Bureau of Mineral Resources, Geology & Geophysics

R E C O R D

BMR Record 1991/21

SOUTHERN MARGIN SAMPLING PROGRAM

(Project 121.27)

Research Cruise Proposal

D.A. FEARY

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CONTENTS

APPENDICES

FIGURES

EXECUTIVE SUMMARY

The Great Australian Bight region of southern Australia contains a number of primarily Mesozoic sedimentary basins, containing from 5 to 12 km of sediment and ranging in area from 5000 to 18,000 km^2, in water depths between 60 and 5000 m. Despite the very large area and volume of sediment, this region remains inadequately explored for hydrocarbons, probably in large part as a result of the considerable water depths involved. In anticipation that exploration activity will in due course expand into deeper water, the Great Australian Bight region has been one of the primary areas for framework study as part of the BMR's Continental Margin Program. In addition, Australia's southern margin is recognised internationally as being of critical importance in developing and evaluating models of passive margin tectonic evolution, high energy, cool-water carbonate deposition, and mantle magmatism.

The detailed processing and analysis of data collected during two *R/V RIG SEISMIC* cruises in 1986 culminated in the compilation, in co-operation with the South Australian Department of Mines and Energy, and release of Continental Margins Program Folio 5, which presented a detailed review of existing data throughout the Great Australian Bight region. During the earlier *R/V RIG SEISMIC* sampling program in 1986, operational constraints restricted sampling operations to shallow and intermediate water depths (<3500 m depth). The present proposal is that the *R/V RIG SEISMIC* undertake a four week cruise in the eastern and central Great Australian Bight in June/July 1991 to complement and expand on earlier work. Objectives identified for this sampling program are, in order of priority:

- to determine the biostratigraphy and sedimentary facies of the deep Ceduna Sub-basin sequence (45% of operational time);
- to determine the sedimentary characteristics and develop an appropriate facies model for high energy, cool-water Cenozoic carbonate deposition on the Eucla Shelf-Eyre Terrace (41% of operational time);
- to document the Late Quaternary paleochemistry of the southern margin, in order to evaluate the nature and extent of glacial/interglacial cyclicity as the control on sea-level variation, organic carbon fluxes, seafloor mineral accumulation, and continental weathering (7% of operational time);
- to determine the geochemical characteristics of Southern Ocean magmatism between the continent-ocean boundary and magnetic anomaly 13 (7% of operational time).

The operational plan for this proposed cruise is primarily based on dredging in deep water. In addition, vibrocoring on the Eucla Shelf and gravity coring for the paleochemistry transect and for deeper water Eyre Terrace sampling are planned. A small program of high-resolution, single watergun seismic will be required to provide facies geometry data on which to base the Eucla Shelf-Eyre Terrace sampling program. It is recognised that this is not the optimum weather period to work on this part of the margin, and that inevitably some cruise time will be lost through poor weather conditions. However operational considerations and Divisional priorities require that any southern margin sampling program should proceed at this time. Nevertheless the mix of sampling methods proposed, with the emphasis on deep dredging, will minimise lost operational time.

INTRODUCTION

The Great Australian Bight region (Fig. 1) has been one of the primary areas of investigation for BMR's Continental Margins Program. This reflects the reconnaissance nature of most earlier basin studies along the 1300 km of margin between the Duntroon Embayment and Cape Leeuwin, which, despite the identification of up to 12 km of sediment thickness and the drilling of 5 wells, remains very poorly understood. The BMR southern margin work program has been designed both to undertake broad framework studies with a view to evaluating petroleum prospectivity, as well as to refine models of mantle magmatism, passive margin tectonic evolution, and basin development.

The geology and petroleum prospectivity of Australia's southern margin has primarily been discussed as part of regional reviews, based on patchy distribution of high quality seismic and other geophysical data, a notable paucity of geological data, and 5 exploration wells. More focussed reviews of specific geographic areas have described the Ceduna Terrace (Whyte, 1978; Fraser & Tilbury, 1979; Tilbury & Fraser, 1981) and Eyre Terrace (Bein & Taylor, 1981) sequences.

