site will sample the outermost extended continental crust.

Location:	35° 37.6'S 130° 29.4' E
Water Depth:	5150 m
Sediment thickness:	1100 m
Seismic coverage:	AGSO line 65-14P2, at Julian time 310.2110

Objectives:
1. Drill through a possible primary detachment surface into lower continental crust.
2. Establish uplift/subsidence history at time of breakup.

Proposed drilling program:
RCB drilling through approximately 1100 metres of sedimentary section with significant penetration of the underlying ?metamorphic core complex.

Logging & downhole operations:
Standard strings (geophysical, geochemical, and FMS).

Rocks anticipated:
Possible abyssal plain turbidites and pelagic sediments; claystone, siltstone, fine sandstone; lower continental crust.

Pollution prevention & safety:
The sediments at this site exibit some structuring and could be regarded as providing a possible trap for potential hydrocarbons. However, this would require migration from the flanking areas of somewhat thicker sediment. This scenario is considered unlikely as there have been no hydrocarbon discoveries on the adjacent part of the continental margin.

Site GAB05A

Description: This site (Figs 13, 16, 17, 20) will only be drilled if site GAB03A turns out to be oceanic crust. If this is on oceanic crust, then the site will sample a syn-rift sequence immediately above basement. This will provide dating on the age of the extensional faulting and information on the paleoenvironments.

Location: 36° 08.9'S 130° 39.8'E
Water Depth: 5550 m
Sediment thickness: 1500 m
Seismic coverage: AGSO line 65-15P1, at Julian time 311.1307

Objectives:
1. Date and characterise a synrift section deposited within faulted and extended oceanic crust.

Proposed drilling program:
RCB drilling through sag-phase and syn-rift sediments into extended oceanic or lower continental crust.

Logging & downhole operations:
Standard strings (geophysical, geochemical, and FMS).

Rocks anticipated:
Possible abyssal plain turbidites and pelagic sediments; claystone, siltstone, fine sandstone; lower continental crust.

Pollution prevention & safety:
Although 1500 metres of sedimentary section are prognosed for this site, it is located near the centre of a half-graben feature and is off-structure.

Site GAB06A

Description: This site (and site GAB07A) is situated on the oceanwards flank of a major uplifted lower-crust fault block south of the Ceduna Terrace (Figs 13, 21, 22). After penetrating approximately 500 m of sediments, the drill should penetrate a major low-angle fault plane (possibly a detachment sub-branch) and pass into extended lower continental crust. In conjunction with site GAB07A, this site will provide a profile of the lower crust at high extension rates.

Location: 37° 03.2' S 135° 27.2' E
Water Depth: 5325 m
Sediment thickness: 500 m
Seismic coverage: Shell *Petrel* line N.407(5), SP 3900

Objectives:
1. Profile deep continental crust in a highly extended terrane.

Proposed drilling program:
RCB trhough sedimentary section and into basement/ lower continental crust.

Logging & downhole operations:
Standard strings (geophysical, geochemical, and FMS).

Rocks anticipated:
Possible abyssal plain turbidites and pelagic sediments; claystone, siltstone, fine sandstone; lower continental crust.

Pollution prevention & safety:
Thin sedimentary section overlying basement.

Site GAB07A

Description: This site is situated on the oceanwards flank of the same major fault block sampled at site GAB06A (Figs 13, 21, 22) and, in conjunction with that site, provides a profile of the lower crust at a location that has been highly extended.

Location: 37° 02.2'S 135° 26.5' E
Water Depth: 5220 m
Sediment thickness: negligible
Seismic coverage: Shell *Petrel* line N.407(5), SP 3860

Objectives:
1. Profile deep continental crust in a highly extended terrane.

Proposed drilling program:
RCB through surficial sediment and into the basement complex.

Logging & downhole operations:
Standard strings (geophysical, geochemical, and FMS).

Rocks anticipated:
Lower continental crust.

Pollution prevention & safety:
Basement site with little or no sedimentary cover.

APPENDIX 5: ODP SITE SUMMARY FORMS

ODP Site Summary forms are contained on the following pages.

ODP Site Summary Form

Fill out one form for each proposed primary and alternate site and attach to proposal.

Title of Proposal:	Investigation of a lower-plate continental margin: drilling in the Great Australian Bight region
Site-specific Objective(s) (List of general objectives must be inc. in proposal)	Test of a basement 'hummock' south of the Great Australian Bight. Previously interpreted as continent-ocean boundary; interpreted herein as possible exposed lower plate.
Site Name:	GAB01A
Area:	Great Australian Bight
Lat./Long.:	35° 31.8'S 127° 10.3'E
Water Depth:	5250 m
Sediment Thickness:	Negligible
Total penetration:	Approx. 300 m

	Sediments	Basement
Penetration:	<100 m	Approx. 250 m
Lithology(ies):	Pelagic ooze over basement	Continental or oceanic

Coring (circle): 1-2-3-APC VPC* XCB MDCB* PCS (RCB) Re-entry HRGB

Downhole measurements: Standard strings (geophysical, geochemical, FMS)

Estimate of days on site:

*Systems currently under development

Target(s) (see Proposal Submission Guidelines): A (B) C D (E) F G H (circle)

Site Survey Information (see Proposal Submission Guidelines for details and requirements):

		Check	Details of available data and data that is still to be collected
01	High res. seismic refl.		
02	Deep penetration seis. refl.	✓	Shell *Petrel* N.405, SP 440
03	Seismic velocity		
04	Seismic grid		
05a	Refraction (surface)	✓	Lamont sonobuoy data in area
05b	Refraction (near bottom)		
06	3.5 kHz		
07	Swath bathymetry		
08a	Side-looking sonar (surface)		
08b	Side-looking sonar (bottom)		
09	Photography or video		
10	Heat flow		
11a	Magnetics	✓	
11b	Gravity	✓	
12	Sediment cores		
13	Rock sampling		
14	Water current data		
15	OBS microseismicity		
16	Other		

Weather, Ice, Surface Currents: Potential large SW swells; best in southern summer

Seabed Hazards: None known

Territorial Jurisdiction: Australia

Proponent Name, Address, Ph., Fax, Email:

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E-mail: hstagg@agso.gov.au

Date: December, 1994

ODP Site Summary Form

Fill out one form for each proposed primary and alternate site and attach to proposal.

Title of Proposal:	Investigation of a lower-plate continental margin: drilling in the Great Australian Bight region
Site-specific Objective(s) (List of general objectives must be inc. in proposal)	Drill only if GAB01A turns out to be oceanic. Sample and date oldest sediments on oldest crust emplaced between Australia and Antarctica, providing indisputable age of separation.
Site Name:	GAB02A
Area:	Great Australian Bight
Lat./Long.:	35° 38.3'S 127° 10.0'E
Water Depth:	5400 m
Sediment Thickness:	1500 m
Total penetration:	1600 m

	Sediments	Basement
Penetration:	1500 m	100 m
Lithology(ies):	Turbidites & pelagics	Oceanic

Coring (circle): 1-2-3-APC VPC* XCB MDCB* PCS (RCB) Re-entry HRGB

Downhole measurements: Standard strings (geophysical, geochemical, FMS)

Estimate of days on site:

*Systems currently under development

Target(s) (see Proposal Submission Guidelines): A (B) C D (E) F G H (circle)

Site Survey Information (see Proposal Submission Guidelines for details and requirements):

		Check	Details of available data and data that is still to be collected
01	High res. seismic refl.		
02	Deep penetration seis. refl.	✓	Shell *Petrel* N.405, SP 200.
03	Seismic velocity		
04	Seismic grid		
05a	Refraction (surface)	✓	Lamont sonobuoy data in area.
05b	Refraction (near bottom)		
06	3.5 kHz		
07	Swath bathymetry		
08a	Side-looking sonar (surface)		
08b	Side-looking sonar (bottom)		
09	Photography or video		
10	Heat flow		
11a	Magnetics	✓	
11b	Gravity	✓	
12	Sediment cores		
13	Rock sampling		
14	Water current data		
15	OBS microseismicity		
16	Other		

Weather, Ice, Surface Currents: Potential large SW swells; best in southern summer

Seabed Hazards: None known

Territorial Jurisdiction: Australia

Proponent Name, Address, Ph., Fax, Email:

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Date: December, 1994

ODP Site Summary Form

Fill out one form for each proposed primary and alternate site and attach to proposal.

Title of Proposal:	Investigation of a lower-plate continental margin: drilling in the Great Australian Bight region
Site-specific Objective(s) (List of general objectives must be inc. in proposal)	Test of basement high which is interpreted as a possible metamorphic core complex. Previously interpreted as continent-ocean boundary.

Site Name:	GAB03A
Area:	Great Australian Bight
Lat./Long.:	35° 49.3'S 130° 30.4'E
Water Depth:	5550 m
Sediment Thickness:	600 m
Total penetration:	700-800 m

	Sediments	Basement
Penetration:	600 m	100 - 200 m
Lithology(ies):	Abyssal plain turbidites & pelagics, claystone, siltstone	Lower continental crust or, less likely, oceanic crust

Coring (circle): 1-2-3-APC VPC* XCB MDCB* PCS (RCB) Re-entry HRGB

Downhole measurements: Standard strings (geophysical, geochemical, FMS)

Estimate of days on site:

*Systems currently under development

Target(s) (see Proposal Submission Guidelines): A (B) C D (E) F G H (circle)

Site Survey Information (see Proposal Submission Guidelines for details and requirements):

		Check	Details of available data and data that is still to be collected
01	High res. seismic refl.		
02	Deep penetration seis. refl.	✓	AGSO line 65-14P2, Julian time 310.2330
03	Seismic velocity		
04	Seismic grid		
05a	Refraction (surface)	✓	Lamont sonobuoy data in area.
05b	Refraction (near bottom)		
06	3.5 kHz		
07	Swath bathymetry		
08a	Side-looking sonar (surface)		
08b	Side-looking sonar (bottom)		
09	Photography or video		
10	Heat flow		
11a	Magnetics	✓	
11b	Gravity	✓	
12	Sediment cores		
13	Rock sampling		
14	Water current data		
15	OBS microseismicity		
16	Other		

Weather, Ice, Surface Currents: Potential large SW swells; best in southern summer

Seabed Hazards: None known

Territorial Jurisdiction: Australia

Proponent Name, Address, Ph., Fax, Email:

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E-mail: hstagg@agso.gov.au

Date: December, 1994

ODP Site Summary Form

Fill out one form for each proposed primary and alternate site and attach to proposal.

Title of Proposal:	Investigation of a lower-plate continental margin: drilling in the Great Australian Bight region
Site-specific Objective(s) (List of general objectives must be inc. in proposal)	Drill through possible primary detachment into lower continental crust. If GAB03A proved oceanic, then GAB04A would be outermost extended continental crust.
Site Name:	GAB04A
Area:	Great Australian Bight
Lat./Long.:	35° 37.6'S 130° 29.4'E
Water Depth:	5150 m
Sediment Thickness:	1100 m
Total penetration:	1200 - 1300 m

	Sediments	Basement
Penetration:	1100 m	100 - 200 m
Lithology(ies):	Abyssal plain turbidites & pelagics, claystone, siltstone.	Lower continental crust or, less likely, oceanic crust.

