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# INVESTIGATION OF LINEARLY MAGNETISED RIFTED CRUST AND THE EVOLUTION OF HIGH EXTENSION/SLOW SPREADING CONTINENTAL MARGINS: A PROPOSAL FOR DRILLING IN THE GREAT AUSTRALIAN BIGHT REGION BY THE OCEAN DRILLING PROGRAM



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# INVESTIGATION OF LINEARLY MAGNETISED RIFTED CRUST AND THE EVOLUTION OF HIGH EXTENSION/SLOW SPREADING CONTINENTAL MARGINS:

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

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# FOREWORD

In early 1994, Stagg & Willcox (1994) submitted a Letter of Intent to the Ocean Drilling Program that foreshadowed the submission of a formal proposal for ODP drilling on the southern margin of Australia. It addressed a number of objectives that included (I) the testing of pure and simple shear detachment models to margin formation (drilling of a potential detachment surface), (ii) Gondwanan rifting and breakup history, and (iii) crustal development within a high extension/slow seafloor spreading regime.

Following favourable comment received from ODP, a full proposal for Australian southern margin drilling was submitted in December 1995 - 'Investigation of a Lower-Plate Continental Margin: A Proposal for Drilling in the Great Australian Bight Region by the Ocean Drilling Program' (Stagg & Willcox, 1995). The proposal (Proposal 466) underwent review by the thematic panels in Spring 1995 and was rated 11th by the Tectonics Panel. Although the panel was convinced by the data presented in the proposal that a significant contribution to the study of divergent margin processes could be gained from drilling at the locations presented, they however suggested that the scientific focus should be redirected to answer only the simple question: 'Why are there linear magnetic anomalies over faulted crust?' They also recommended that plate kinematics, petrology and biostratigraphic experts be brought into the proposal.

The document presented herein is essentially a new ODP proposal entitled 'Investigation of Linearly Magnetised Rifted Crust and the Evolution of High Extension/Slow Spreading Continental Margins', which takes cognisance of the deliberations of the ODP Tectonics Panel. This proposal replaces the former Proposal 466.

# ABSTRACT

Linear magnetic anomalies have been observed over zones of deep-seated, normally faulted crust of uncertain origin in a number of locations world-wide, including the South African margin, the Red Sea, the Scotia Basin margin of eastern Canada and the Great Australian Bight. The widespread distribution of these provinces suggests that the processes which have governed their formation are an important component in the understanding of the tectonic development of non-volcanic rifted margins. The southern margin of Australia, formed by the separation of Australia and Antarctica in the Cretaceous and long considered an example of a classic, non-volcanic, rifted margin, provides an ideal region to determine the origins of such linearly magnetised rifted crust.

In the western part of the Great Australian Bight the rifted margin consists of a broad band of highly extended continental crust that underlies the continental rise. The age of rifting can be deduced from high quality deep seismic data and exploration wells in the area. The band of extended crust is bounded on its southern side by an east-west trending basement ridge (possibly up to 1000 km long) considered by many workers to be the continent-ocean (COB) boundary and to mark the oceanward extent of the continental lithosphere. Beyond the basement ridge lies a zone of enigmatic crust that is characterised by:

- linear magnetic anomalies (interpreted to be a product of slow seafloor spreading and dated as A34, Cenomanian, and younger);
- rotated tilt-blocks with southerly dipping faults.

As the margin has been relatively sediment-starved since breakup, particularly in the Tertiary, and since there has been minimal post-breakup reactivation, it provides a relatively easy target for ODP drilling.

A suite of three sites proposed within the linearly magnetised rifted crust, has the potential to address two quite different problems:

1. If the basement penetrated is continental or transitional, then what is the nature of the crust that can produce pseudo seafloor spreading magnetic lineations?
2. If the basement penetrated is normal oceanic, then what are the processes that have led to the re-rifting of oceanic crust?

The sites are:

**Site SAAP01A** on an extensive easterly trending ridge, probably composed of basement. It marks the oceanward edge of crust that is interpreted as highly extended and continental in origin, usually interpreted as the continent-ocean boundary.

**Site SAAP02A** targeted near the crest of a clearly defined tilt-block corresponding in position to Anomaly 34. The nature of the 'basement' within these blocks should be a key indicator of the source of the magnetic lineations in the region. Three possibilities exist: oceanic basement, continental basement, or exhumed and rifted upper mantle.

**Site SAAP03A** intended to sample the oldest syn-rift sediment deposited during development of the enigmatic tilt blocks.

# LINEAR MAGNETIC ANOMALIES AND RIFTED TRANSITIONAL CRUST

Linear magnetic anomalies have been observed over zones of deep-seated, normally faulted crust of uncertain origin in a number of locations world-wide, including the South African margin (LaBreque & Zitellini, unpub. manuscript), the Red Sea (LaBreque & Zitellini, 1985), and most notably the Scotia Basin margin of eastern Canada (Chian et al., 1995) and the Great Australian Bight (GAB) (Stagg & Willcox, 1992; Figs 1-3). The widespread distribution of these provinces suggests that the processes which have governed their formation are an important component in the understanding of the tectonic development of non-volcanic rifted margins. It further appears that these provinces are significantly different to margins of the 'Galicia type', where a peridotite ridge, giving rise to a discrete magnetic anomaly, marks the landward limit of normal oceanic crust (Sawyer, Whitmarsh, Klaus et al., 1994).

In particular, these margins, which incorporate a *pseudo-transitional zone* (or PTZ), have several distinguishing characteristics:

- The rifted crust, although generally assumed to be of oceanic affinity, is neither obviously oceanic nor obviously continental;
- The associated magnetic anomalies are typically quite poorly defined;
- The crust appears to be thin and highly extended;
- Initial spreading rates for the generation of oceanic crust are considered to be low to very low.

Our prime concern in this drilling proposal, is to try to understand the mechanism that has led to the formation of this rifted, linearly magnetised crust of the PTZ, and particularly,

- is there a relationship between the 'rift' features and the interpreted slow initial seafloor spreading rates? and
- does the age of the margin and the high degree of lithospheric extension inferred near the continent-ocean boundary (COB) exert any controls over the structure of the emplaced oceanic crust?

To date, the only model proposed for the origin of these subdued lineations is that of LaBreque & Zitellini (1985), which is as yet untested. Their model uses a process filter as a representation of the myriad processes that blur the magnetisation patterns that record the seafloor spreading process. The process filter acts as a smoothing filter by taking into account the dispersion of feeder dykes or width of the rift zone and the volcanic effusion and thickness of layer 2. However, high-quality seismic data from the GAB and the Scotia Basin are characterised by the presence of rotated fault blocks and show no obvious evidence for high levels of magmatism, suggesting that LaBreque & Zitellini's model may not be appropriate, at least at margins of this type.

An alternative explanation for the coincidence of lineated magnetic anomalies and rifted crust within a PTZ, may be related to the occurrence of slow spreading oceanic crust, as in the North Atlantic. Mutter & Karson (1992) proposed that mechanical deformation by major normal faulting was the primary mechanism in the evolution of slow spreading oceanic ridges. A model derived from their observations indicates that the faulting predominantly dips *away* from the spreading ridge. In contrast, Salisbury & Keen's (1993) interpretation of deep seismic data off the coast of Nova Scotia, while also concluding that mechanical deformation is the dominant spreading mechanism, shows the faults dipping *towards* the ridge. Seismic data from the Great Australian Bight (Stagg & Willcox, 1995) also show extensional faults with this sense of dip (Figs 3, 4). While neither of these cases directly discussed the effect of mechanical deformation on the generation of seafloor spreading magnetic anomalies, it would intuitively be expected that faulting of the magnetised layer would have a smoothing effect on the anomalies that is comparable to the effects in LaBreque & Zitellini's (1985) model.

The foregoing studies lead us to propose the following fundamental question:

### What is the connection between linear marginal magnetic anomalies and rifted transitional crust on a non-volcanic continental margin (PTM)?

The Great Australian Bight presents an excellent opportunity to address this question, as:

- The margin has been relatively sediment-starved since ?Cenomanian breakup, leaving the pre-rift section less than 1500 m below seabed at some key locations;

- Magnetic lineations, interpreted as generated during slow seafloor spreading (Cande & Mutter, 1982), overlie faulted and extended crust;

- The magnetic lineations parallel a basement ridge which extends for over 1000 km and which has generally been interpreted to mark the oceanward extent of continental lithosphere (eg Veevers, 1986);

- Post-rift deformation, as documented in the sedimentary basins on the adjacent continental margin appears to be virtually absent, with the principal structuring at this time being mainly due to adjustments during post-rift thermal subsidence; and

- Framework seismic reflection, magnetic, and satellite gravity data are available, with new deep-seismic data scheduled to be acquired in late 1996 (Appendix 1). Since the regional geology is relatively uniform, although wells are few, the stratigraphy can be interpreted with reasonable confidence. A regional seismic refraction data set (Talwani et al., 1979), encompassing all the major crustal provinces, is also available. It has been interpreted as showing the transitional velocity characteristics of the PTZ.

In this proposal, we suggest that three sites in the central Great Australian Bight provide a good opportunity for the Ocean Drilling Program to address an important aspect of one of the initiatives emphasised in the current Long Range Plan (Ocean Drilling Program, 1996) - ie 'Exploring the deep structure of continental margins and oceanic crust'.

This drilling proposal supersedes that previously proposed for the Great Australian Bight region by Stagg & Willcox (1995) which was principally designed to address aspects of detachment models in continental margin formation. Drilling on the Galicia margin (eg Sawyer, Whitmarsh, Klaus et al., 1994), which had similar structural objectives, was inconclusive in answering the key questions proposed by existing detachment models. The ODP sites put forward in this document, although a addressing a totally different problem, could indirectly shed some light on detachment concepts depending on the basement geology that is actually drilled.

**The ODP Long Range Plan**

The current ODP Long Range Plan (Ocean Drilling Program, 1996) seeks to build on ODP's existing record of achievement through the pursuit of two major research themes, viz:

- Dynamics of Earth's environment, and

- Dynamics of Earth's interior.

Within these themes, the Long Range Plan (LRP) identified three frontier initiatives that would capitalise on new drilling and logging technologies and on advances in scientific techniques and conceptual frameworks:

- Understanding natural climate variability and the causes of rapid climate change;

- *In situ* monitoring of geological processes; and

- **Exploring the deep structure of continental margins and oceanic crust.**

In the third of these initiatives, the LRP specifically identified the deep structure of rifted continental margins, deformation at convergent margins, and the deep structure of oceanic crust as the types of challenges that can bee addresses with deep drilling.

# 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. 1). 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. 2) -

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 (Fig. 5), 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 (Fig. 6) 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 (Fig. 3). 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 (Fig. 3).