Earlier cruises of the *R/V RIG SEISMIC* in 1986 (surveys 65 and 66) further refined the geological and geophysical framework of the Eyre and Ceduna Terrace sequences. Analysis of data collected during these cruises (Willcox, Stagg, Davies, & others, 1988; Stagg & others, 1990) demonstrated that:

(1) Late Cretaceous spreading between Australia and Antarctica was directed N-S, although possible NW-SE strike-slip faulting beneath the outer margin of the Ceduna Terrace may reflect a NW-SE early continental extension direction.

(2) The Eyre Sub-basin is bounded to the south by a ridge of Precambrian basement overlying a probable south-dipping, primary detachment surface. Rotated blocks of a 4-6 km thick, probable Cretaceous and Tertiary sedimentary sequence overly the basement block. This sequence contains at least nine unconformable seismic sequences, some of which clearly prograde southward.

(3) The Ceduna Terrace sequence includes a thick, progradational unit characterised by large-scale foreset beds, probably bounded by Cenomanian and Maastrichtian unconformities (Fraser & Tilbury, 1979).

(4) The Great Australian Bight Basin contains a Maastrichtian to Middle Eocene sequence of dominantly terrigenous marine sediments, with little non-marine sediment, overlain by a Middle Eocene to Quaternary sequence dominated by pelagic carbonate.

The proposed *R/V RIG SEISMIC* southern margin sampling cruise is designed to complement this earlier work, as well as to advance our understanding of specific depositional, tectonic, magmatic, and geochemical processes. Work will be focussed on the eastern and central Great Australian Bight region, in expectation that a further *R/V RIG SEISMIC* cruise, at present planned for 1992, will concentrate on the western Great Australian Bight Basin, Bremer Basin, Diamantina Fracture Zone, and Naturaliste Plateau regions.

The proposed program for the 1991 *R/V RIG SEISMIC* southern margin sampling cruise includes work concentrated on the following geological themes, which in turn correspond to four specific geographic areas (Fig. 2). In order of priority, these are:

<u>Area A</u> - to determine the biostratigraphy and sedimentary facies of the deep Ceduna Sub-basin sequence (45% of operational time);