Coring (circle): 1-2-3-APC VPC* XCB MDCB* PCS (RCB) Re-entry HRGB

Downhole measurements: Standard strings (geophysical, geochemical, FMS)

Estimate of days on site:

*Systems currently under development

Target(s) (see Proposal Submission Guidelines): A (B) C D (E) F G H (circle)

Site Survey Information (see Proposal Submission Guidelines for details and requirements):

		Check	Details of available data and data that is still to be collected
01	High res. seismic refl.		
02	Deep penetration seis. refl.	✓	AGSO line 65-14P2, Julian time 310.2110
03	Seismic velocity		
04	Seismic grid		
05a	Refraction (surface)	✓	Lamont sonobuoy data in area.
05b	Refraction (near bottom)		
06	3.5 kHz		
07	Swath bathymetry		
08a	Side-looking sonar (surface)		
08b	Side-looking sonar (bottom)		
09	Photography or video		
10	Heat flow		
11a	Magnetics	✓	
11b	Gravity	✓	
12	Sediment cores		
13	Rock sampling		
14	Water current data		
15	OBS microseismicity		
16	Other		

Weather, Ice, Surface Currents: Potential large SW swells; best in southern summer

Seabed Hazards: None known

Territorial Jurisdiction: Australia

Proponent Name, Address, Ph., Fax, Email:

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E-mail: hstagg@agso.gov.au

Date: December, 1994

ODP Site Summary Form

Fill out one form for each proposed primary and alternate site and attach to proposal.

Title of Proposal:	Investigation of a lower-plate continental margin: drilling in the Great Australian Bight region
Site-specific Objective(s) (List of general objectives must be inc. in proposal)	Date and characterise a syn-rift section within faulted and extended oceanic crust or possibly lower continental crust. To be drilled only if GAB03A is oceanic.
Site Name:	GAB05A
Area:	Great Australian Bight
Lat./Long.:	36° 08.9'S 130° 39.8'E
Water Depth:	5550 m
Sediment Thickness:	1500 m
Total penetration:	1600 m

	Sediments	Basement
Penetration:	1500 m	100 m
Lithology(ies):	Abyssal plain turbidites & pelagics, claystone, siltstone.	Lower continental crust or oceanic crust.

Coring (circle): 1-2-3-APC VPC* XCB MDCB* PCS (RCB) Re-entry HRGB

Downhole measurements: Standard strings (geophysical, geochemical, FMS)

Estimate of days on site:

*Systems currently under development

Target(s) (see Proposal Submission Guidelines): A (B) C D (E) F G H (circle)

Site Survey Information (see Proposal Submission Guidelines for details and requirements):

		Check	Details of available data and data that is still to be collected
01	High res. seismic refl.		
02	Deep penetration seis. refl.	✓	AGSO line 65-15P1, Julian time 311.1307
03	Seismic velocity		
04	Seismic grid		
05a	Refraction (surface)	✓	Lamont sonobuoy data in area.
05b	Refraction (near bottom)		
06	3.5 kHz		
07	Swath bathymetry		
08a	Side-looking sonar (surface)		
08b	Side-looking sonar (bottom)		
09	Photography or video		
10	Heat flow		
11a	Magnetics	✓	
11b	Gravity	✓	
12	Sediment cores		
13	Rock sampling		
14	Water current data		
15	OBS microseismicity		
16	Other		

Weather, Ice, Surface Currents: Potential large SW swells; best in southern summer

Seabed Hazards: None known

Territorial Jurisdiction: Australia

Proponent Name, Address, Ph., Fax, Email:

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E-mail: hstagg@agso.gov.au

Date: December, 1994

ODP Site Summary Form
Fill out one form for each proposed primary and alternate site and attach to proposal.

Title of Proposal:	Investigation of a lower-plate continental margin: drilling in the Great Australian Bight region
Site-specific Objective(s) (List of general objectives must be inc. in proposal)	**Profile deep continental crust in a highly extended terrane. Penetrate major low-angle fault plane - possibly a sub-branch of the main detachment.**

Site Name:	GAB06A
Area:	Great Australian Bight
Lat./Long.:	37° 03.2'S 135° 27.2'E
Water Depth:	**5325 m**
Sediment Thickness:	**500 m**
Total penetration:	**600 - 700 m**

	Sediments	Basement
Penetration:	**500 m**	**100 - 200 m**
Lithology(ies):	**Abyssal plain turbidites & pelagics, claystone, siltstone.**	**Lower continental crust.**

Coring (circle): 1-2-3-APC VPC* XCB MDCB* PCS (RCB) Re-entry HRGB

Downhole measurements: **Standard strings (geophysical, geochemical, FMS)**

Estimate of days on site:

*Systems currently under development

Target(s) (see Proposal Submission Guidelines): A (B) C D E F G H (circle)

Site Survey Information (see Proposal Submission Guidelines for details and requirements):

		Check	Details of available data and data that is still to be collected
01	High res. seismic refl.		
02	Deep penetration seis. refl.	✓	**Shell *Petrel* line N.407(5), SP 3900**
03	Seismic velocity		
04	Seismic grid		
05a	Refraction (surface)	✓	**Lamont sonobuoy data in area.**
05b	Refraction (near bottom)		
06	3.5 kHz		
07	Swath bathymetry		
08a	Side-looking sonar (surface)		
08b	Side-looking sonar (bottom)		
09	Photography or video		
10	Heat flow		
11a	Magnetics	✓	
11b	Gravity	✓	
12	Sediment cores		
13	Rock sampling		
14	Water current data		
15	OBS microseismicity		
16	Other		

Weather, Ice, Surface Currents: Potential large SW swells; best in southern summer

Seabed Hazards: None known

Territorial Jurisdiction: Australia

Proponent Name, Address, Ph., Fax, Email:

H.M.J. Stagg & J.B. Willcox,
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Date: December, 1994

ODP Site Summary Form

Fill out one form for each proposed primary and alternate site and attach to proposal.

Title of Proposal:	Investigation of a lower-plate continental margin: drilling in the Great Australian Bight region
Site-specific Objective(s) (List of general objectives must be inc. in proposal)	Provide a drilled profile of the lower continental crust in conjunction with GAB06A.

Site Name:	GAB07A
Area:	Great Australian Bight
Lat./Long.:	37° 02.2'S 135° 26.5'E
Water Depth:	5220 m
Sediment Thickness:	Negligible
Total penetration:	Approx. 300 m

	Sediments	Basement
Penetration:	<100 m	250 m
Lithology(ies):	Pelagic ooze.	Lower continental crust.

Coring (circle): 1-2-3-APC VPC* XCB MDCB* PCS (RCB) Re-entry HRGB

Downhole measurements: Standard strings (geophysical, geochemical, FMS)

Estimate of days on site:

*Systems currently under development

Target(s) (see Proposal Submission Guidelines): A (B) C D E F G H (circle)

Site Survey Information (see Proposal Submission Guidelines for details and requirements):

		Check	Details of available data and data that is still to be collected
01	High res. seismic refl.		
02	Deep penetration seis. refl.	✓	Shell *Petrel* line N.407(5), SP 3860
03	Seismic velocity		
04	Seismic grid		
05a	Refraction (surface)	✓	Lamont sonobuoy data in area.
05b	Refraction (near bottom)		
06	3.5 kHz		
07	Swath bathymetry		
08a	Side-looking sonar (surface)		
08b	Side-looking sonar (bottom)		
09	Photography or video		
10	Heat flow		
11a	Magnetics	✓	
11b	Gravity	✓	
12	Sediment cores		
13	Rock sampling		
14	Water current data		
15	OBS microseismicity		
16	Other		

Weather, Ice, Surface Currents: Potential large SW swells; best in southern summer

Seabed Hazards: None known

Territorial Jurisdiction: Australia

Proponent Name, Address, Ph., Fax, Email:

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Australian Geological Survey Organisation, GPO Box 378, Canberra, ACT 2601, Australia
Phone: 61-6-2499343 Fax: 61-6-2499980
E-mail: hstagg@agso.gov.au

Date: December, 1994

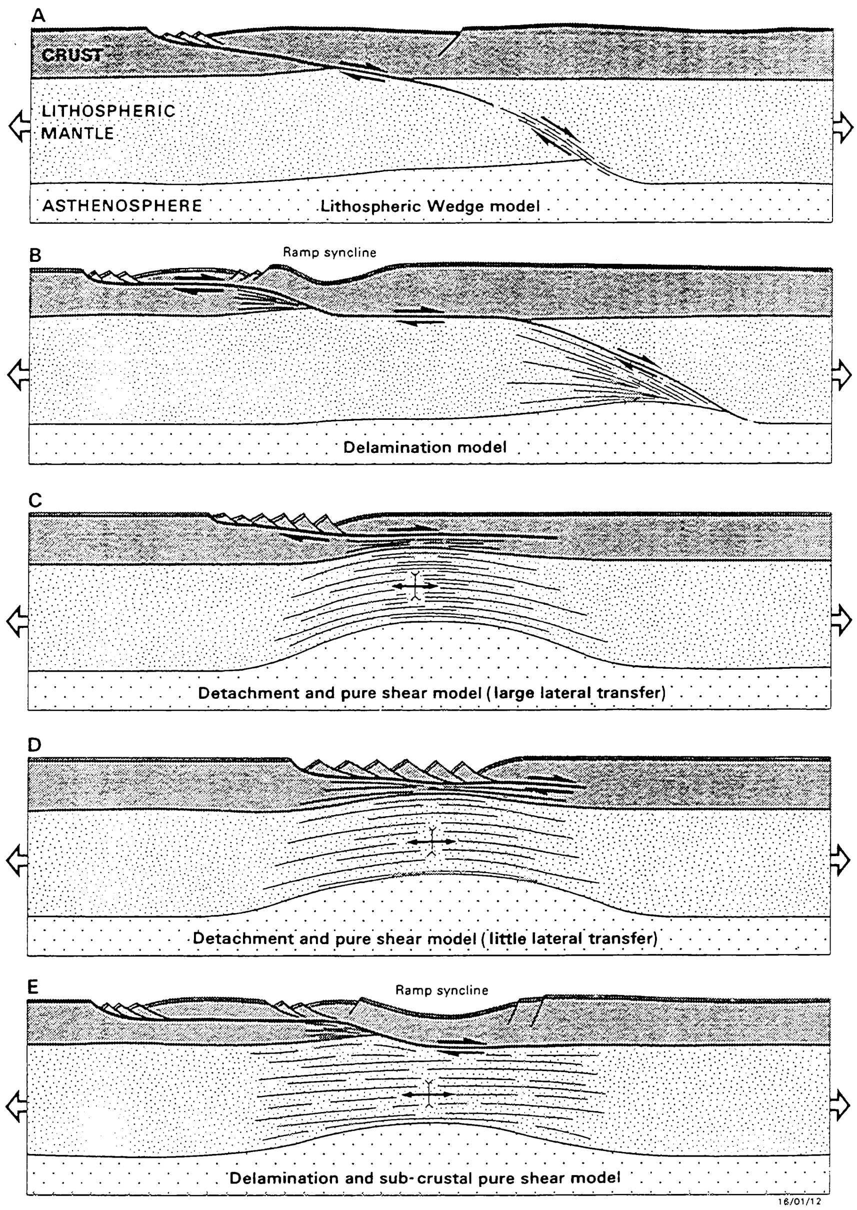

Figure 1: Five models for extension using detachments (after Lister et al., 1991): (A) throughgoing detachment; (B) ramps and flats on a detachment leading to the development of marginal plateaux and ramp basins; (C) detachment plus pure shear stretching of the lithosphere at the end of the detachment, with the zone of ductile stretching substantially offset from the zone of brittle faulting; (D) detachment plus pure shear stretching below the detachment, but the zone of ductile stretching below the detachment is offset only a little from the zone of brittle extension in the upper crust; (E) ramps and flats in the detachment plus ductile stretching below the detachment.