## 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. 6).

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 we present interpretations of portions of key seismic transects in the western and central GAB. The westernmost transect (Figs 5 & 7), BMR line 65-6 and Shell *Petrel* line N405 (the 'Eyre transect'), traverse the Eyre and Recherche Sub-basins (underlying the Eyre Terrace and continental rise, respectively), while the central GAB line (a composite of an industry seismic line and AGSO line 65-14; the 'Ceduna transect') extends from the continental shelf, across the major depocentre of the Ceduna Sub-basin, to the northern flank of the South Australian Abyssal Plain (Fig. 3).

During the 1980's, Lister et al. (1986) 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.

Using these principals, the central GAB was interpreted to have formed when the 'lower plate' Australian margin was pulled out from beneath the 'upper plate' Antarctic margin (Etheridge et al., 1990). Highly extended remnants of the upper plate were considered to be present 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 crustal extension, usually assumed by early workers to be N-S, has been reinterpreted 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.

During the past few years the nature of the lithospheric extension which leads to the formation of passive continental margins has been the subject of considerable debate. Pure extension has sometimes been favoured, particularly following from the analysis of basin subsidence histories. Brun & Beslier (in press) note that the symmetry of conjugate margins formed by such a mechanism, as observed, for example across the Goban Spur/ Flemish Cap zone in the North Atlantic, could be a potential argument in its favour. However, more commonly there is an apparent asymmetry, with a high displacement margin often associated with numerous extensional tilt-blocks, and a simpler ramp-type margin (the upper plate of Etheridge et al, 1990). Such a situation lends strength to arguments related to simple shear and associated lithospheric detachments.

Brun & Beslier (in press) consider that, on the basis of laboratory experiments, internal asymmetry can develop in a model undergoing pure shear. In their model, they demonstrate how the lower lithospheric mantle can be progressively exhumed during pure shear, and provide a mechanism by which the lower mantle will break through a 'heterogeneous boudinage' of the overlying brittle material. They relate the process to the presence of sheared peridotite on the Iberian margin. The authors consider that their model can be applied 'not only to Atlantic-type margins, but also to other examples such as the Tyrrhenian Sea and the southwest Australia margin.

## Eyre Transect

AGSO Line 65-6 (Fig. 5) 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 (Fig. 6). 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 7 is a portion of Shell *Petrel* Line N.405, beyond the southern end of line 65-6, in which ND can be seen to onlap a basement hummock which Veevers (1986, fig. 3) 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.

**Ceduna Transect**

The Ceduna transect (Fig. 3) traverses the continental margin from the unextended crust of the northern GAB, across the Ceduna Sub-basin, to the northern flank of the South Australian Abyssal Plain. The positions of the 'COB' and seafloor spreading magnetic anomaly A34, as identified from magnetic data by Veevers et al. (1990) are shown on the section; the 'COB' again corresponds to a basement high in the seismic data. A stacked seismic section with no migration shows a highly-diffracting basement surface south of the COB, that could readily be identified as 'typical' oceanic crust. However, migration of the seismic data (Figs 3 & 4) 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".

## 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 modelled 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.

## PROPOSED DRILLING SITES AND DRILLING STRATEGY

We are in accord with the Tectonics Panel in agreeing that the enigmatic relationship between deep-seated rifted crust and linear magnetic anomalies would best be addressed by a sequence of four ODP test sites, as follows:

- 2 sites along one tilted block associated with linear magnetic anomalies - the first aimed at the oldest syn-rift sediments, and the second close to the crest of the block and aimed at penetrating basement;
- 1 hole to basement at the crest of the furthest seaward block;
- 1 hole to basement at the landward occurrence of normal diffractive oceanic crust.

However, there are two problems that restrict our ability to identify the sites suggested by the Tectonics Panel:

1. The available seismic lines do not extend as far as Anomaly 33, although they clearly cross Anomaly 34, as defined by Cande & Mutter (1982) and Veevers et al. (1990);
2. The lines do not extend as far as the boundary between faulted blocks and diffractive crust. The available *Eltanin* profiles meet this requirement, but their published records to which we have access are generally too poor in quality to propose even tentative sites

It is possible that this problem will be obviated in late 1996 with the programmed acquisition of deep-seismic data in the region by AGSO (Appendix 2; Fig. 8). In the event of this survey taking place, the new data will be used to define the additional sites proposed by the Tectonics Panel and to further refine the sites proposed here.

It should also be noted that the three proposed sites are located on two seismic lines, not the single transect recommended by the Tectonics Panel. However, as the seismic lines are tied and the sites are relatively closely spaced (all within 40 km), we do not believe that this presents a problem.

Bearing these temporary limitations in mind, we propose to evaluate the crux of the problem with three sites, as follows:

**Site SAAP01A** (Figs 9-15). The site lies on an extensive easterly trending high, probably composed of basement. In the past this structure has been interpreted as the COB (Veevers & others, 1990) or as a metamorphic core complex (Stagg & Willcox, 1992). It could possibly fit the characteristics of exhumed mantle as modelled by Brun & Beslier (in press). In any case, it appears to lie along the seaward edge of crust that is interpreted as highly extended and continental in origin, and along the landward flank of deep-seated faulted crust that is associated with magnetic lineations. The principal objective at this site is to determine the basement type within the rifted continent-ocean transition - be it oceanic, thinned continental, or exhumed upper mantle. This site will encounter about 600 m of sediment, probably abyssal plain turbidites and pelagics, before penetrating basement.

Site SAAP02A (Figs 9-14, 16). The site is targeted near the crest of a clearly defined tilt-block corresponding in position to Anomaly 34 as defined by Cande & Mutter (1982) and Veevers et al. (1990). It lies approximately 40 km to the south-southeast of Site SAAP01A. The nature of the 'basement' within these blocks should be a key indicator of the source of the magnetic lineations in the region. Three possibilities exist:
Oceanic basement - suggesting that we are dealing with a rifting mechanism that was operative during either the formation of oceanic crust and possibly related to an episode of slow spreading, or operative on older oceanic crust as has been suggested by some age correlations (Stagg & Willcox, 1992);
Continental basement - suggesting that an ultra-thin continental crust has been heavily injected by linear magnetic 'dike swarms', or that continental crust has been broken into slivers separated by E-W trending bands of magnetic oceanic material (Stagg & Willcox, 1992);
Exhumed and rifted upper mantle - in this case, the blocks may possibly represent rifting of upper mantle material that has been exhumed by pure shear extensional processes, or possibly they may be the remnants of brittle upper mantle boudinage structures of the type envisaged by Brun & Beslier (in press). The site is expected to penetrate about 900 metres of abyssal plain sediments above the basement block.

Site SAAP03A (Figs 9-14, 16). This site lies approximately 1.3 km south-southwest of site SAAP02A and is intended to sample the oldest syn-rift sediment deposited during development of the tilt blocks. Analysis of the sedimentary section should define the sedimentary environment during rifting, the timing of rifting, and the subsidence history. This site will penetrate approximately 1500 m of sediment (probable abyssal plain turbidites and pelagics) before reaching basement.

In summary, the sites have the potential to address two quite different problems:

1. If the basement penetrated is continental or transitional, then we will be examining the nature of the crust that can produce pseudo seafloor spreading magnetic lineations.

2. If the basement penetrated is normal oceanic, then we will be examining the processes that have led to the re-rifting of oceanic crust.

Site Summary forms for all sites are included in Appendix 3.

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# APPENDIX 1: 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 continental 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 2: EXECUTIVE SUMMARY FROM PROPOSAL FOR A LAW OF THE SEA SURVEY IN THE GREAT AUSTRALIAN BIGHT (after Ramsay & Symonds, in prep.)

Existing bathymetric data from the central Great Australian Bight (GAB) indicate that the position of the foot of the continental slope is such that there is claimable 'legal' Continental Shelf beyond the 200 nautical mile Australian Exclusive Economic Zone. The seaward extent of Continental Shelf is determined by either a fixed distance from the foot of slope position, or by a sediment thickness ratio, also based on the foot of slope position. We have used the former method (the Hedberg formula) to make the initial statement, but it is possible that the area of the Continental Shelf claim may be increased by using the sediment thickness formula. At present, there are no suitable seismic data available to test this option.

We propose to use R/V *Rig Seismic* to conduct a deep seismic survey covering the area delineated by the Hedberg formula, but extending farther south to test the sediment thickness formula. A series of eight lines has been planned, about 50 km apart, orthogonal to the slope of the continental margin. The lines are designed to go as far south as 38°, although they probably will not need to extend that far: the southern extent of each line will have to be determined onboard by reference to the seismic monitors, from which it is assumed the thickness of sediment can be calculated. The total line length planned is just over 2500 km, but a more realistic figure to satisfy this proposal is in the range of 1700 - 1900 km.

This document should be read in conjunction with two other proposals for work in the same general area (Stagg & Willcox, 1995; Feary, 1995). The former is for a number of deep seismic margin transects in the central GAB and across the margin south of Western Australia, while the latter proposes a high-resolution seismic survey in the western GAB; both are in support of subsequent ODP drilling. For reasons of economy, it ought to be possible to combine this present proposal with elements of one or both of these other proposals, to enlarge the work program to at least one normal cruise. Stagg & Willcox (1995) include a very comprehensive summary of the regional geology, while Feary (1995) includes some useful weather information for the area, indicating a preferred time window for such a survey to be successfully completed.

# APPENDIX 3: ODP SITE SUMMARY FORMS

ODP Site Summary forms are contained on the following pages.