<u>Area B</u> - to determine the sedimentary characteristics and develop an

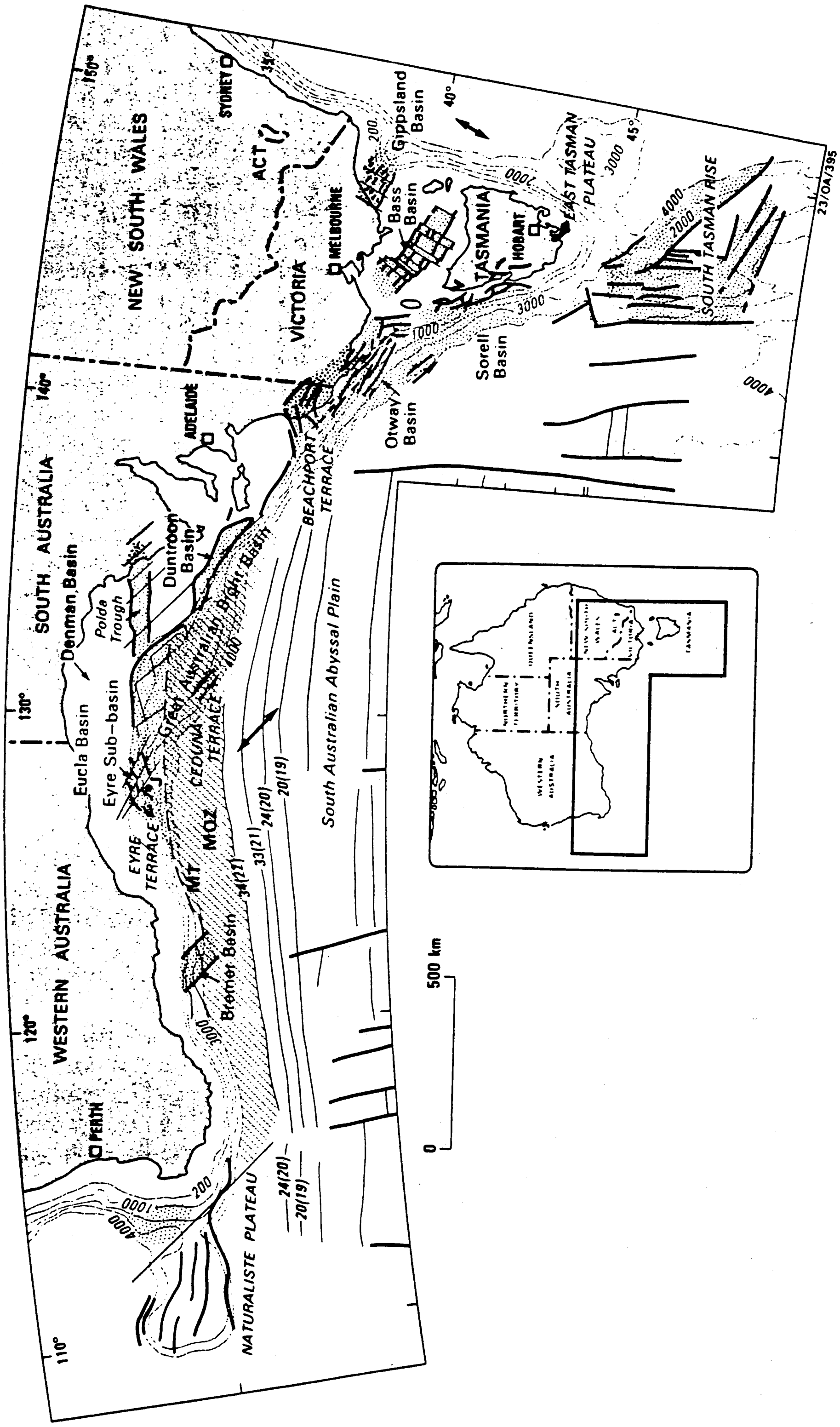

Figure 1. Structural elements of the southern margin of Australia (after Willcox, 1990).

appropriate facies model for high energy, cool-water Cenozoic carbonate deposition on the Eucla Shelf-Eyre Terrace (41% of operational time);
Area C - to document the Late Quaternary paleochemistry of the southern margin, in order to evaluate the nature and extent of glacial/interglacial cyclicity as the control on sea-level variation, organic carbon fluxes, seafloor mineral accumulation, and continental weathering (7% of operational time);
Area D - to determine the geochemical characteristics of Southern Ocean magmatism between the continent-ocean boundary and magnetic anomaly 13 (7% of operational time).

GEOLOGICAL BACKGROUND

The following broad bathymetric and geological descriptions of Australia's southern margin and Great Australian Bight region is based substantially on earlier BMR reports and reviews of the region by Willcox, Stagg, Davies & others (1988) and Stagg & others (1990).

BATHYMETRY

The bathymetry of the Great Australian Bight region (Fig. 2) has been described by Conolly & von der Borch (1967), Conolly & others (1970), and Willcox (1978). A detailed bathymetry map of the Ceduna Terrace was presented by Tilbury & Fraser (1981), and the margin west of the Great Australian Bight was described by Stagg & others (1990).

CONTINENTAL SHELF

The continental shelf is almost featureless, forming a gently sloping plain out to the shelf break at about 125-165 m depth. Minor changes in slope also occur at about 25 and 90 m depth. From the vicinity of Albany to the western end of the Great Australian Bight, the shelf is 40-60 km wide, and the seabed falls away sharply below the shelf edge. Between the Archipelago of the Recherche and the Eyre Peninsula, the shelf forms a large arcuate plain with a maximum width of 300 km to the east of Eucla. Farther eastwards, the shelf width varies from 50 to 200 km, while in the extreme southeast it narrows to about 20 km. The shelf on the eastern side of the Great Australian Bight has been extensively modified by the Pleistocene courses of the Murray River.

CONTINENTAL SLOPE AND MARGINAL TERRACES

The continental slope is highly variable in width and gradient and is interrupted by several terraces. From offshore Albany to the western Great Australian Bight, gradients are up to 6°. Canyon development is extensive, particularly to the west of Esperance, although individual canyons are poorly defined due to the paucity of lines parallel to the slope.