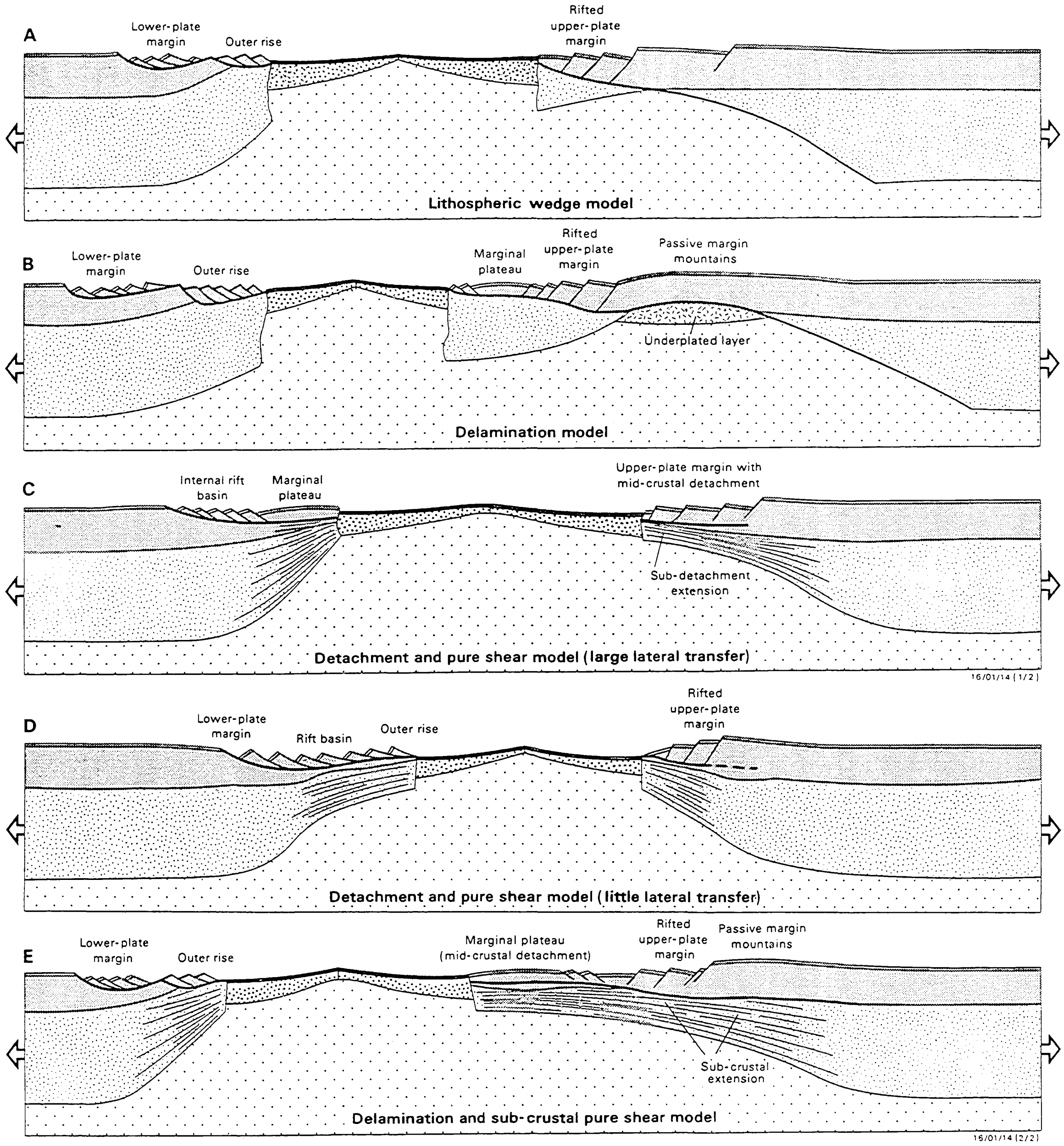

Figure 2: The same five models in the previous figure taken to large extensions, past the stage of early seafloor spreading (after Lister et al., 1991). Margin architectures illustrate the complementary asymmetry and specific spatial relationships between different margin elements predicted by the five detachment models.

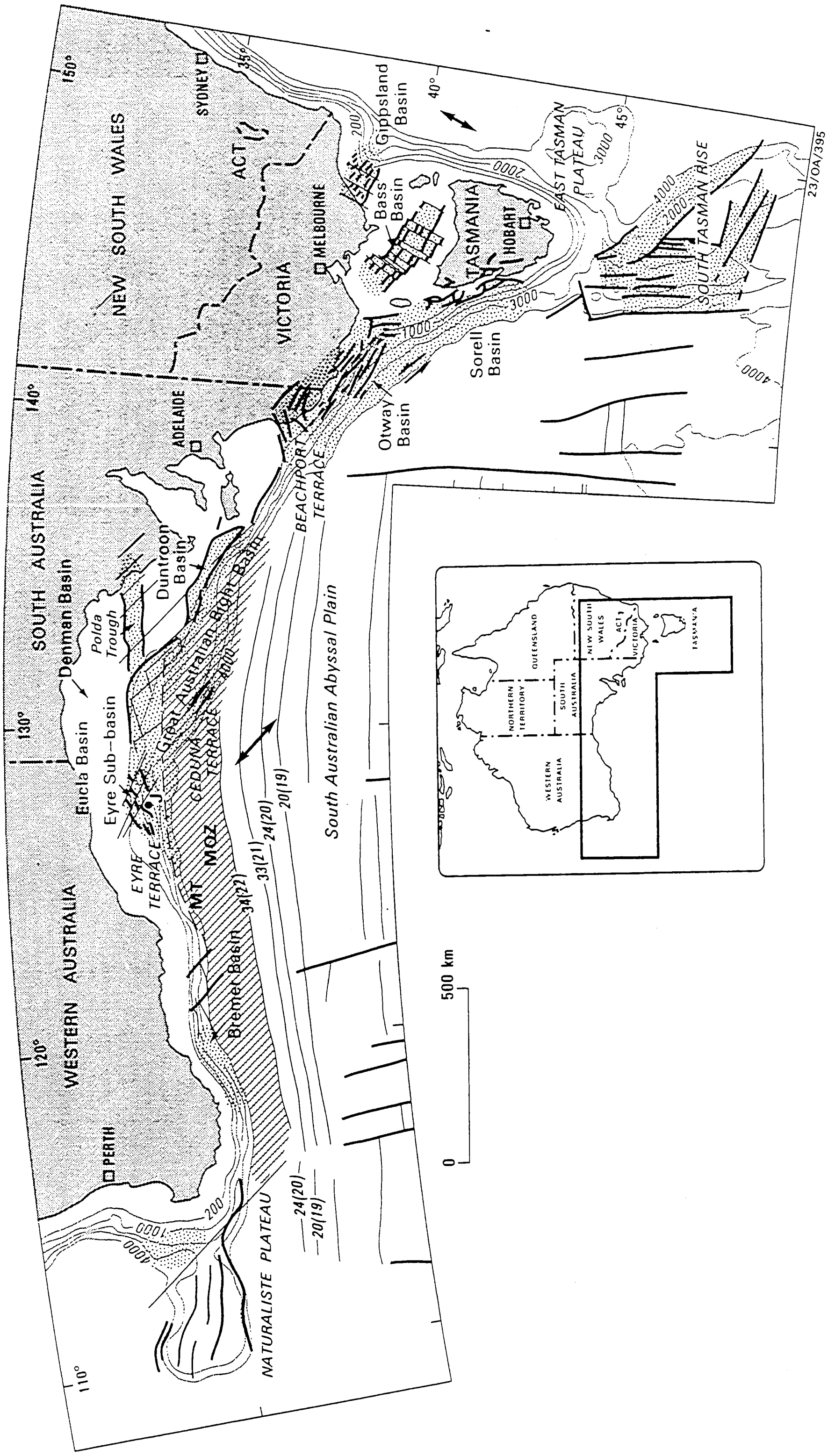

Figure 3: Map of the southern margin of Australia and part of the Southern Ocean (after Willcox, 1990), showing the major structural features of the passive margin. Gross bathymetry shown by the 200 m and 1000-4000 m isobaths; sedimentary basins showing main extensional and transfer faults are screened; J = Jerboa-1 exploration well. Numbered lines on the oceanwards side of the Magnetic Quiet Zone (MQZ) are seafloor spreading magnetic anomaly traces interpreted by Cande & Mutter (1982). MT is the magnetic trough which defines the landward edge of the MQZ. Arrows show the sense of lithospheric extension based on seismic and gravity data.

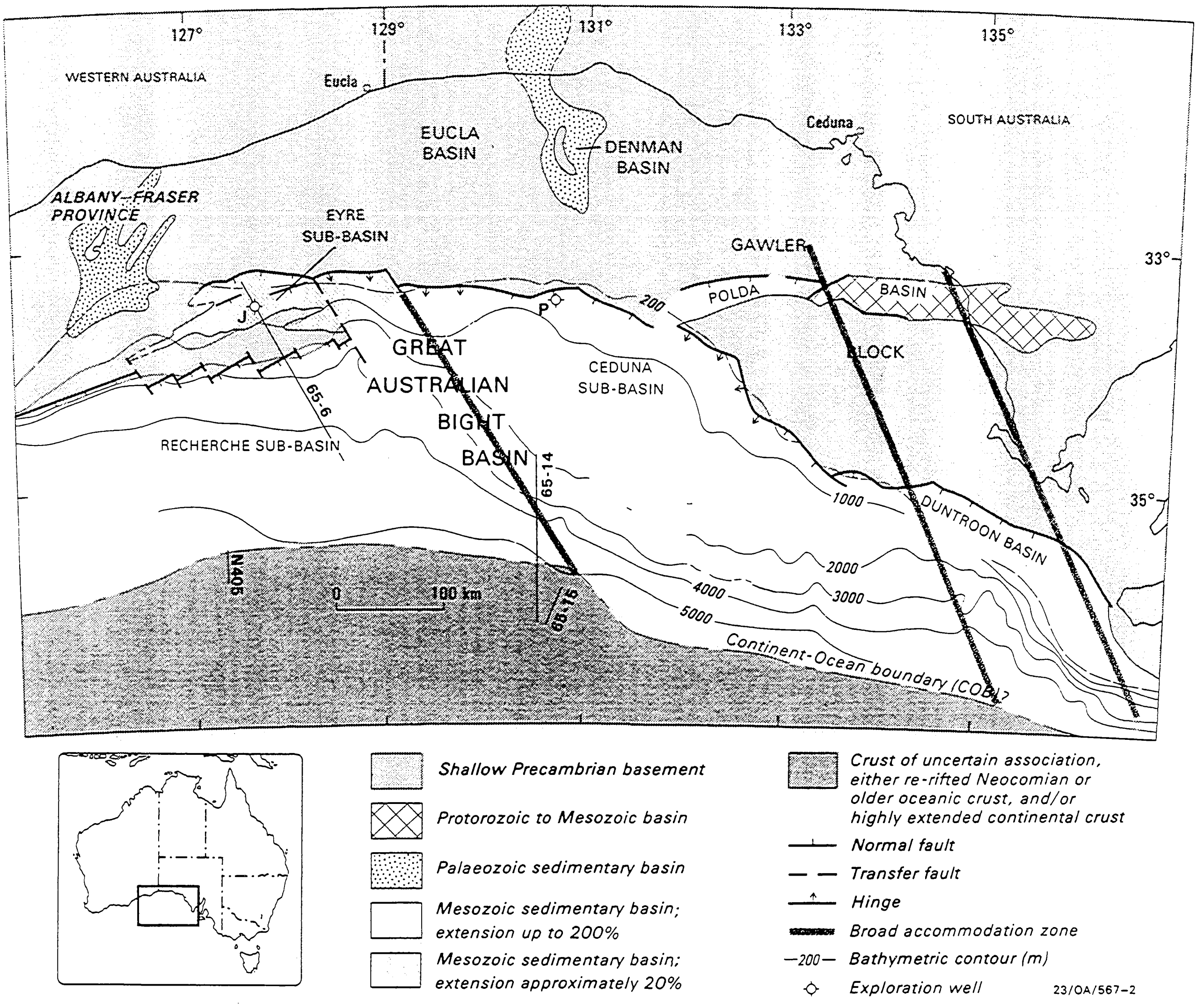

Figure 4: Tectonic elements of the Great Australian Bight region, southern margin of Australia (after Stagg & Willcox, 1992).