## ODP Site Summary Form (6/93) Fill out one form for each proposed site and attach to proposal

| | |
|---|---|
| Title of Proposal: | Investigation of linear magnetic anomalies over 'rifted crust' and the evolution of high extension/slow spreading continental margins |
| Site-specific Objective(s) (List of general objectives must be inc. in proposal) | Define basement type within rifted continent-ocean transition (crust may be oceanic, thinned continental, or exhumed upper mantle). |

| | Proposed Site | Alternate Site |
|---|---|---|
| Site Name: | SAAP01A | |
| Area: | South Australian Abyssal Plain | |
| Lat./Long.: | 35° 49.3'S 130° 30.4'E | |
| Water Depth: | 5550 m | |
| Sed. Thickness: | 600 m | |
| Total penetration: | 700-800 m | |

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

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

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

*Systems currently under development

**Target(s)** :(see Appendix of Proposal Submission Guidelines6/93) A B C D E F G (check)ß

**Site Survey Information** (see Appendix of Proposal Submission Guidelines6/93 for details and requirements):

| | | Check | Details of data available and data still to be collected |
|---|---|---|---|
| 01 | SCS deep penetration | | |
| 02 | SCS High Resolution | | |
| 03 | MCS and velocity | ✓ | AGSO line 65-14, Julian time 310.2330 |
| 04 | Seismic grid | | |
| 05 | Refraction | ✓ | Extensive crustal refraction data in region. |
| 06 | 3.5 or 12 kHz | ✓ | |
| 07 | Swath bathymetry | | |
| 08 | H.-res side-looking sonar | | |
| 09 | Photography/video | | |
| 10 | Heat flow | | |
| 11 | Magnetics/gravity | ✓ | |
| 12 | Coring | | |
| 13 | Rock sampling | | |
| 14 | Current meter | | |
| 15 | Other | | |

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

Territorial Jurisdiction: Australia

Other Remarks:


| | Name/Address | Phone/FAX/Email |
|---|---|---|
| Contact Proponent: | H.M.J. Stagg,<br>Australian Geological Survey Organisation,<br>GPO Box 378,<br>Canberra ACT 2601 Australia | Phone: 61-6-2499343<br>Fax: 61-6-2499980<br>e-mail: hstagg@agso.gov.au |

## ODP Site Summary Form (6/93) Fill out one form for each proposed site and attach to proposal

| | |
|---|---|
| Title of Proposal: | Investigation of linear magnetic anomalies over 'rifted crust' and the evolution of high extension/slow spreading continental margins |
| Site-specific Objective(s) (List of general objectives must be inc. in proposal) | Define basement type in zone of magnetically lineated rifted crust within continent-ocean transition (thinned continental; exhumed and rifted upper mantle, or re-rifted oceanic). |

| | Proposed Site | Alternate Site |
|---|---|---|
| Site Name: | SAAP02A | |
| Area: | South Australian Abyssal Plain | |
| Lat./Long.: | 36° 08.3'S 130° 40.2'E | |
| Water Depth: | 5550 m | |
| Sed. Thickness: | 900 m | |
| Total penetration: | 1000 m | |

| | Sediments | Basement |
|---|---|---|
| Penetration: | 900 m | 100 m |
| Lithology(ies): | Abyssal plain turbidites & pelagics, claystone, siltstone | Transitional or oceanic crust |
| Coring (check): | 1-2-3-APC VPC* XCB MDCB* PCS RCB DCS* Re-entry | |
| Downhole measurements: | Standard strings (geophysical, geochemical, FMS) | |

*Systems currently under development

**Target(s)** :(see Appendix of Proposal Submission Guidelines6/93) A B C D E F G (check)ß

**Site Survey Information** (see Appendix of Proposal Submission Guidelines6/93 for details and requirements):

| | | Check | Details of data available and data still to be collected |
|---|---|---|---|
| 01 | SCS deep penetration | | |
| 02 | SCS High Resolution | | |
| 03 | MCS and velocity | ✓ | AGSO line 65-15, Julian time 311.1315 |
| 04 | Seismic grid | | |
| 05 | Refraction | ✓ | Extensive crustal refraction data in region. |
| 06 | 3.5 or 12 kHz | ✓ | |
| 07 | Swath bathymetry | | |
| 08 | H.-res side-looking sonar | | |
| 09 | Photography/video | | |
| 10 | Heat flow | | |
| 11 | Magnetics/gravity | ✓ | |
| 12 | Coring | | |
| 13 | Rock sampling | | |
| 14 | Current meter | | |
| 15 | Other | | |

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

Territorial Jurisdiction: Australia

Other Remarks:

| | Name/Address | Phone/FAX/Email |
|---|---|---|
| Contact Proponent: | H.M.J. Stagg,<br>Australian Geological Survey Organisation,<br>GPO Box 378,<br>Canberra ACT 2601 Australia | Phone: 61-6-2499343<br>Fax: 61-6-2499980<br>e-mail: hstagg@agso.gov.au |

## ODP Site Summary Form(6/93) Fill out one form for each proposed site and attach to proposal

| | |
|---|---|
| Title of Proposal: | Investigation of linear magnetic anomalies over 'rifted crust' and the evolution of high extension/slow spreading continental margins |
| Site-specific Objective(s) (List of general objectives must be inc. in proposal) | Sample oldest syn-rift section between tilted blocks in zone of magnetically lineated rifted crust. Date rifting and define sedimentary environments. |

| | Proposed Site | Alternate Site |
|---|---|---|
| Site Name: | SAAP03A | |
| Area: | South Australian Abyssal Plain | |
| Lat./Long.: | 36° 08.9'S 130° 39.8'E | |
| Water Depth: | 5550 m | |
| Sed. Thickness: | 1500 m | |
| Total penetration: | 1600 m | |

| | Sediments | Basement |
|---|---|---|
| Penetration: | 1500 m | 100 m |
| Lithology(ies): | Abyssal plain turbidites & pelagics, claystone, siltstone | Transitional or oceanic crust |

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

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

*Systems currently under development

**Target(s)** :(see Appendix of Proposal Submission Guidelines6/93) A B C D E F G (check)ß

**Site Survey Information** (see Appendix of Proposal Submission Guidelines6/93 for details and requirements):

| | | Check | Details of data available and data still to be collected |
|---|---|---|---|
| 01 | SCS deep penetration | | |
| 02 | SCS High Resolution | | |
| 03 | MCS and velocity | ✓ | AGSO line 65-15, Julian time 311.1307 |
| 04 | Seismic grid | | |
| 05 | Refraction | ✓ | Extensive crustal refraction data in region. |
| 06 | 3.5 or 12 kHz | ✓ | |
| 07 | Swath bathymetry | | |
| 08 | H.-res side-looking sonar | | |
| 09 | Photography/video | | |
| 10 | Heat flow | | |
| 11 | Magnetics/gravity | ✓ | |
| 12 | Coring | | |
| 13 | Rock sampling | | |
| 14 | Current meter | | |
| 15 | Other | | |

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

Territorial Jurisdiction: Australia

Other Remarks:

Contact Proponent:


| Name/Address | Phone/FAX/Email | |
|---|---|---|
| H.M.J. Stagg, 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 |

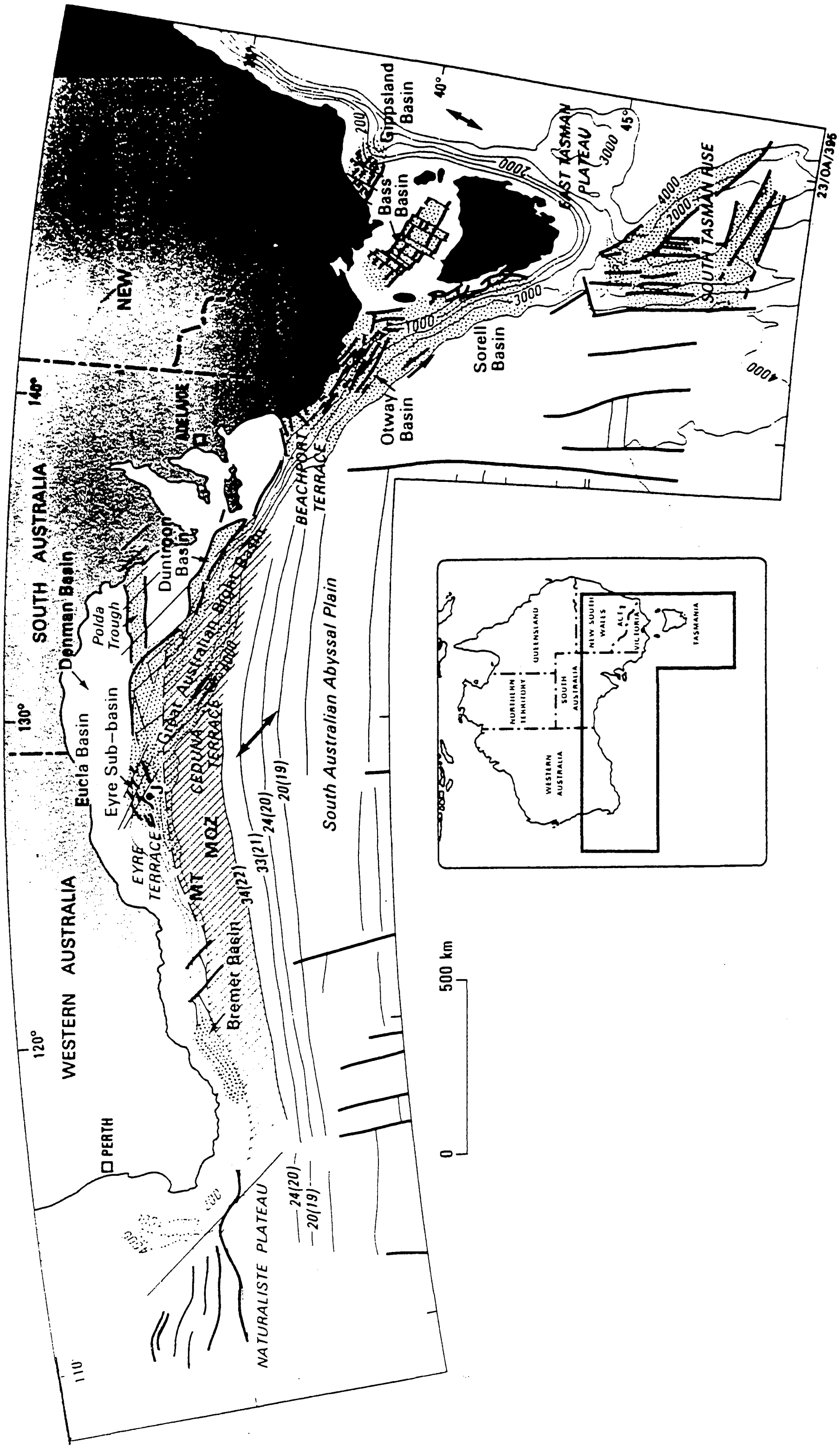


Figure 1: Southern margin of Australia and part of the Southern Ocean (after Willcox, 1990), showing the major structural features of the passive margin. Bathymetry shown by the 200 m and 1000-4000 m isobaths; sedimentary basins showing main extensional and transfer faults are screened; J = Jerboa-1 exploration well. Numbered lines oceanwards 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.