The major part of the slope between Eyre and Ceduna is occupied by the Eyre and Ceduna Terraces. Offshore from Eyre, the continental slope dips at about 2° SSW from the shelf edge at about 200 m. At 400 m depth it levels out to about 1° to form the Eyre Terrace, an oval feature about 60 km wide and 300 km long (Fig. 2). The outer limit of the terrace lies at about the 1600 m isobath. Below the outer margin, the slope steepens to about 5° and merges with the rise at about 3500 m. The southeasterly-trending Eyre Canyon extends from near the middle of the terrace onto the continental slope at its southern edge. The Eucla Canyon has cut several hundred metres into the continental slope at about 129°E, at the junction of the Eyre and Ceduna Terraces.

The Ceduna Terrace is sigmoidal in outline, some 70,000 km^2 in area, and up to 200 km in width and 600 km in length (Fig. 2). It is bounded to the north and northeast by an upper slope between the shelf break at 150-200 m and the 500 m isobath, and to the southwest by a lower slope between the 2500 and 4000 m isobaths. The surface of the terrace slopes gently to the southwest with an average gradient of 0.6°, compared with an average of 2° for the continental slope. The lower slope merges with the continental rise at about 4000 m.

The most striking features of the bathymetry of the Ceduna Terrace are the numerous submarine valleys which dissect its surface (Tilbury & Fraser, 1981). They are mostly broad and shallow and form a dendritic tributary system feeding steeper-walled canyons on the lower slope. The valleys originate on the upper slope as small channels; these coalesce to form valleys 5-10 km wide on the upper part of the terrace; and these in turn converge on the lower slope to form valleys about 20 km wide that eventually feed the canyons of the lower slope.

To the east of the Ceduna Terrace, the continental slope off Kangaroo Island is similar to that on the western side of the Great Australian Bight, with gradients of up to 8° and extensive canyon development. The slope here extends down to about 4600 m. It is extensively incised by the numerous paleo-channels and active channels of the Murray River canyon system; von der Borch & others (1970) have recorded the depth of the main canyon as about 1800 m below the adjacent seabed. Some canyons in this area are almost parallel to the slope, deepening westwards.

CONTINENTAL RISE AND ABYSSAL PLAIN

The continental rise is composed of a smooth apron of sediments lying between the continental slope and the abyssal plain (between the continental slope and the Diamantina Zone in the west). The upper boundary of the rise varies from about 4000 m off Albany, to about 3000 m south of the Archipelago of the Recherche, to as deep as 5000 m in the extreme southeast. South of the Eyre Terrace, the rise is abnormally broad, in excess of 200 km, with a gradient of about 0.5°. By contrast, south of the Ceduna Terrace, the rise is only about 50 km wide with a gradient of up to 2°.

The South Australian Abyssal Plain, in excess of 5500 m deep, is a relatively small area of smooth ocean floor occupying the area between the rise, the Diamantina Zone in the west, and the rugged northern flank of the Southeast Indian Ridge.

REGIONAL STRUCTURE AND SUBDIVISION OF BASINS

The southern margin of the Australian continent is a divergent, passive, continental margin, extending for 4000 km from the Perth Basin in Western Australia to the Sorrel Basin in Tasmania (Fig. 1). The margin developed during the Jurassic to Cretaceous by extension and rifting between the Australia and Antarctic plates. Seafloor spreading was initiated in the