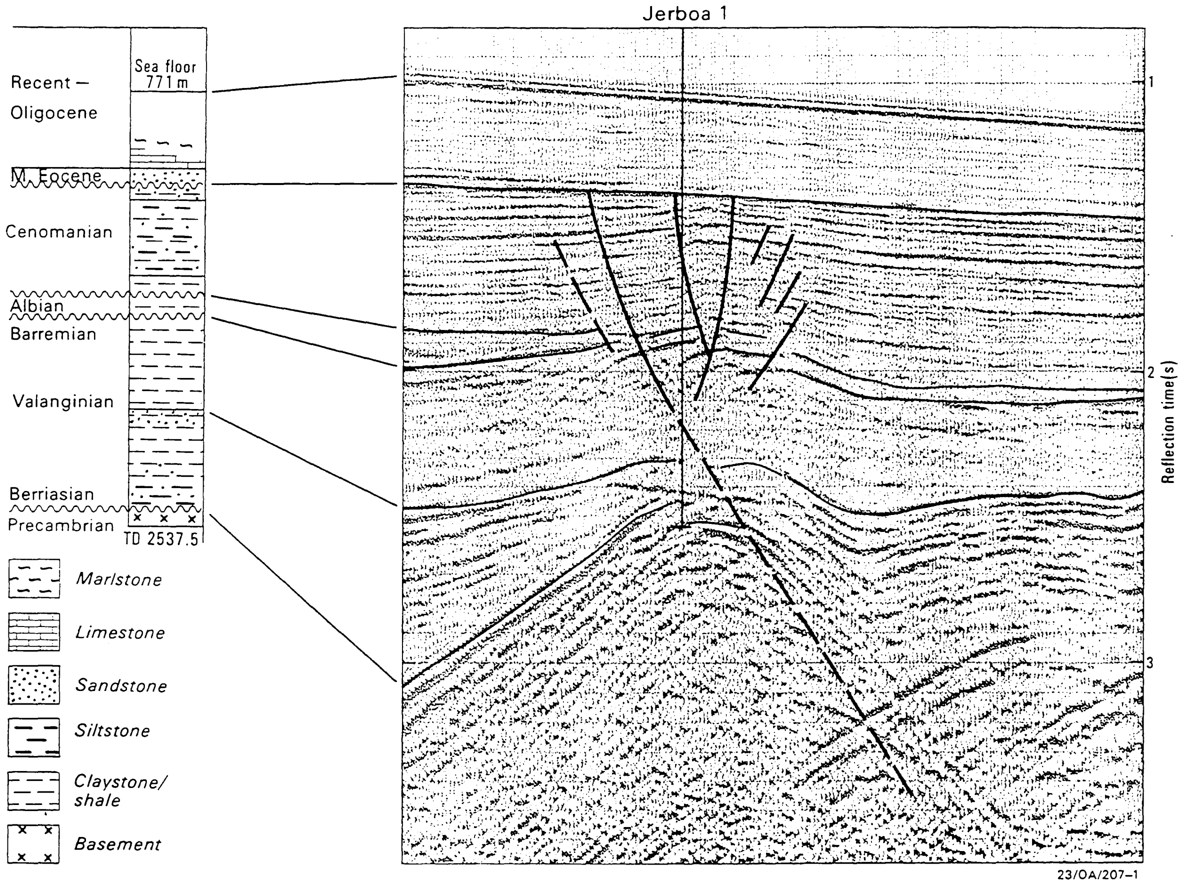

Figure 5: Portion of AGSO seismic line 65-6 through Esso Jerboa-1 exploration well, showing ages and lithologies of sequences penetrated (after Stagg & Willcox, 1992).

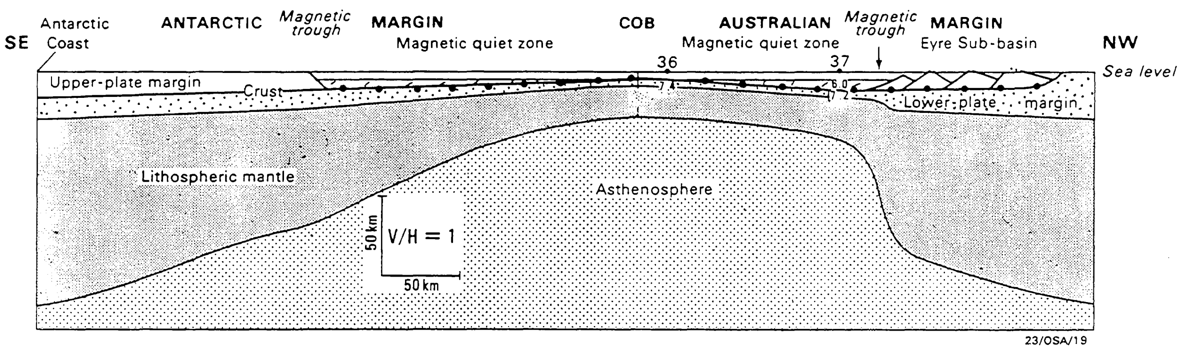

Figure 6: Balanced detachment model interpretation of the Eyre Sub-basin portion of the southern Australian margin and its complementary Antarctic margin (after Etheridge et al., 1990).

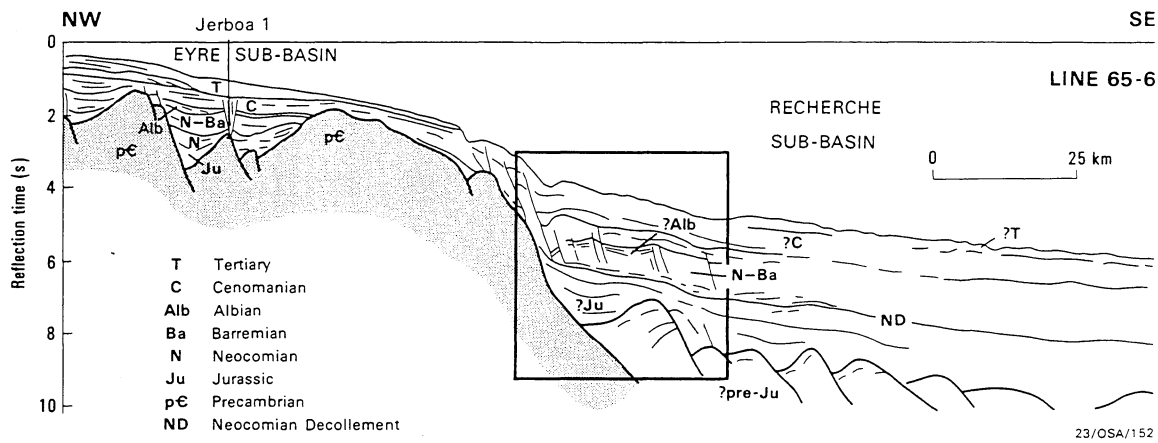

Figure 7: Line drawing of AGSO seismic line 65-6 across the Eyre Sub-basin and continental rise (Recherche Sub-basin) in the western Great Australian Bight (after Stagg & Willcox, 1992).

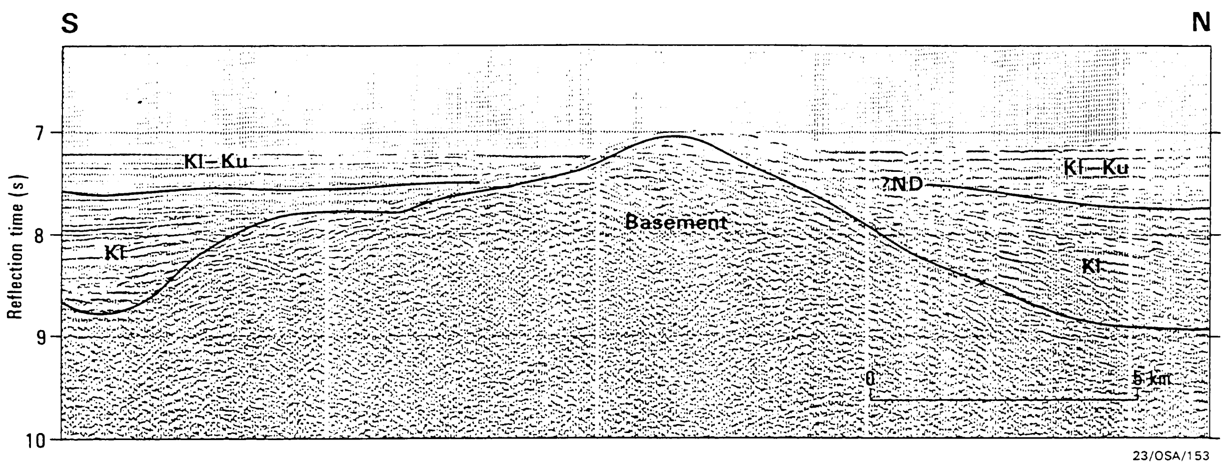

Figure 8: Portion of Shell *Petrel* line N.405 across the basement hummock that has been interpreted as the COB in the western Great Australian Bight (after Stagg & Willcox, 1992). Correlation of the Valanginian horizon *ND* across this hummock on to oceanic crust is shown.

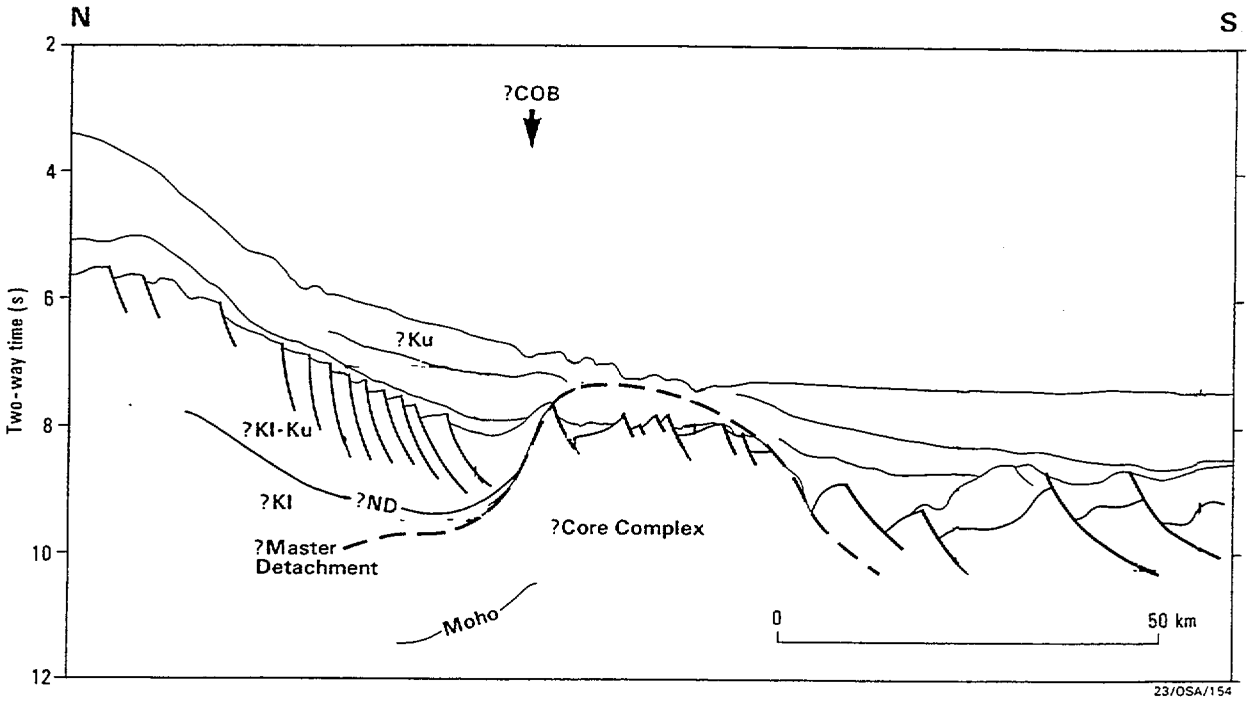

Figure 9: Line drawing of AGSO line 65-14, extending from the outer margin of the Ceduna Terrace, across the narrow continental rise, and on to the South Australian Abyssal Plain (after Stagg & Willcox, 1992). Position of the magnetically-defined COB is shown. If the shallow basement shown in the centre of the profile is a metamorphic core complex (or 'outer high'), then the true position of the COB is to the south of the profile shown here.