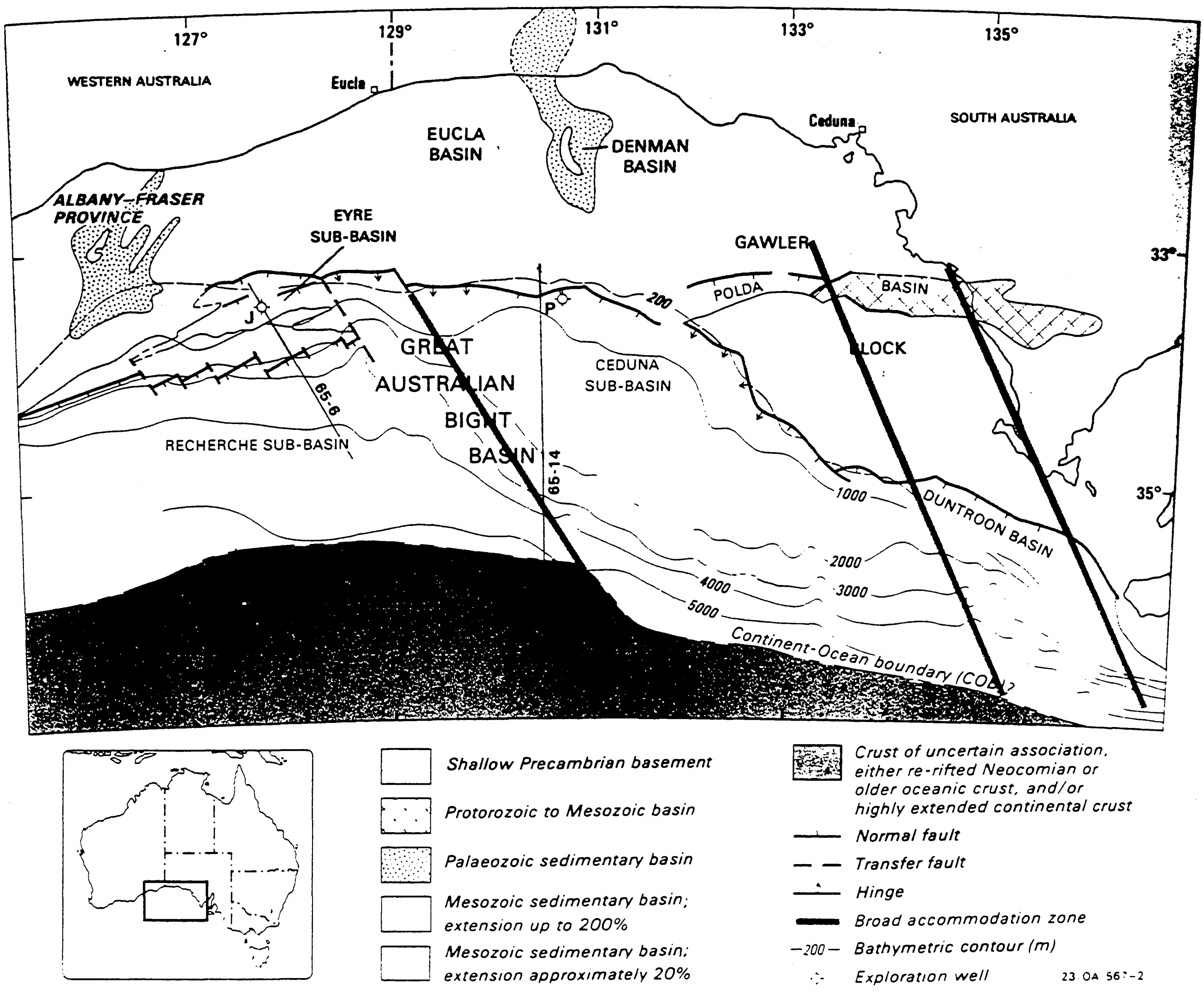


Figure 2: Tectonic elements of the Great Australian Bight region, southern margin of Australia (after Stagg & Willcox, 1992). North-south line in the centre of the map indicates the location of the Ceduna transect (Figs 3, 14). The location of the Eyre transect (Figs 5, 7) is indicated by the short lines labelled 65-6 and N405. The short line labelled 65-15 is the location of the seismic section illustrated in Figure 4.

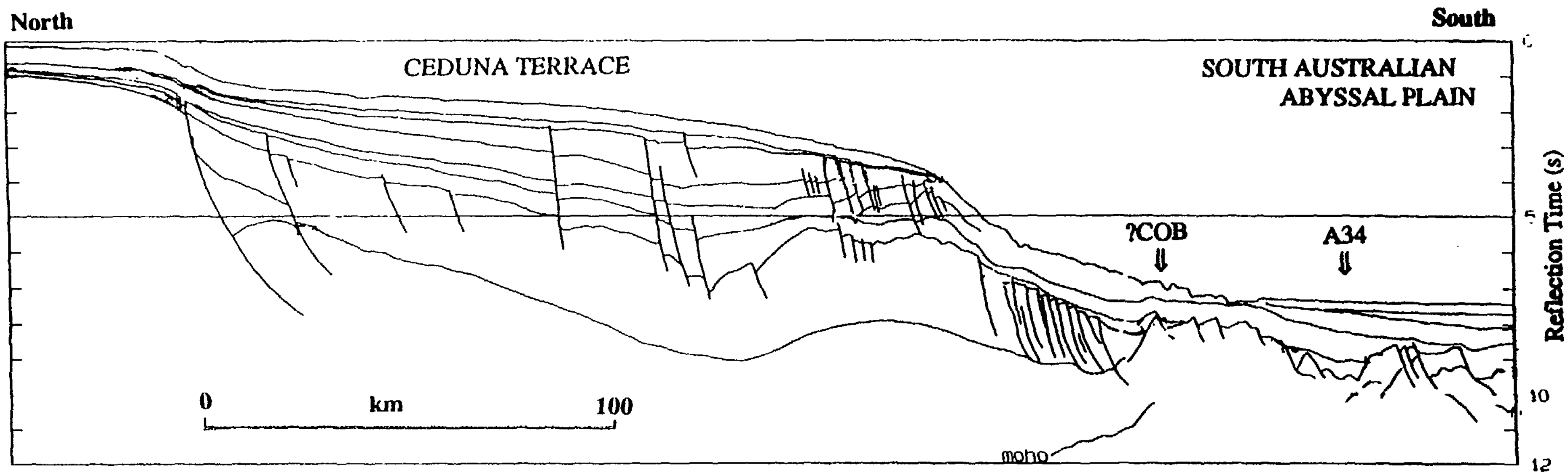


Figure 3: Line drawing of Ceduna transect, extending from unextended crust in the northern GAB, across the Ceduna Sub-basin, to the northern flank of the South Australian Abyssal Plain. Positions of the magnetically-defined COB and seafloor spreading anomaly A34 are shown. Location of profile shown in Figure 2.

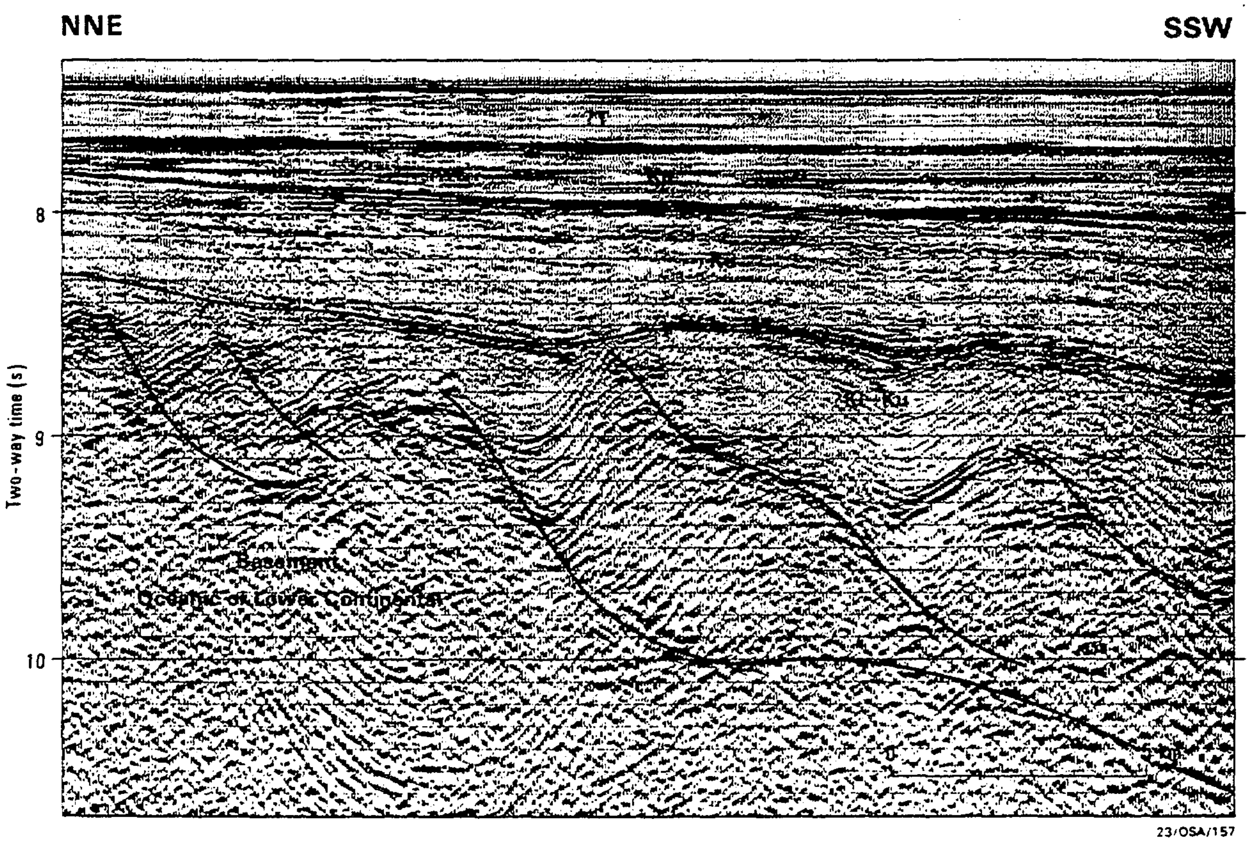


Figure 4: Portion of AGSO line 65-15, showing south-dipping listric faults within basement that has traditionally been interpreted as oceanic crust (after Stagg & Willcox, 1992). Location of profile shown in Figure 2.