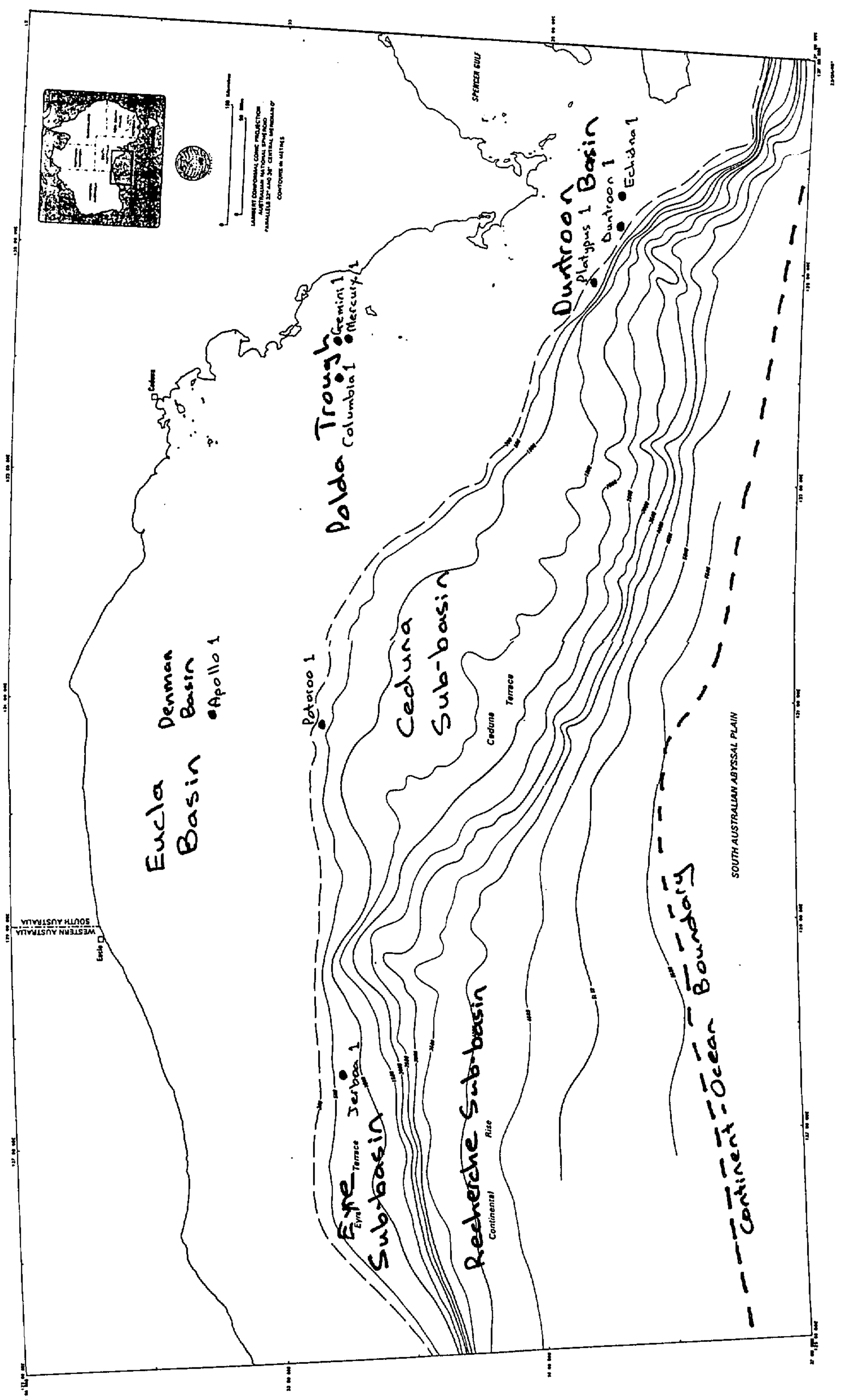

Figure 2. Bathymetric map of the Great Australian Bight, showing sedimentary basins and sub-basins, and exploration wells.

mid-Cretaceous (Cande & Mutter, 1982; Veevers, 1986; Veevers & others, 1990) and continues to the present day.

Stagg & others (1990) proposed the name 'Southern Rift System' for the broad zone that has been affected by the Jurassic-Tertiary rifting and spreading event along Australia's southern margin. Within the Southern Rift System, a number of basins, sub-basins, troughs, and embayments have been identified and named in the past. In some cases, the sparsity of data (particularly in deep water) has resulted both in the overlooking of major sediment bodies and in the mis-identification or non-identification of the relationships between recognised sediment bodies. The following summary is based on the attempt by Stagg & others (1990) to rationalise the subdivision and nomenclature of sediment bodies within the western half of the Southern Rift System.