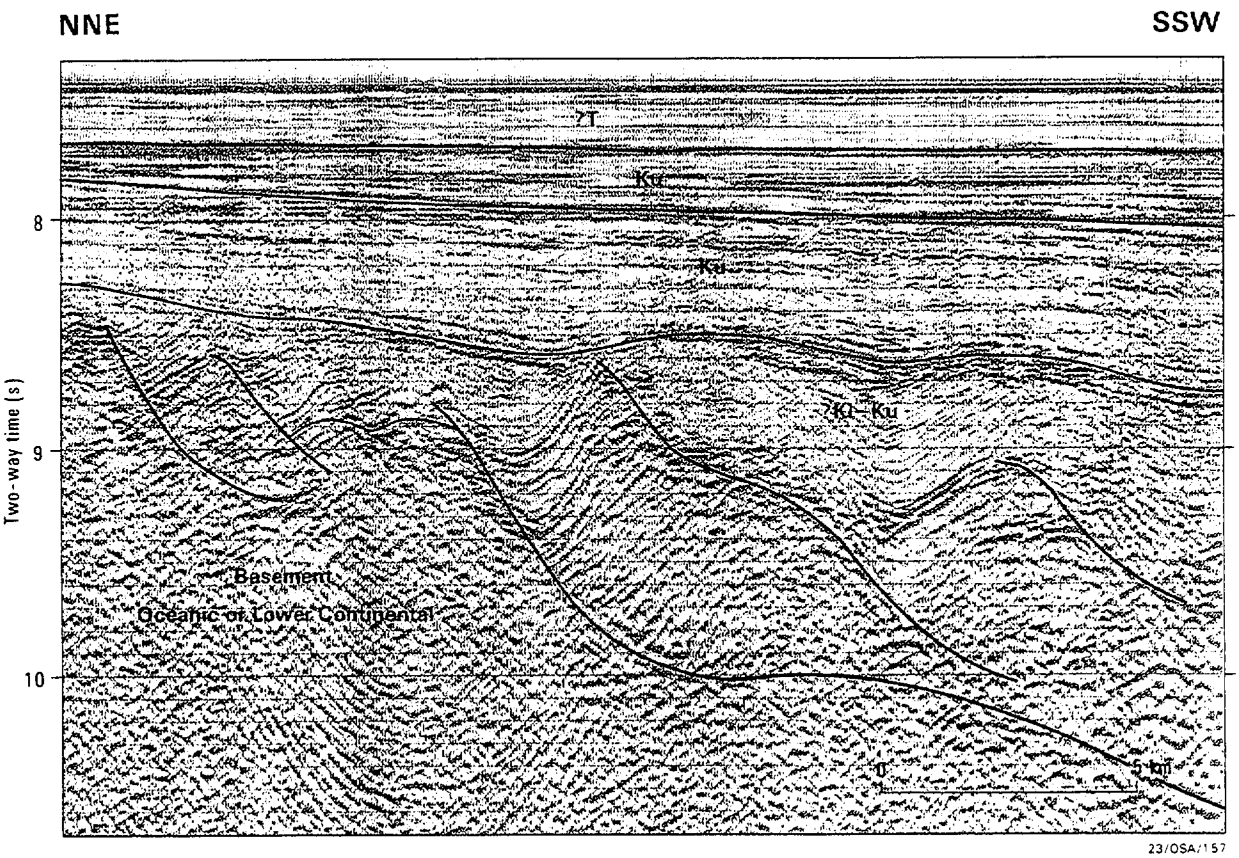

Figure 10: Portion of AGSO line 65-15, showing south-dipping listric faults within basement and ?Lower to Upper Cretaceous sediments south of the interpreted metamorphic core complex (after Stagg & Willcox, 1992).

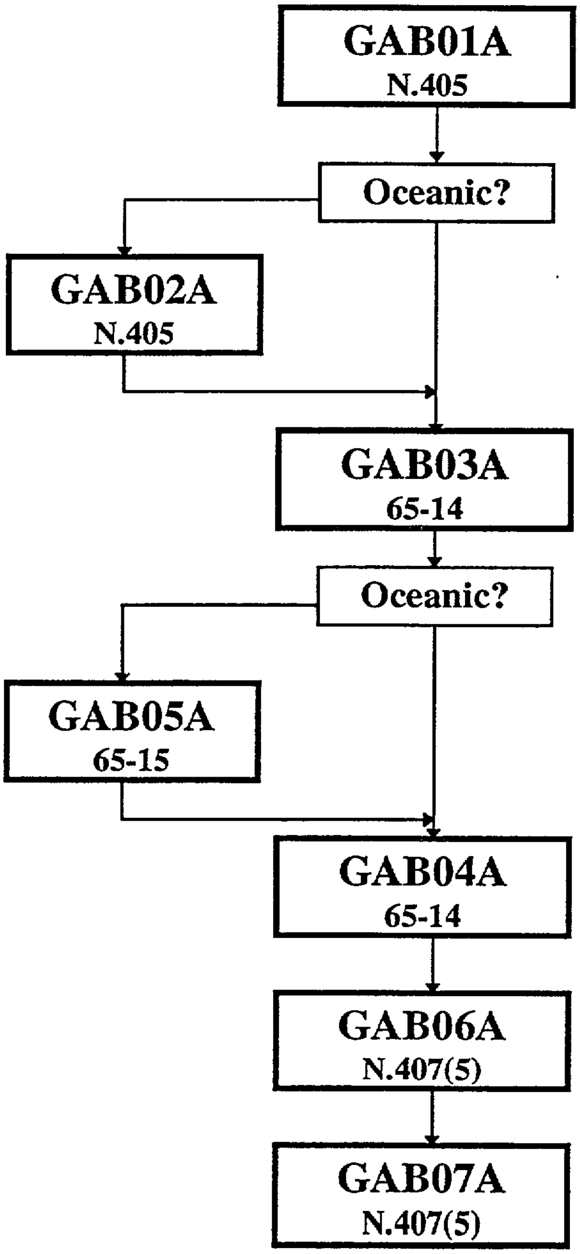

Figure 11: Flow chart showing the decisions to be followed in drilling ODP sites GAB01A to GAB07A.

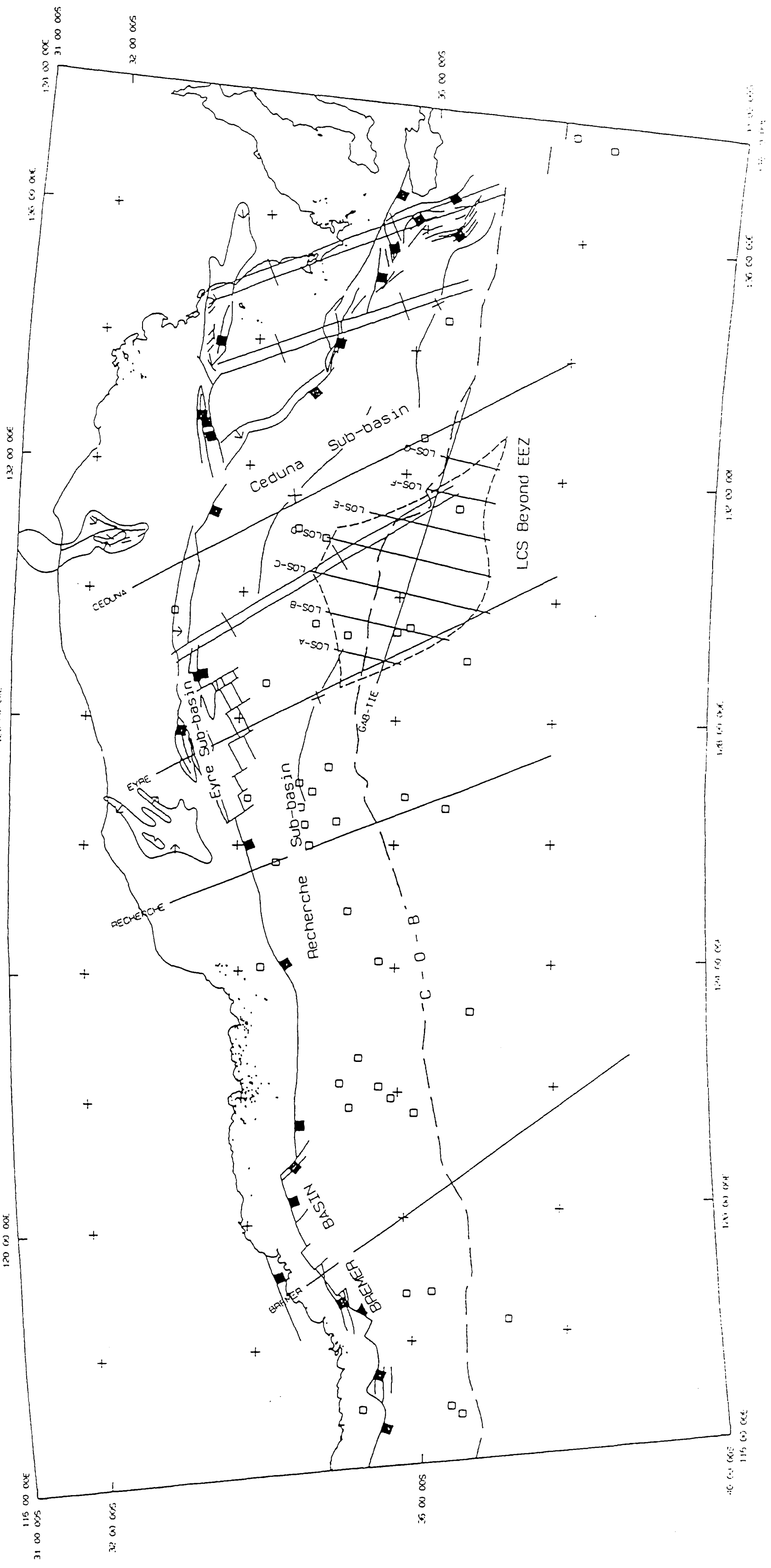

Figure 12: Locations of proposed AGSO deep-seismic profiles on the southern margin of Australia. Profiles are labelled 'Bremer', 'Recherche', 'Eyre', 'Ceduna', 'LOS-A' to 'LOS-G', and 'GAB-TIE'.