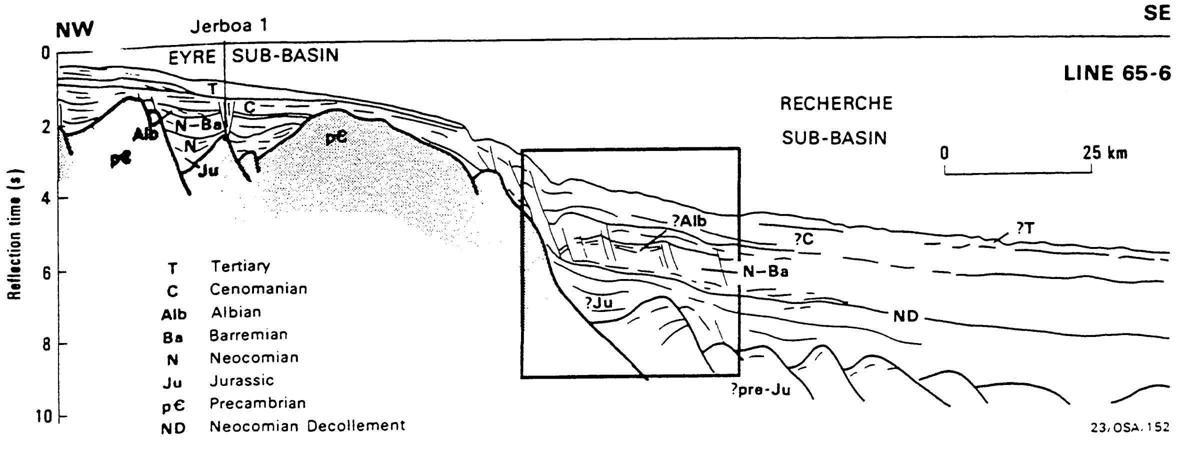


Figure 5: Line drawing of AGSO seismic line 65-6 across the Eyre Sub-basin and continental rise (Recherche Sub-basin) in the western Great Australian Bight (after Stagg & Willcox, 1992). Location of profile shown in Figure 2.

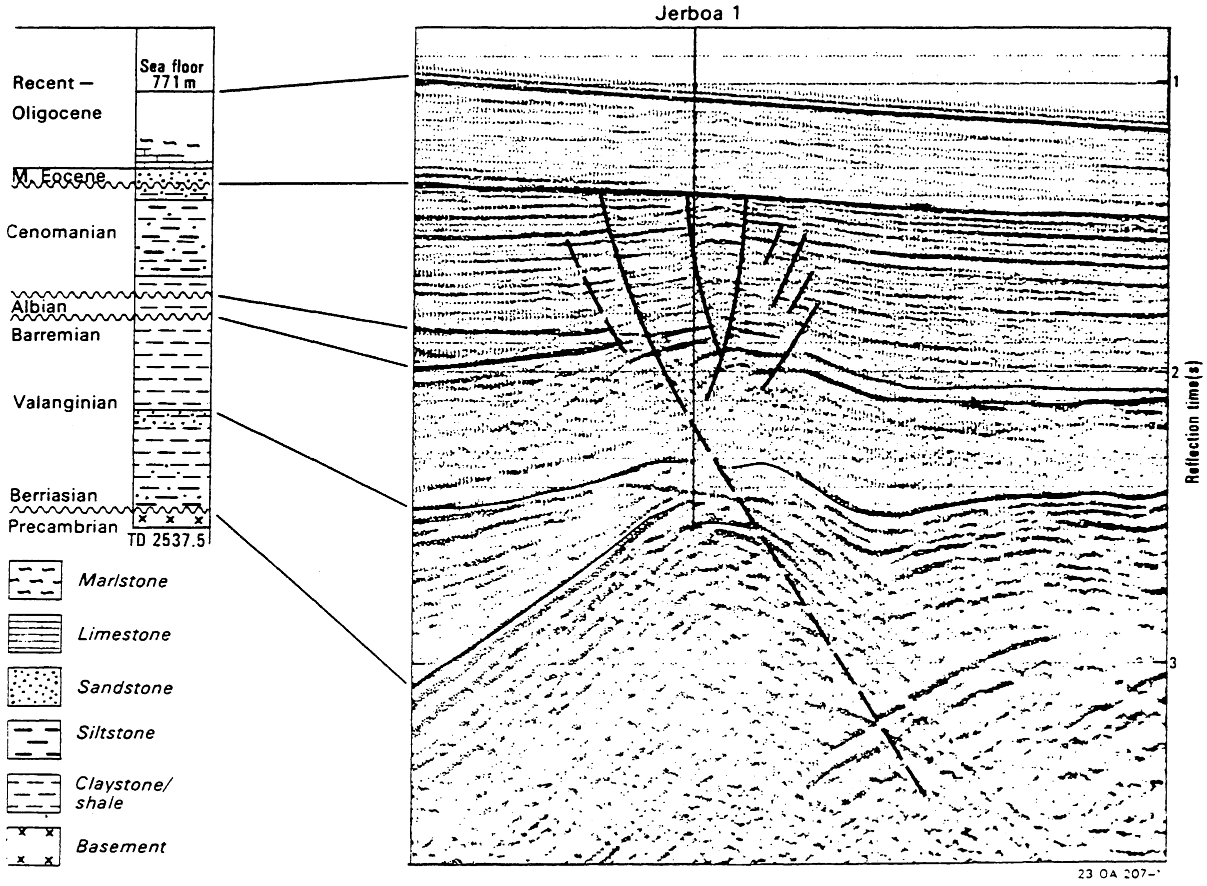


Figure 6: Portion of AGSO seismic line 65-6 through Esso Jerboa-1 exploration well, showing ages and lithologies of sequences penetrated (after Stagg & Willcox, 1992).

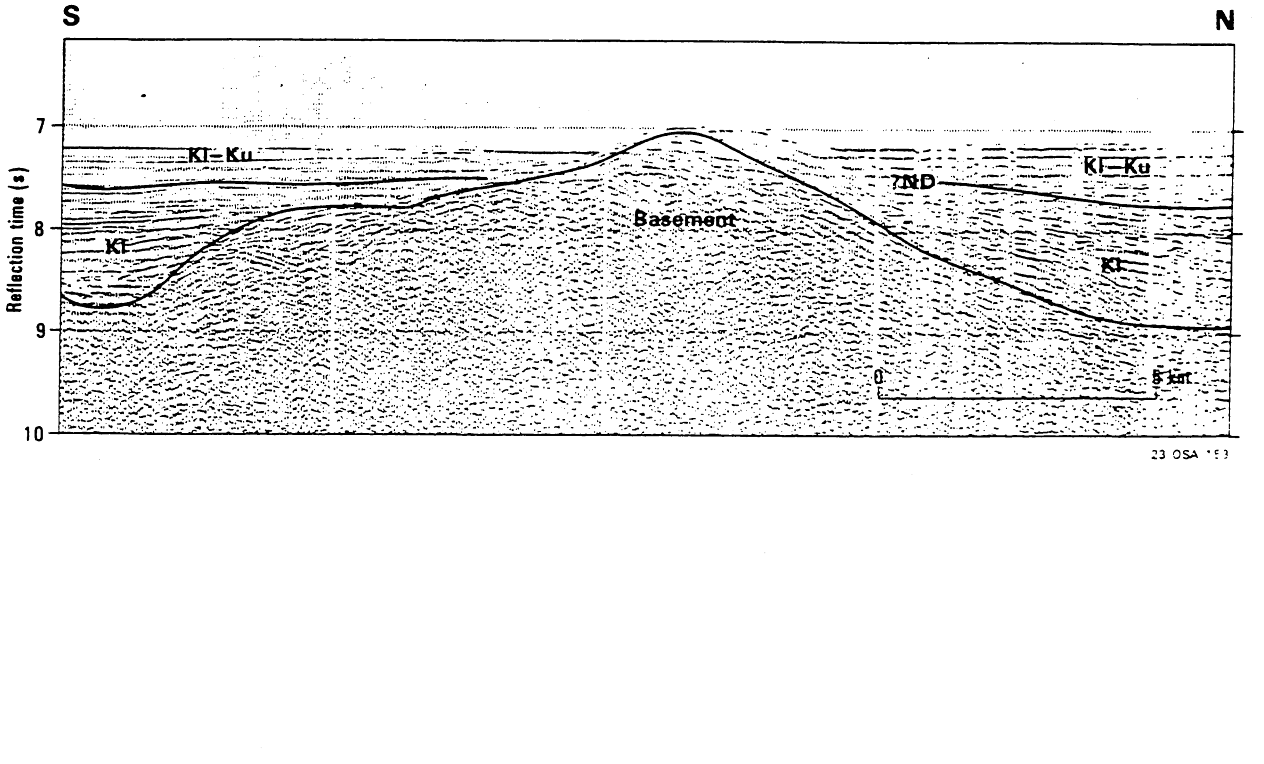


Figure 7: Portion of Shell *Petrel* line N.405 across the basement hummock that has been interpreted as the COB in the western Great Australian Bight (after Stagg & Willcox, 1992). Correlation of the Valanginian horizon *ND* across this hummock on to oceanic crust is shown. Location of profile shown in Figure 2.

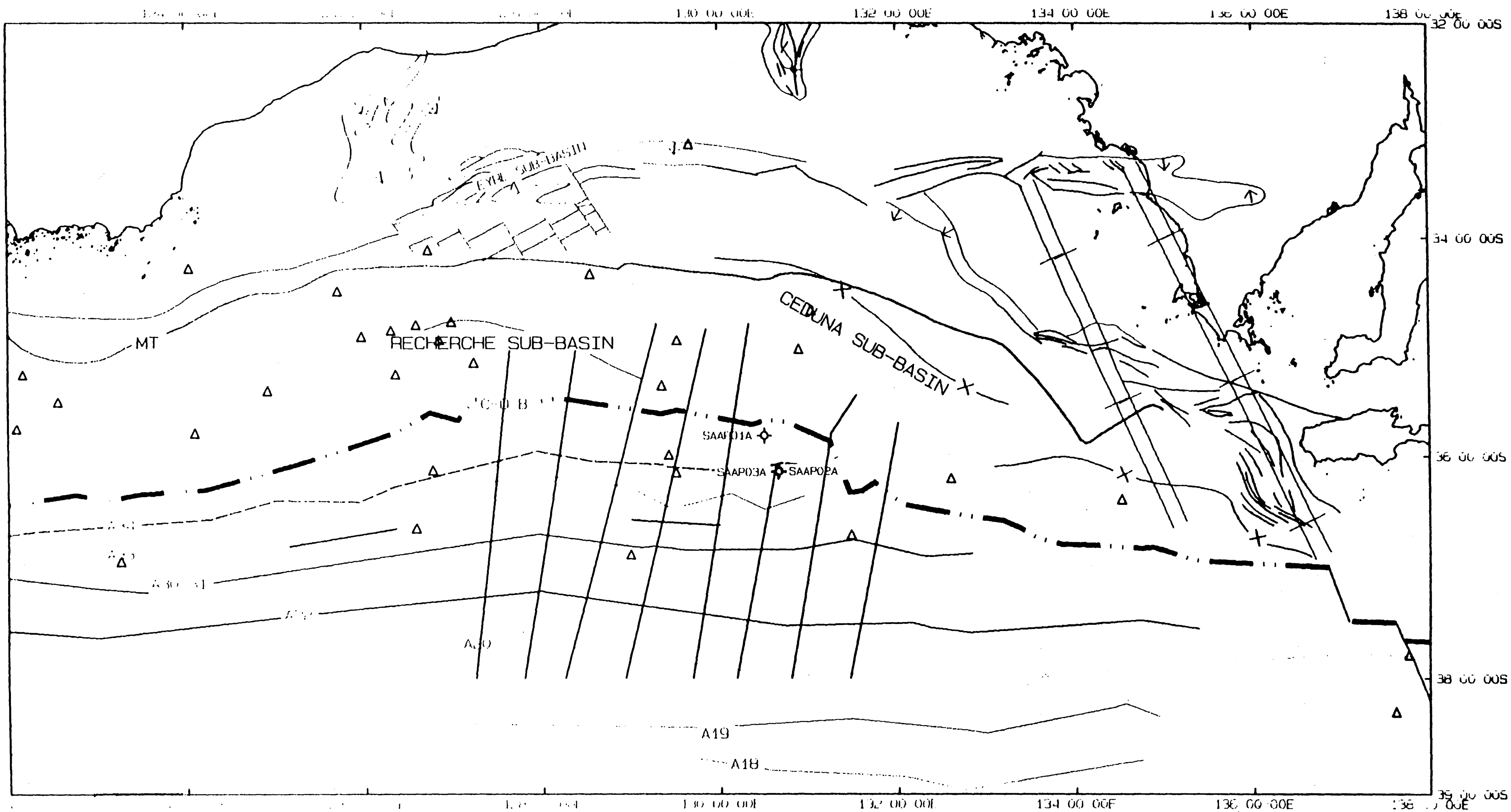


Figure 8: Tectonic elements of the Great Australian Bight, showing the locations of deep-seismic lines proposed to be acquired by AGSO in late 1996.