In the east, the **Duntroon Basin** (Fig. 2), formerly also known as the Duntroon Embayment, is inferred to lie between two approximately northwest-southeast trending accommodation zones; the East Duntroon and West Duntroon Accommodation Zones. The East Duntroon Accommodation Zone, immediately to the west of Kangaroo Island, is considered to be the boundary between the Duntroon Basin and the Otway Basin to the east, while the West Duntroon Accommodation Zone marks the junction of the Duntroon and Bight Basins. Both of these accommodation zones may have expression in the Polda Trough to the north.

The **Bight Basin** (Fig. 2) occurs almost exclusively beneath the continental slope and rise which underlies most of the Great Australian Bight west of the Duntroon Basin. Within the Bight Basin, three sub-basins can be identified. The main sediment accumulation underlies the bathymetric Ceduna Terrace and has been referred to in the past as the 'Great Australian Bight Basin' (eg Willcox, 1978; Fraser & Tilbury, 1979) or the 'Ceduna Depocentre' (Veevers, 1984); this feature is informally named the 'Ceduna Sub-basin' by Stagg & others (1990). The Eyre Sub-basin is a discrete extensional basin 'perched' high on the continental slope on the western side of the Great Australian Bight, separated from the continental rise to the south by shallow basement, but apparently contiguous with the Ceduna Sub-basin to the east. The quite different structural styles of the Ceduna and Eyre Sub-basins warrants their continued separate names. The thick sediment accumulation beneath the continental rise, principally on the western side of the Great Australian Bight, which has previously been referred to as the 'rise basin', actually constitutes a sub-basin of the Bight Basin, being separated from the Ceduna Sub-basin to the northeast by the Southwest Ceduna Accommodation Zone; this feature was informally named the 'Recherche Sub-basin' by Stagg & others (1990). The western limit of the Recherche Sub-basin is ill-defined, and it may continue well to the west of the Great Australian Bight.

To the west of the Great Australian Bight, the only easily-identified extensional basin is the Bremer Basin, which underlies the continental slope approximately between Albany and Esperance (Fig. 1). To the west, the basin terminates against shallow basement, while to the east it terminates against a major transfer fault or accommodation zone.

The northern and southern limits of the Southern Rift System are relatively easily defined. The northern margin is considered to be the major basement fault or monocline that marks the landward extent of the Duntroon, Bight, and Bremer Basins and which underlies the continental slope elsewhere. This fault system marks the northern limit of thick Cretaceous sediments. The southern boundary of the Southern Rift System is taken as the basement ridge beneath the abyssal plain that has been interpreted by Veevers (1986) as the continent-ocean boundary.

North of the Southern Rift System bounding fault in the Bight Basin, the continental shelf is underlain by a thin sequence of Cretaceous and Tertiary sediments that extend onshore to about 30°S. These sediments are very condensed in character, being related to stable platform deposition rather than a rifting regime. Such sediments are now included in the Tertiary-Cretaceous Eucla Basin which was formed in a continental platform sag regime, and dips gently towards the rifted Bight Basin.

The Permian Denman Basin underlies part of the Eucla Basin. This basin occupies a north-south elongate depression between approximately 31-33°S and 130-131°E (Fig. 1). It appears to be coincident with the deepest depressions within the Eucla Basin and is probably related to an earlier zone of weakness.

The Polda Trough (or Polda Basin) is an east-west oriented elongate intra-cratonic basin, approximately 350 km long by 40 km wide. It extends onshore to 136°E and westward to 132°45'E where it debouches into the Bight Basin (Fig. 1). Its geographic location, structural trend, and Upper Proterozoic, Palaeozoic, and Jurassic sediment fill indicate that it formed within an ancient zone of crustal weakness, and was reactivated during formation of the Southern Rift System. However basement strength was apparently sufficient to block significant rift development and the basin remains as a Jurassic aulacogen.

In the nearshore areas on the eastern flank of the Great Australian Bight, large areas of shallow basement are covered by a thin veneer of Cenozoic (mainly Tertiary) sediments. Robertson & others (1979) used the term "Eyre-Encounter Bay Shelf" to describe these sediments. However, the seismic data in this area is both sparse and of poor quality and the relationship of the sediments to other basins, such as Eucla, Murray, St. Vincent, and Cowell remains to be determined before more formal basin naming is proposed.