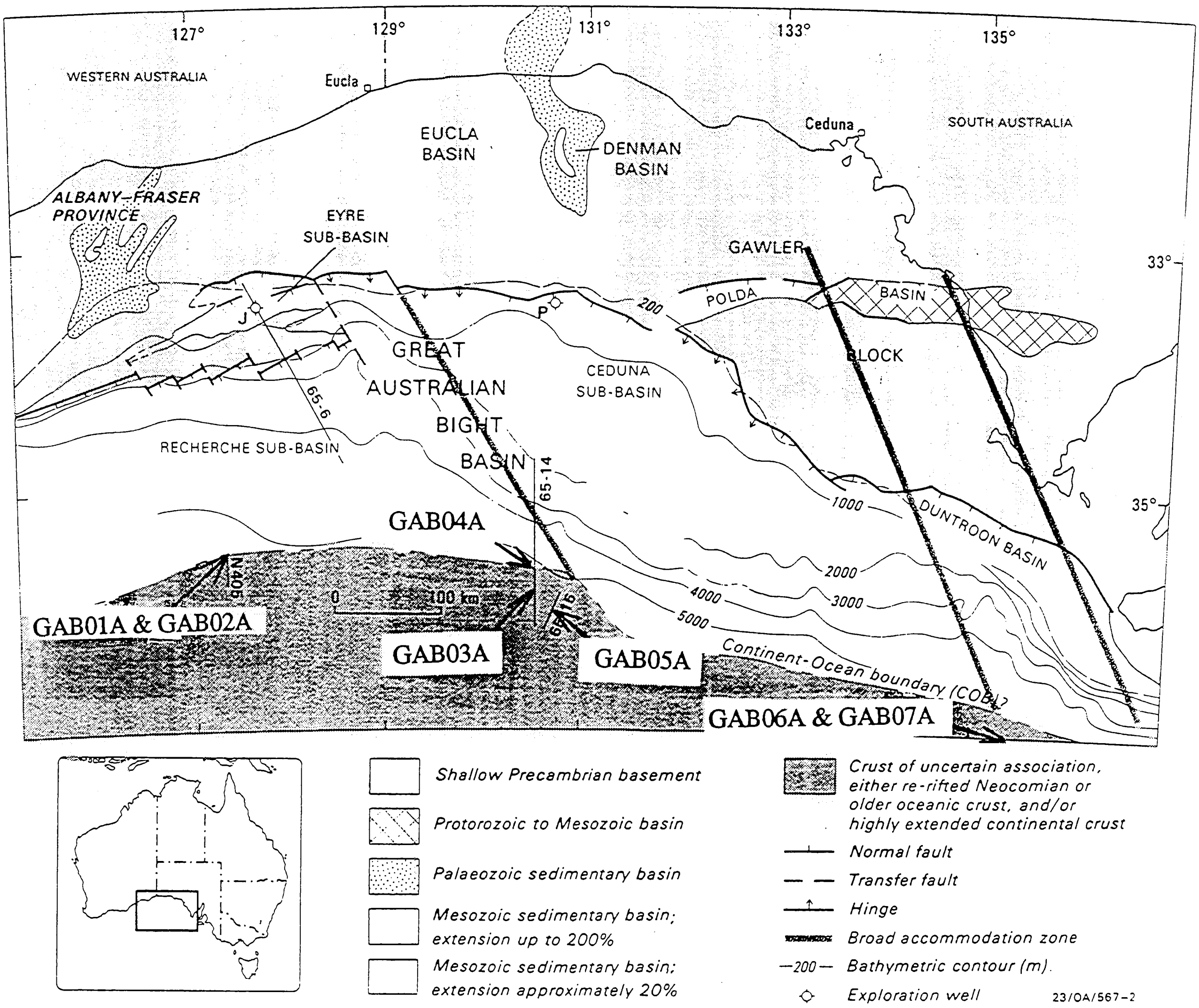

Figure 13: Tectonic elements of the Great Australian Bight, showing the locations of proposed ODP sites GAB01A to GAB07A.

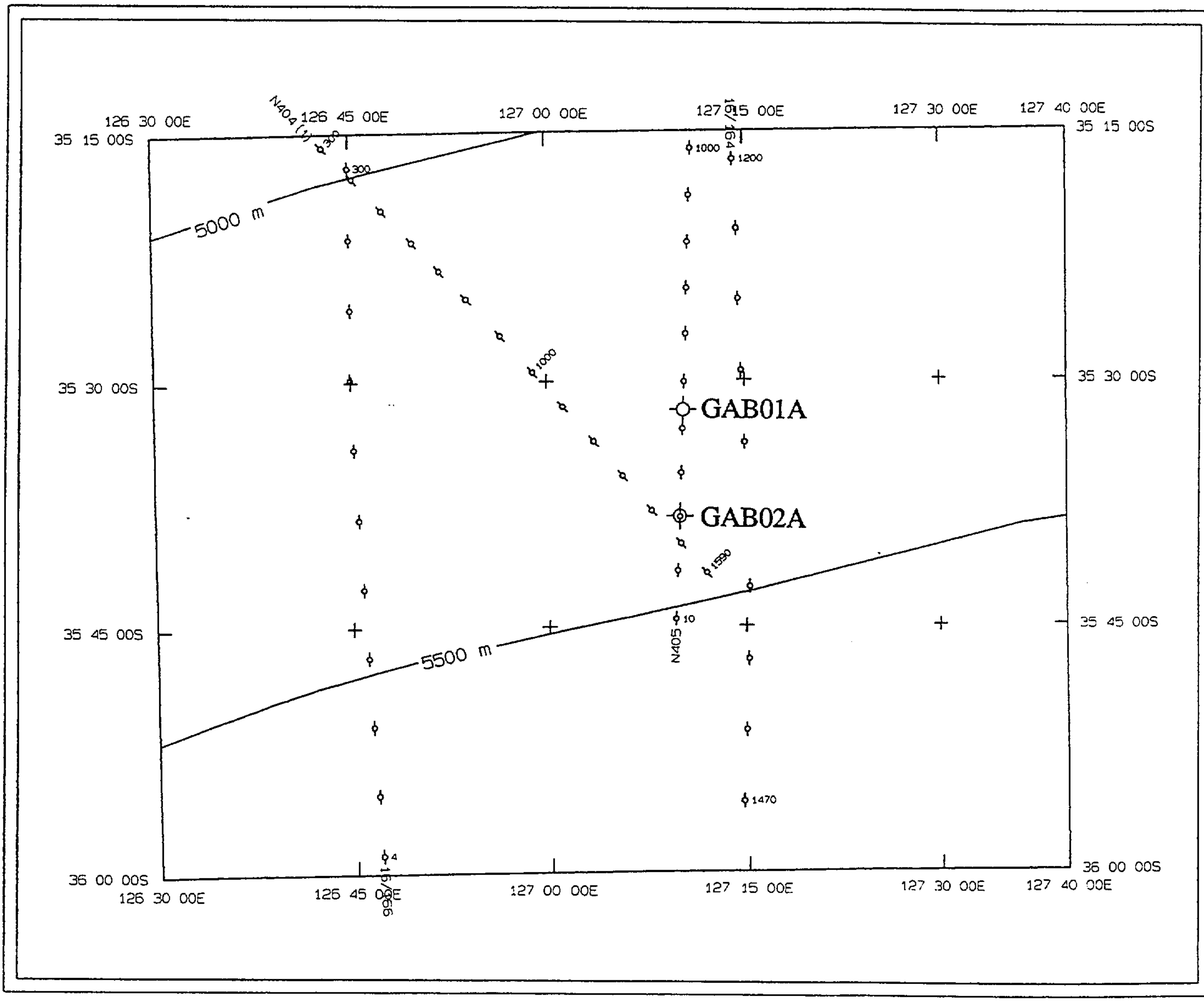

Figure 14: Location map for ODP sites GAB01A and GAB02A. Bathymetric contours in metres.

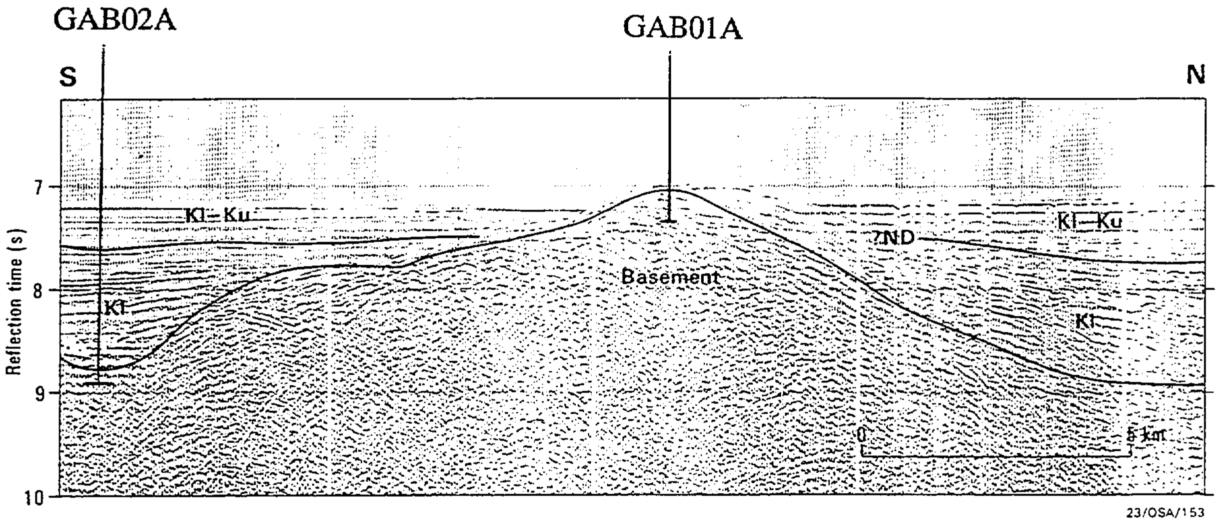

Figure 15: Portion of Shell *Petrel* line N.405 showing the location of ODP sites GAB01A and GAB02A

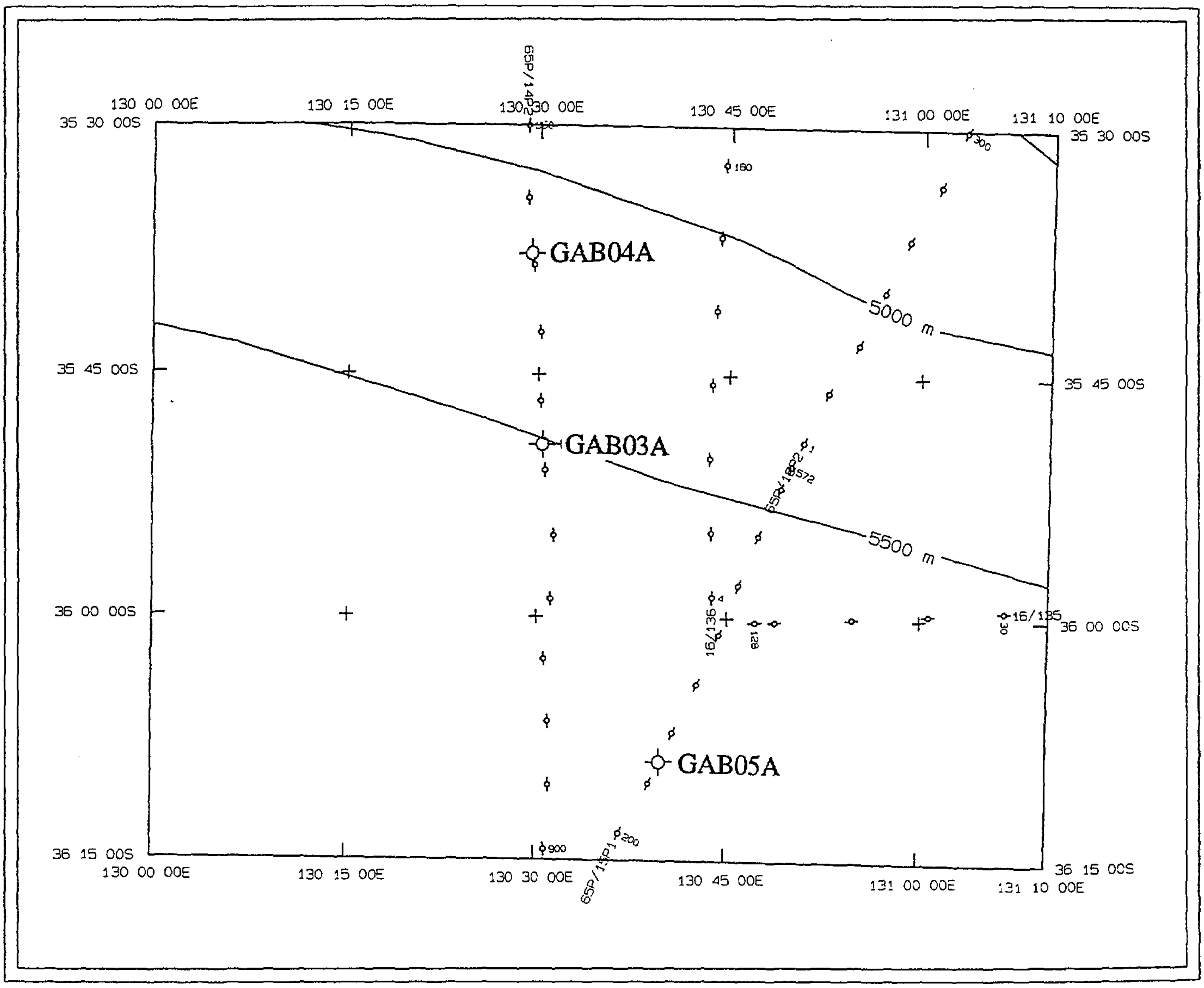

Figure 16: Location map for ODP sites GAB03A to GAB05A. Bathymetric contours in metres.