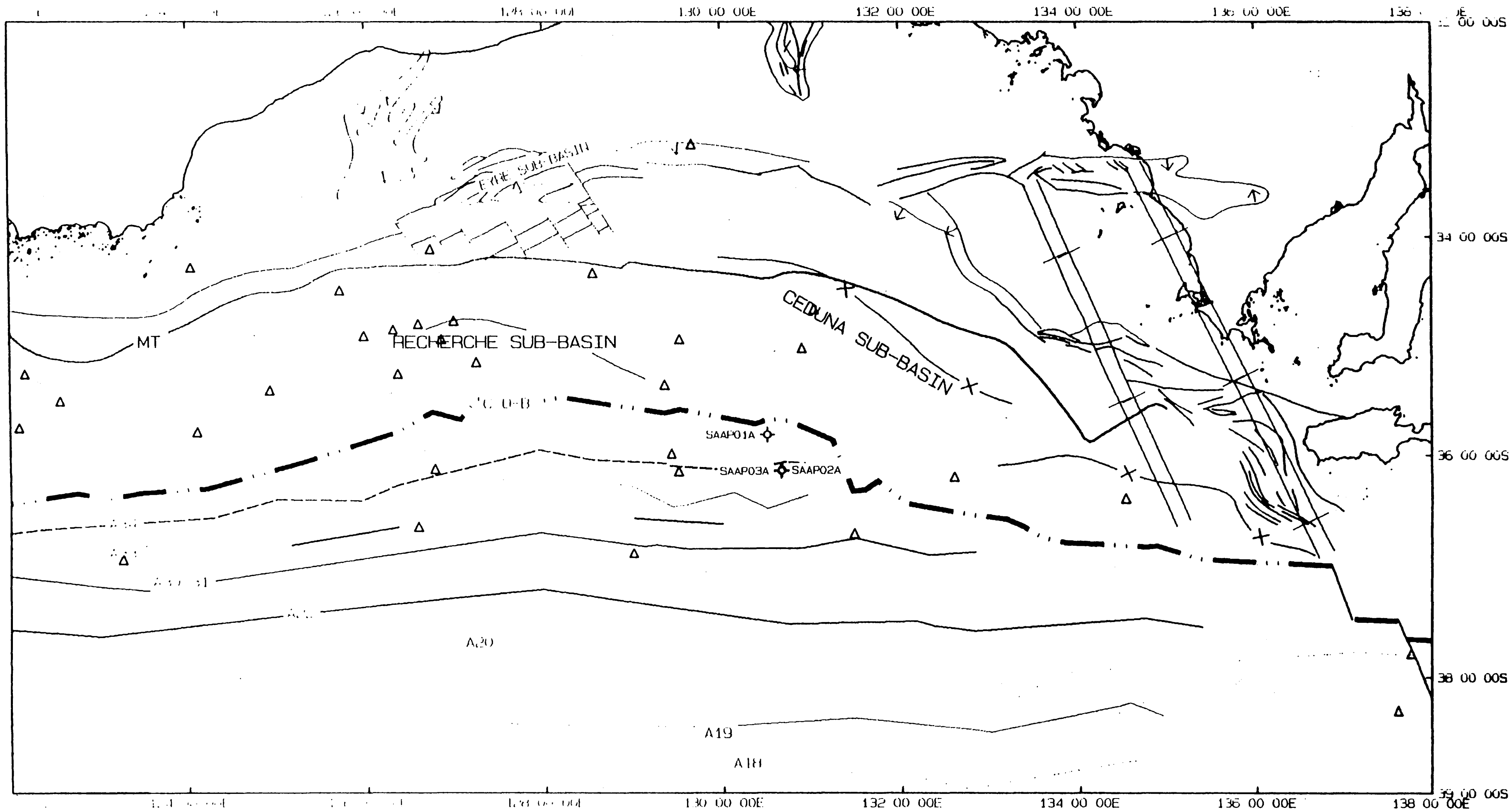


Figure 9: Tectonic elements of the Great Australian Bight, showing the locations of proposed ODP sites SAAP01A, SAAP02A, and SAAP03A. Triangles indicate locations of sonobuoy refraction stations.

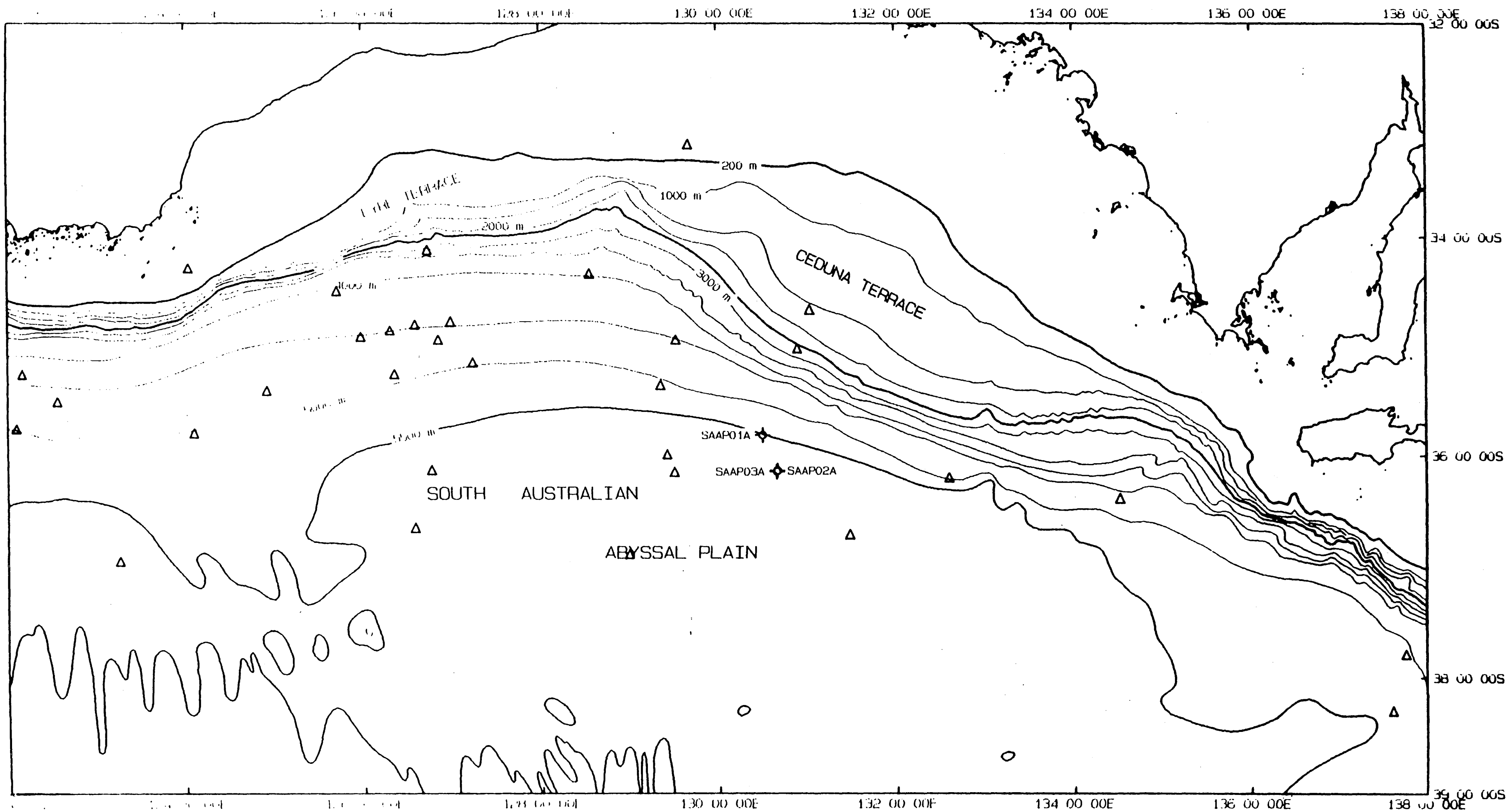


Figure 10: Bathymetry of the Great Australian Bight, showing the locations of proposed ODP sites SAAP01A, SAAP02A, and SAAP03A. Triangles indicate locations of sonobuoy refraction stations.