SPREADING HISTORY

Magnetic lineations were first identified and mapped by Weissel & Hayes (1972), based on *USNS ELTANIN* data. These authors concluded that the oldest identifiable anomaly was anomaly 22, and that Australia-Antarctica breakup occurred in the Early Eocene, at about 55 Ma. In addition to the basic lineation pattern, Weissel & Hayes (1972) also identified several large-scale anomalous magnetic and/or morphologic features that have remained difficult to explain:

(1) The Australia-Antarctic Discordance (AAD) is a region of anomalously deep crust astride the Southeast Indian Ridge system south of the Great Australian Bight, containing subdued magnetic anomalies.

(2) The Diamantina Zone is a latitudinal band of extremely rough seafloor topography south of southwest Australia. The Diamantina Zone is most pronounced west of 125°E, and becomes progressively more buried by sediment towards the east so that its eastward extent is difficult to define.

(3) A broad Magnetic Quiet Zone (MQZ), bounded landward by a prominent magnetic trough, extends along the Australia's southern margin from the west of the continent, where the magnetic signature is relatively disturbed, to the eastern side of the Great Australian Bight, where it encompasses the oldest magnetic anomalies. The crust beneath the MQZ has variously been interpreted

as continental (Falvey, 1974; Boeuf & Doust, 1975; Deighton & others, 1976) or hybrid "rift-valley" (Talwani & others, 1979) crust.

In a major reinterpretation of the oldest part of the magnetic anomaly record, Cande & Mutter (1982) suggested that the anomalies originally identified as 19-22 could be more appropriately modelled as anomalies 20-34, corresponding to a period of extremely slow spreading (approximately 4.5 mm/yr). On this basis, Cande & Mutter (1982) estimated that Australia-Antarctica breakup occurred at some time between 90 and 110 Ma. This revised, and now generally accepted interpretation provides explanations for many previously anomalous features off Australia's southern margin. The roughness of the Diamantina Zone can be attributed to the period of slow spreading; previous difficulties in identifying the oldest magnetic anomalies can be resolved; and this reinterpretation accounts for the period of rapid basin subsidence prior to 90 Ma identified along Australia's southern margin (Falvey & Mutter, 1981).

More recently, Veevers (1986, 1988) and Veevers & others (1990) have refined the estimate of breakup age to 96 $\pm$ 4 Ma (Cenomanian-Turonian) by proposing that Cande & Mutter's Anomaly 34 is, in fact, the continent-ocean boundary edge-effect anomaly, and by extrapolating the 4.5 mm/yr spreading rate (Figs 3, 4).

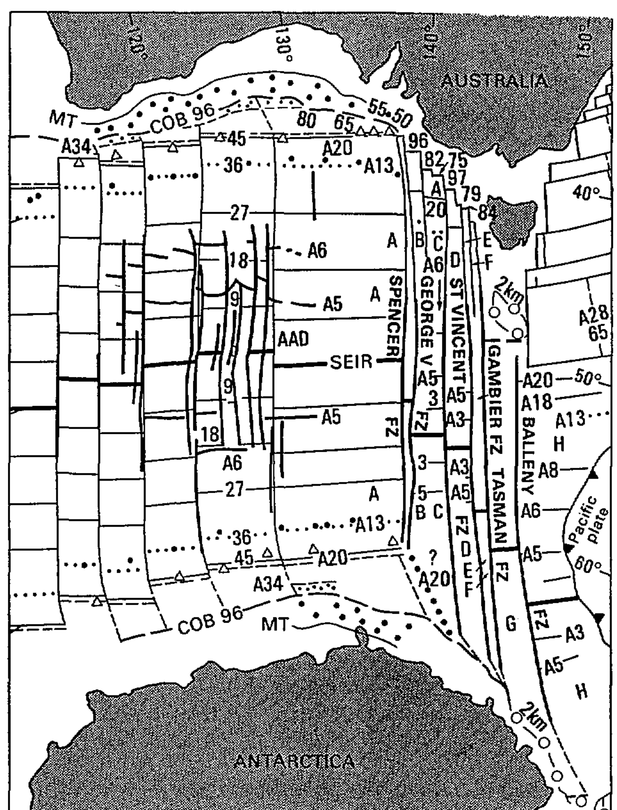

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Figure 3. Australia-Antarctica magnetic anomalies and spreading history (after Veevers & others, 1990).