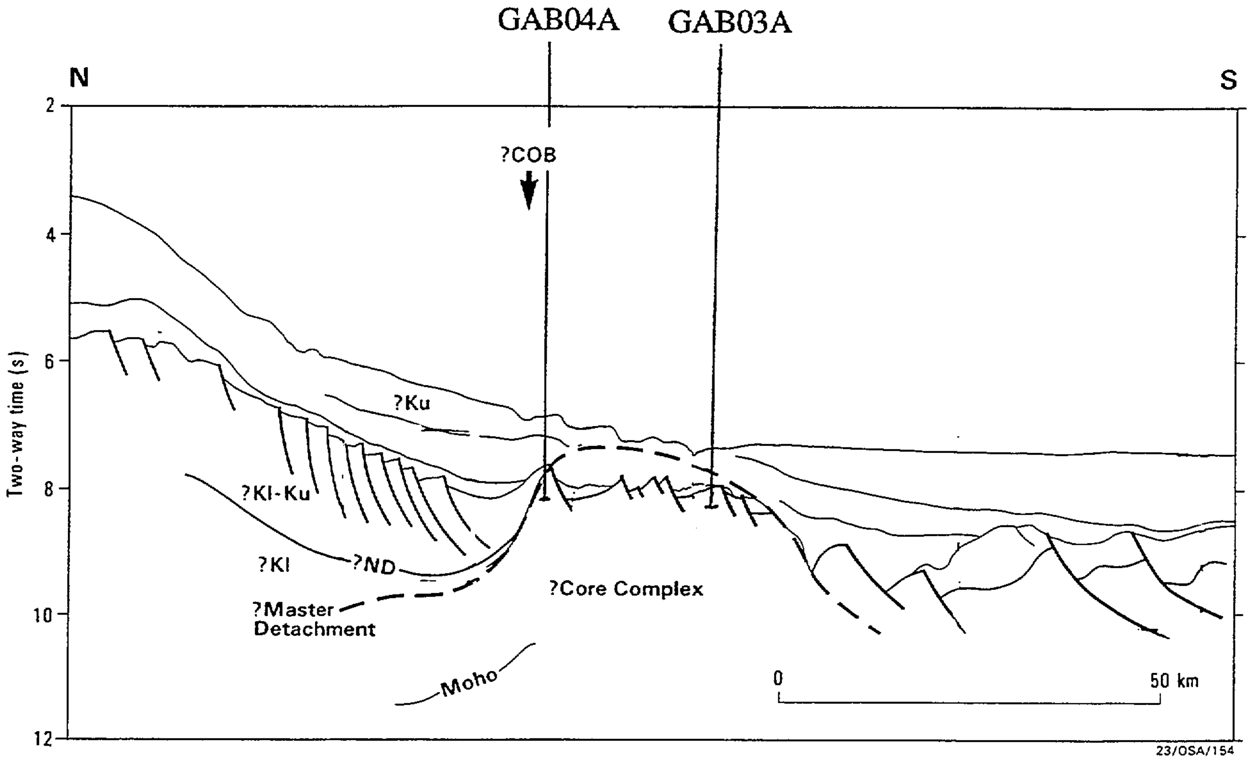

Figure 17: Line drawing of AGSO line 65-14, showing the location of ODP Sites GAB03A and GAB04A.

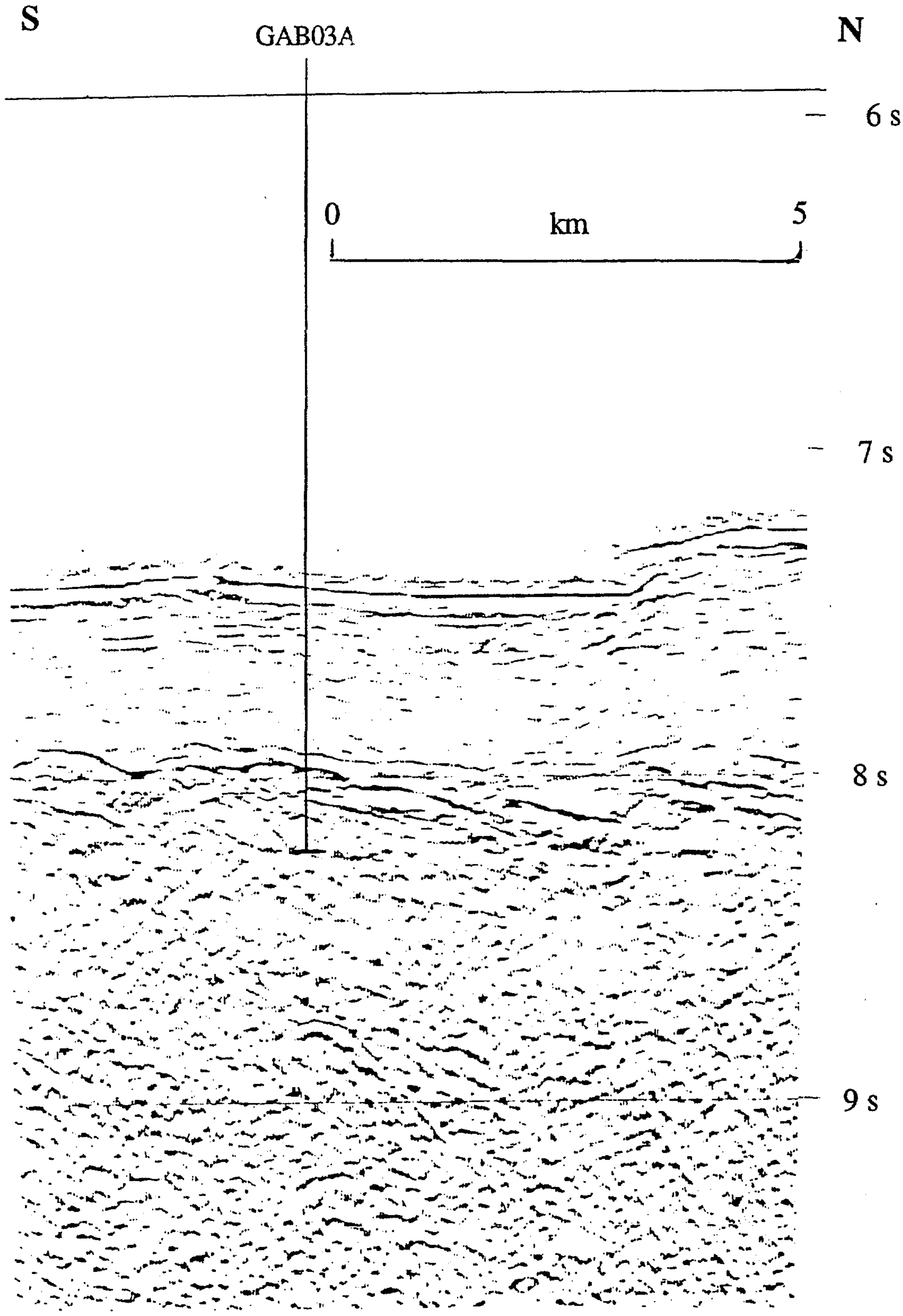

Figure 18: Portion of AGSO line 65-14, showing the location of ODP site GAB03A. Note that the orientation of this display is reversed to the line drawing of 65-14.

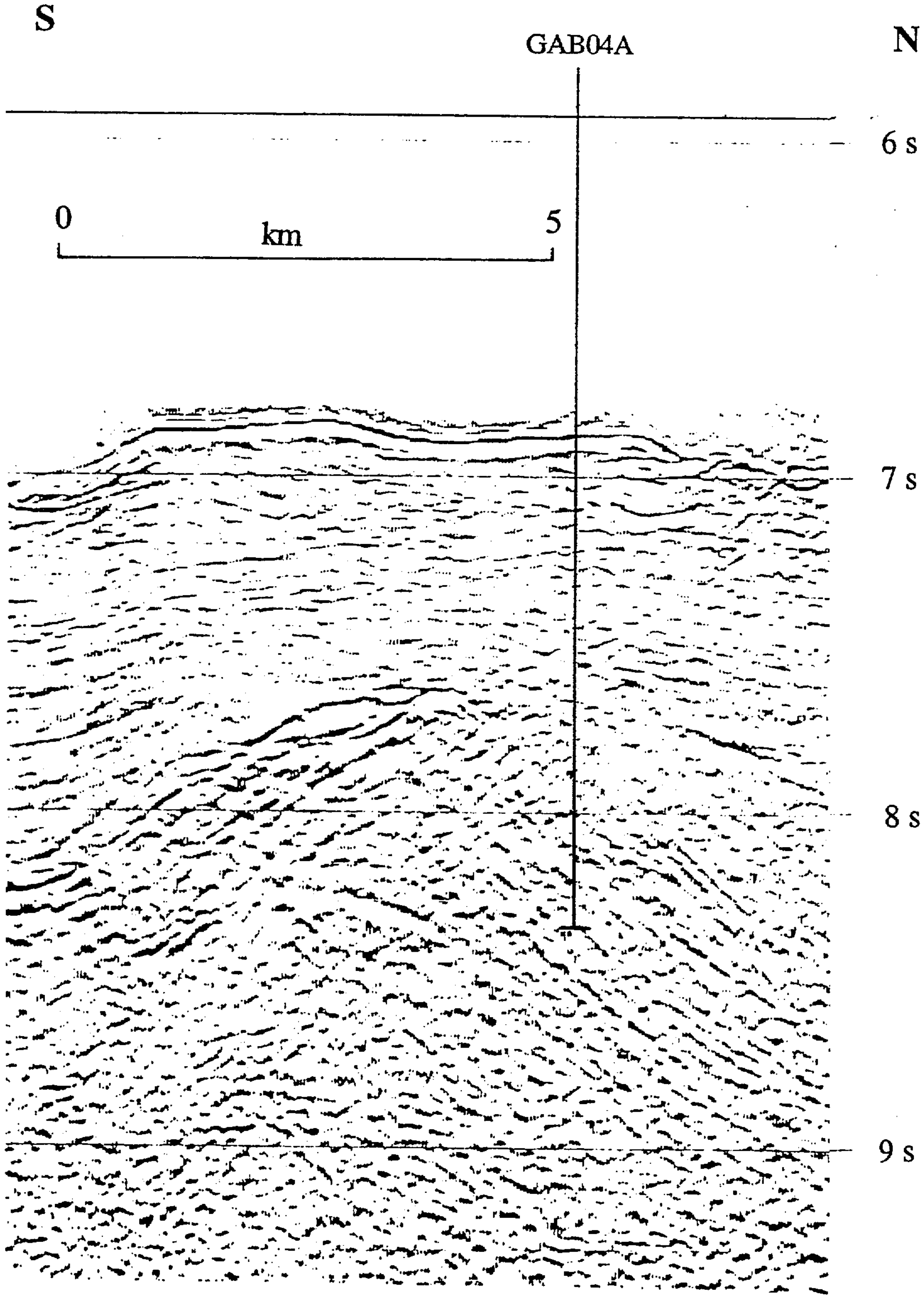

Figure 19: Portion of AGSO line 65-14, showing the location of ODP site GAB04A. Note that the orientation of this display is reversed to the line drawing of 65-14.