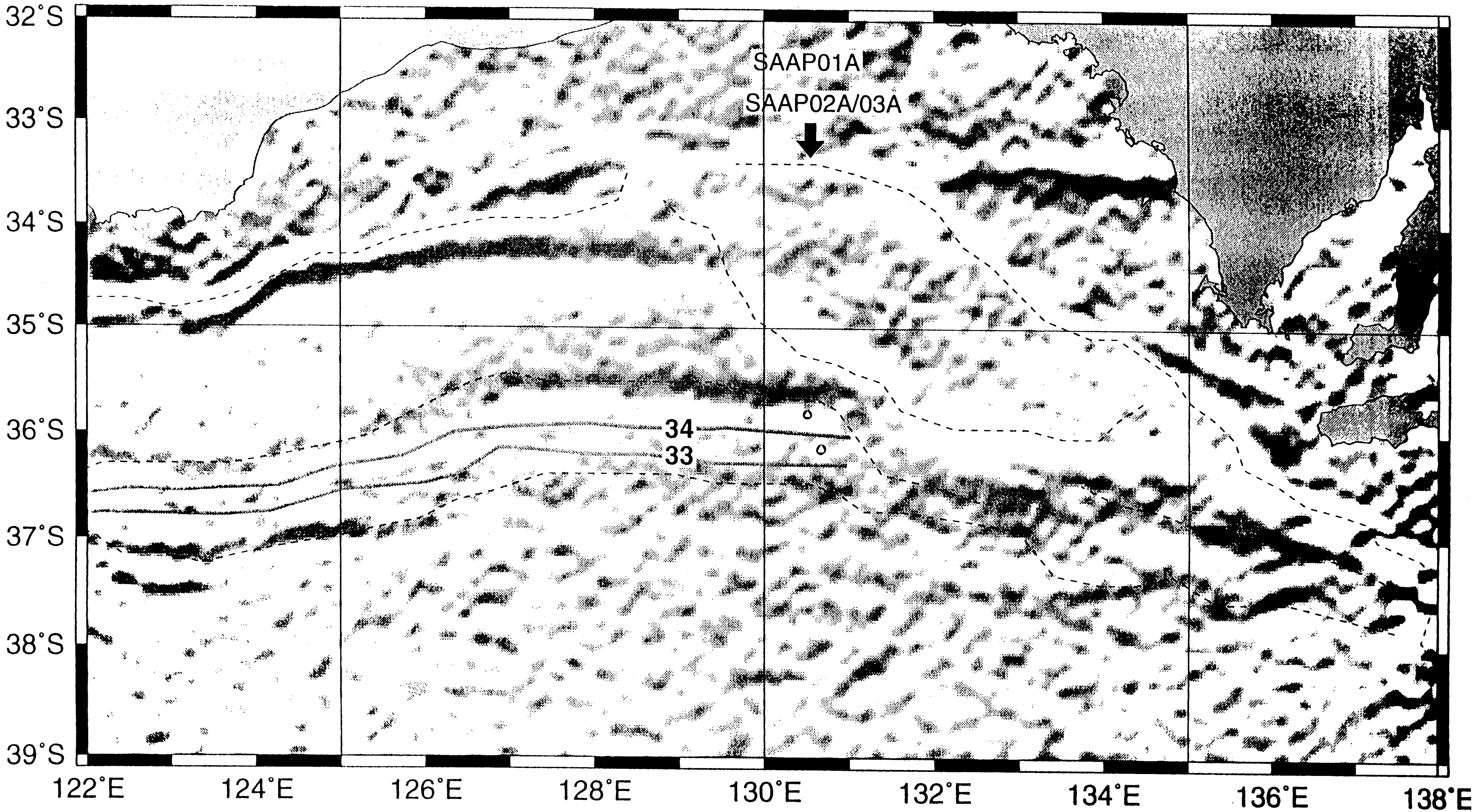


Figure 11: Satellite gravity data image in the Great Australian Bight, illuminated from the south. Locations of proposed ODP sites SAAP01A and SAAP02A/SAAP03A are shown.

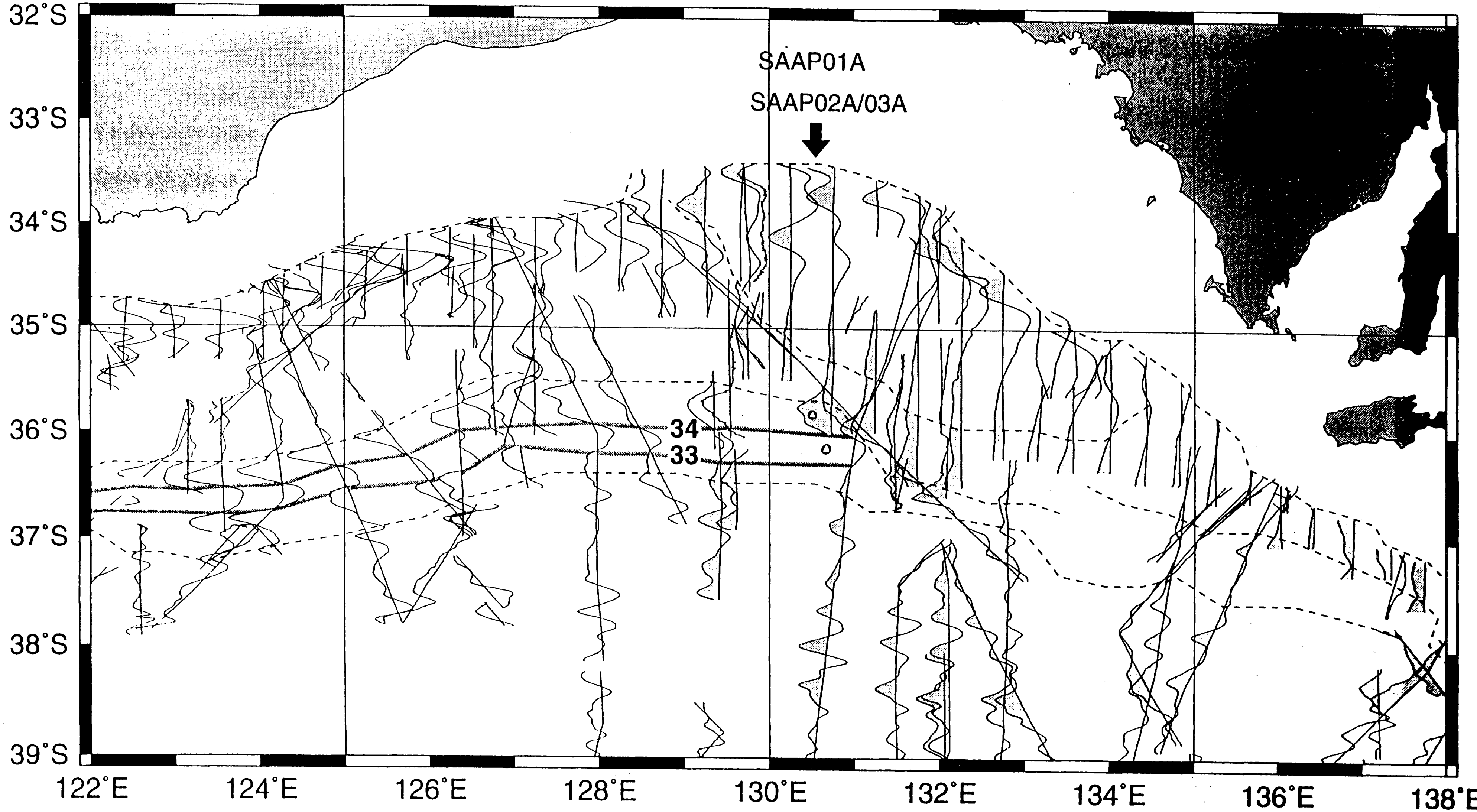


Figure 12: Magnetic profiles from the Great Australian Bight. Locations of proposed ODP sites SAAP01A and SAAP02A/SAAP03A are shown.

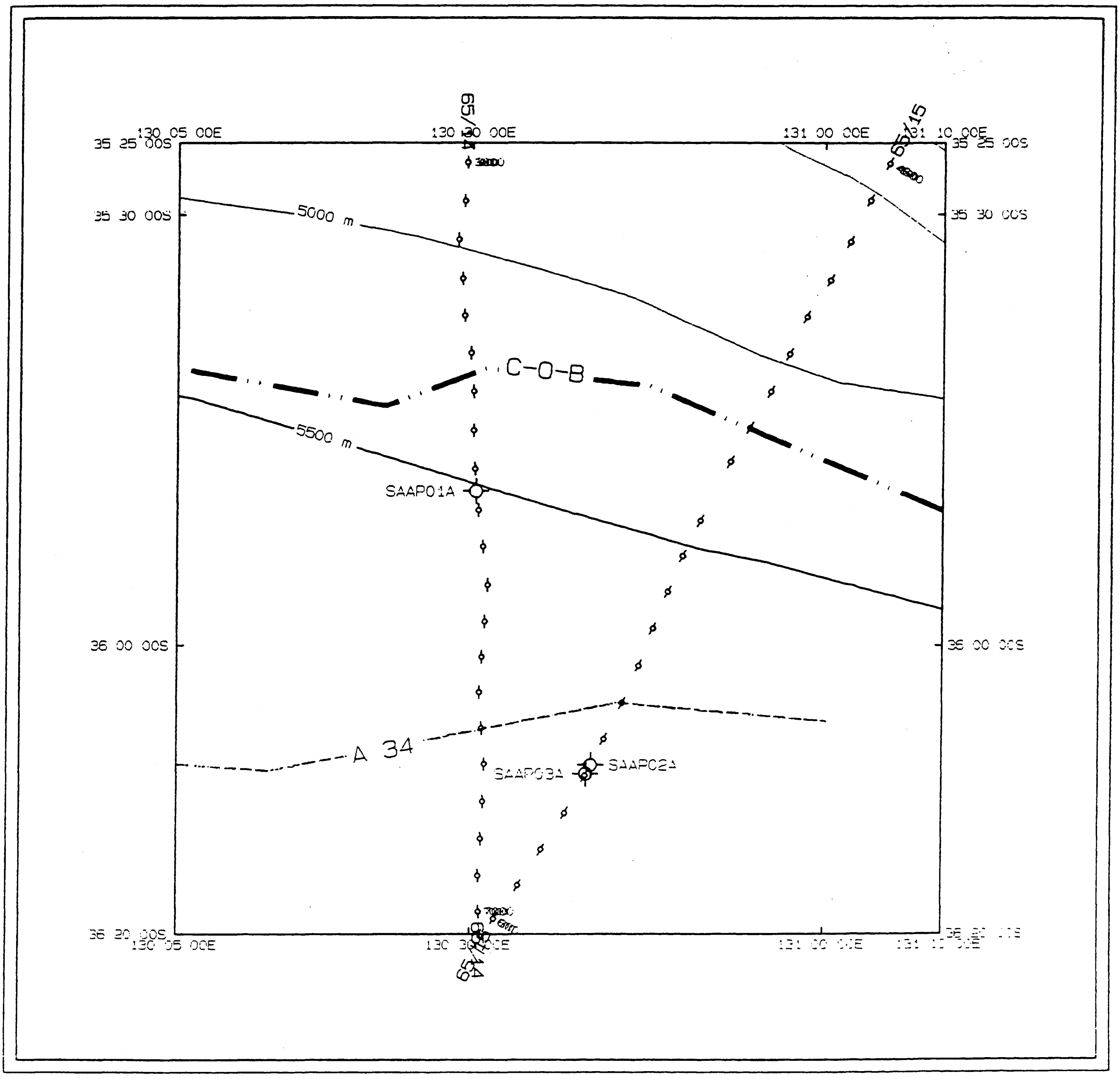


Figure 13: Detailed location map for proposed ODP sites SAAP01A, SAAP02A, and SAAP03A. Bathymetric contours in metres. Magnetically determined continent-ocean boundary and anomaly A34 are also shown.