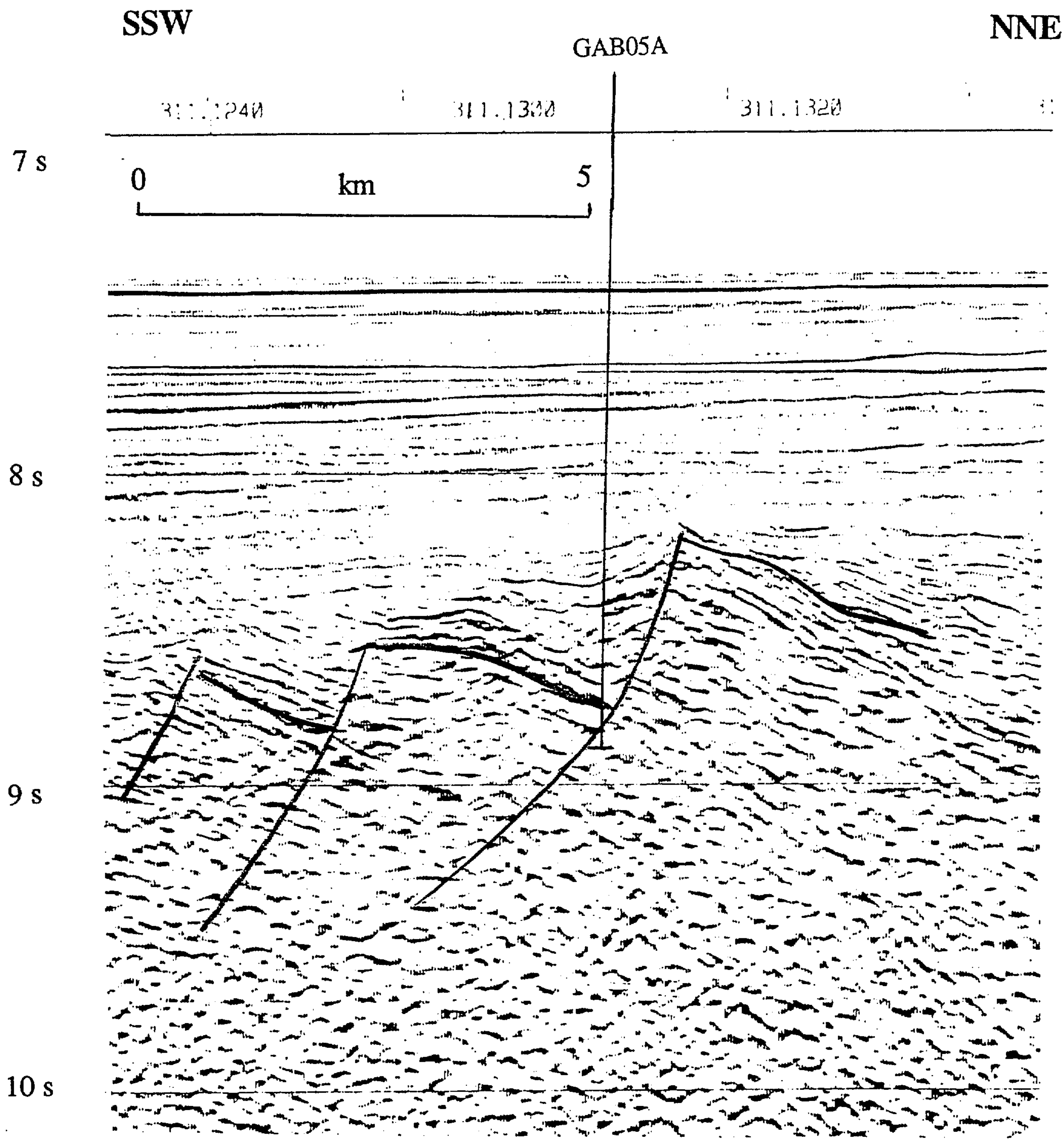

Figure 20: Portion of AGSO line 65-15, showing the location of ODP site GAB05A.

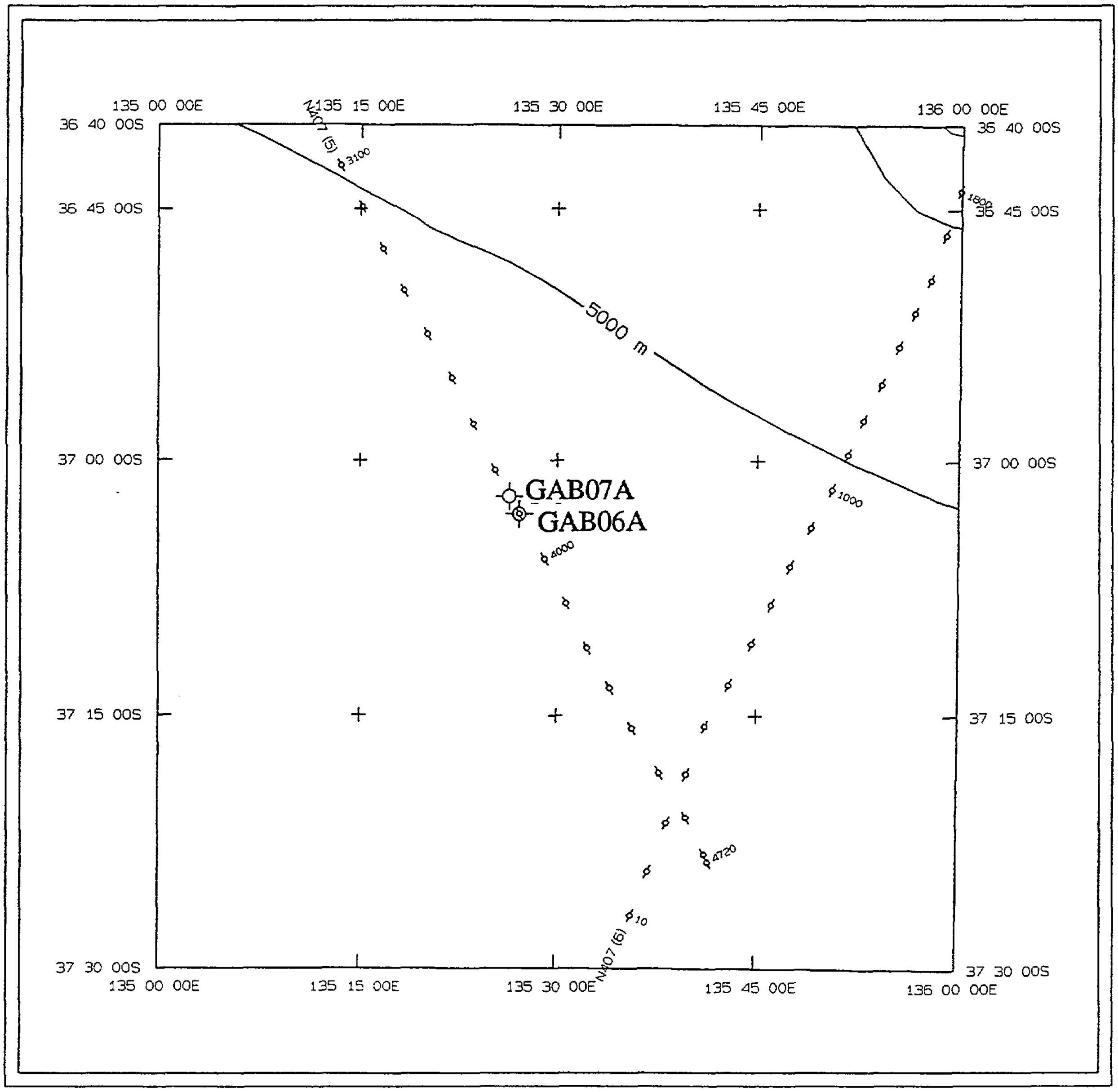

Figure 21: Location map for ODP sites GAB06A and GAB07A. Bathymetric contours in metres.

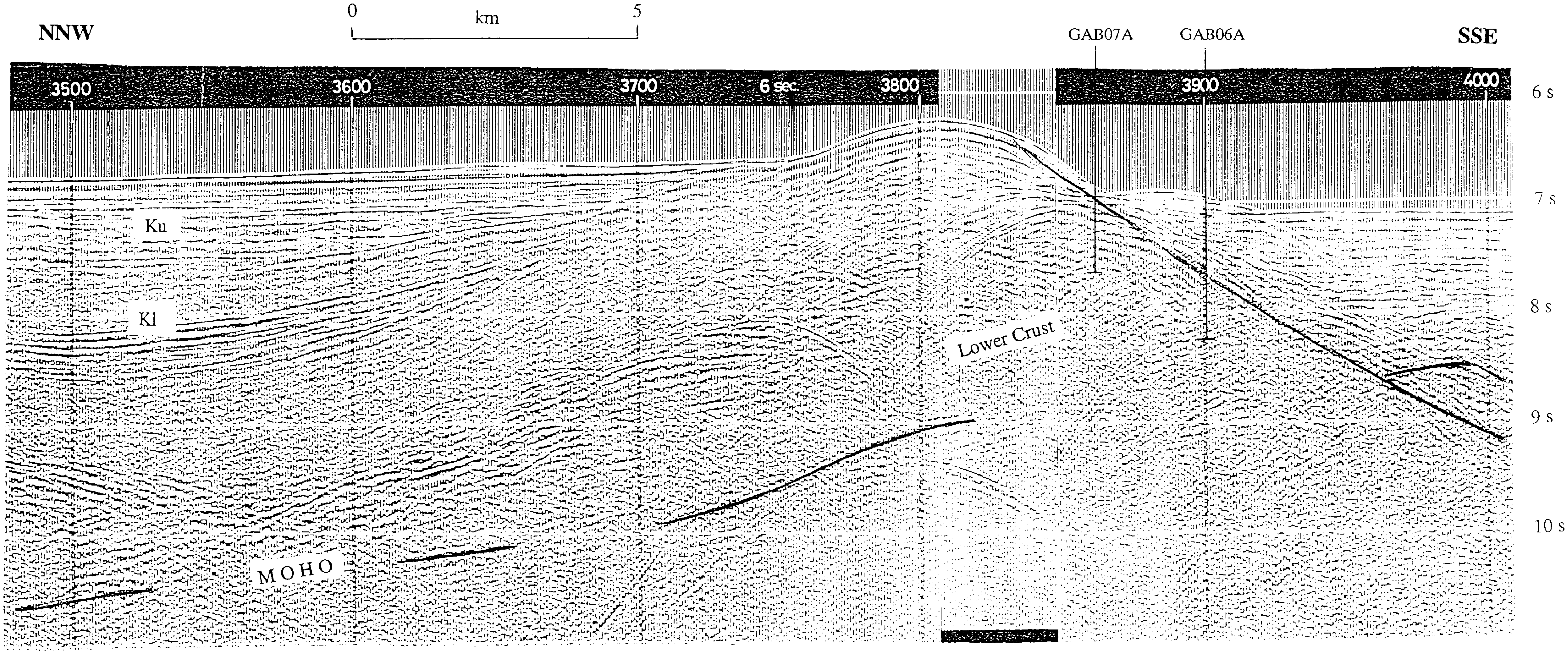

Figure 22: Portion of Shell *Petrel* line N.407(5), showing the location of ODP sites GAB06A and GAB07A.