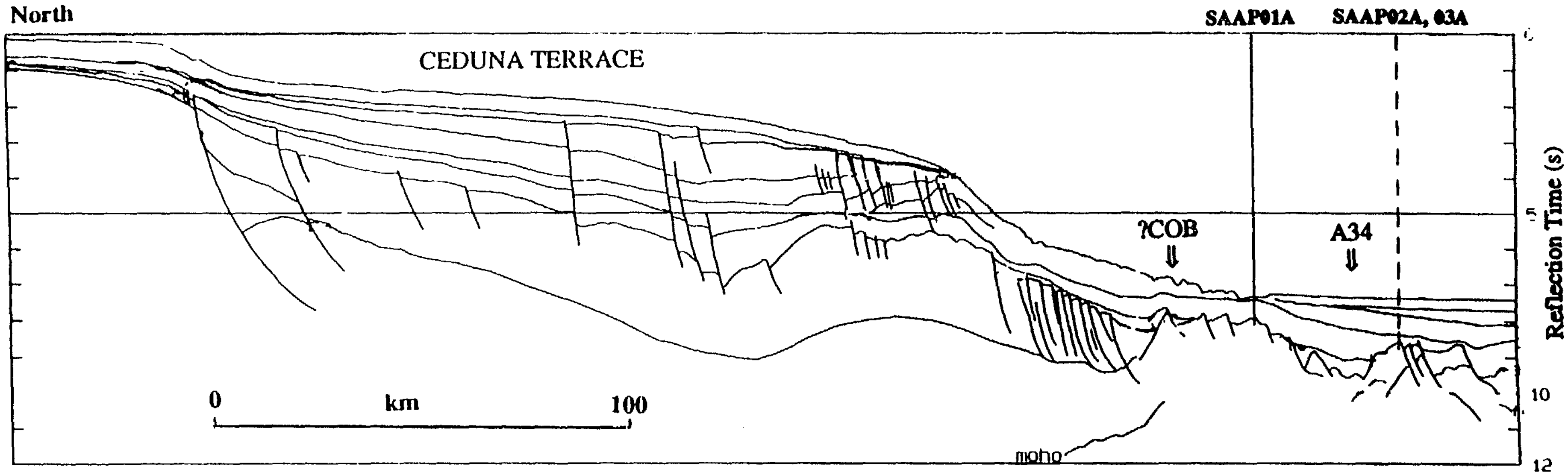


Figure 14: Ceduna transect, showing the location of proposed site SAAP01A and the projected locations of sites SAAP02A and SAAP03A.. Location of profile shown in Figure 2.

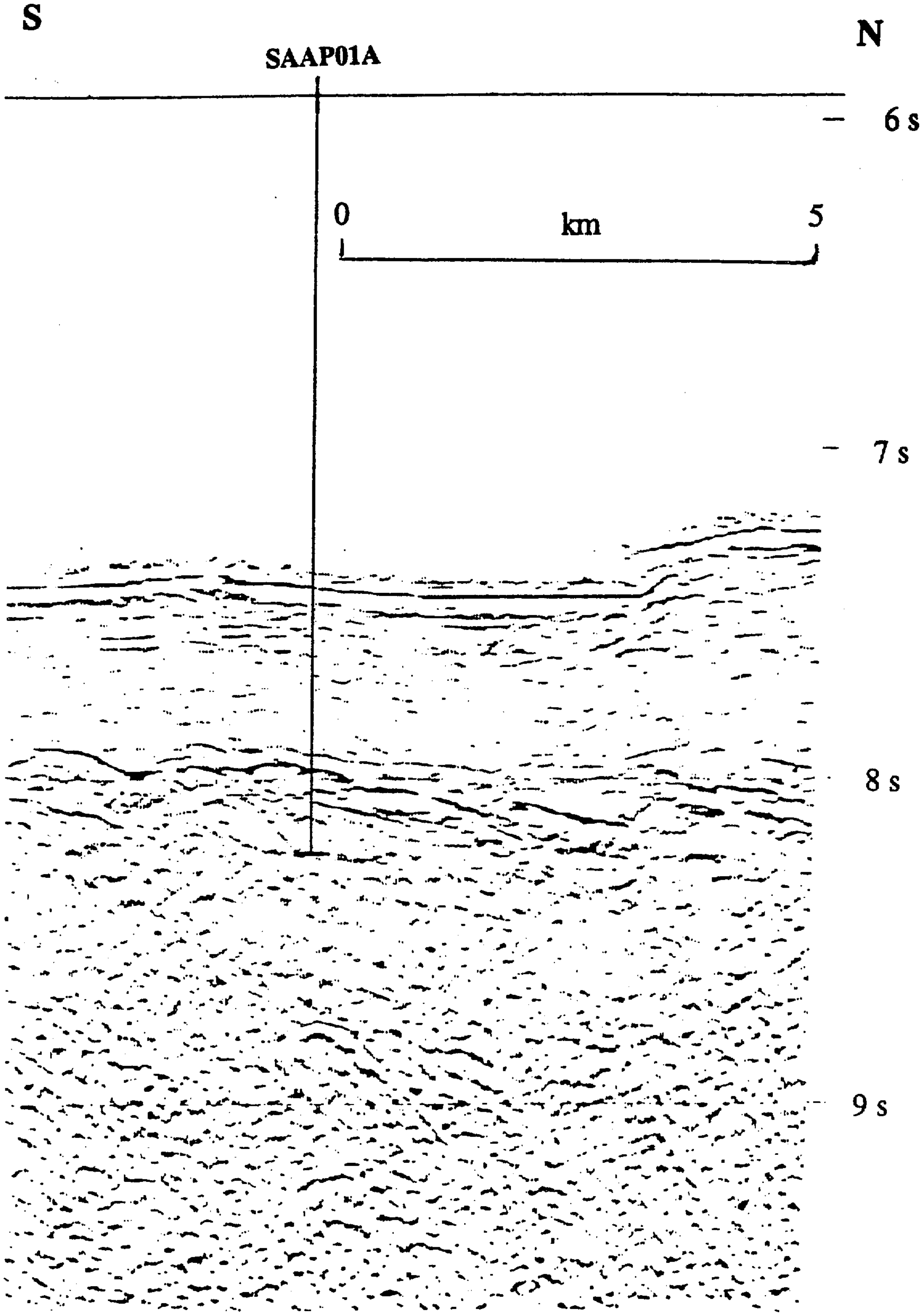


Figure 15: Portion of AGSO line 65-14, showing the location of proposed site SAAP01A. Note that the orientation of this display is reversed to the line drawings shown in Figures 3 and 14.

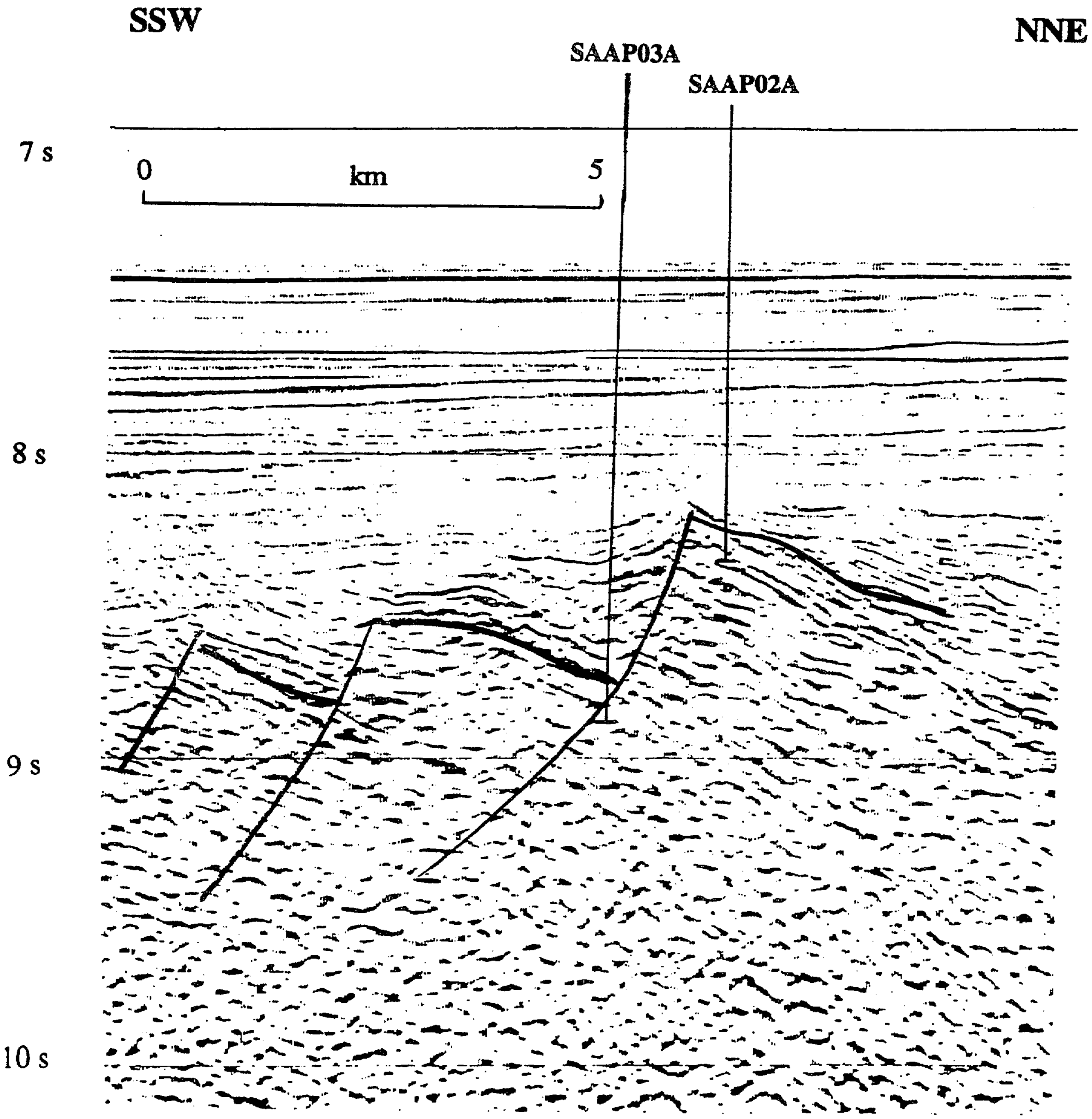


Figure 16: Portion of AGSO line 65-15, showing the locations of proposed sites SAAP02A and SAAP03A.