While Cenomanian breakup is now widely accepted, Stagg & others (1990) believe that there are still several potential problems that remain to be resolved, both with the breakup age and also with other aspects of the seafloor spreading history. These problems, which are critical to a full understanding of the tectonic evolution of the southern margin, include:

(1) The deposition of interpreted Neocomian-Barremian sediments above crust oceanward of the continent-ocean boundary interpreted by Veevers (1986).

(2) The continental character of crust oceanwards of the continent-ocean boundary on some *R/V RIG SEISMIC* Survey 65 seismic lines (Stagg & others, 1990).

(3) The very poor correlation and identification of the oldest magnetic anomalies.

(4) The identification of several discrete subsidence events in the geohistory plots from wells in the Great Australian Bight (eg. Jerboa-1).

(5) The existence of a major tectonic event in the Late Cretaceous-Early Tertiary, reflected in seismic records margin-wide (Stagg & others, 1990). Stagg & others (1990) do not believe that this event can be ascribed to eustatic sea-level changes or to deep ocean currents.

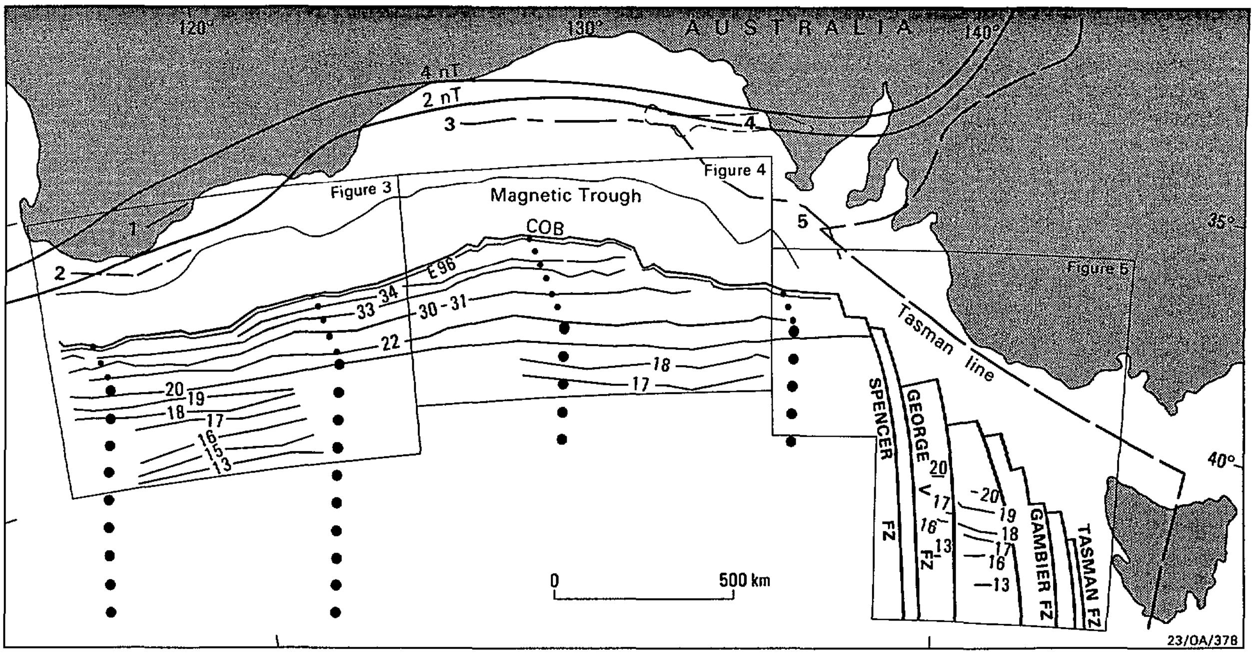

Figure 4. Magnetic trends and anomalies adjacent to Australia's southern margin.

REGIONAL STRATIGRAPHY AND PALEOENVIRONMENTS

Well control in the offshore portions of the platform-sag Eucla Basin, rifted Bight and Duntroon Basins, and intra-cratonic/rifted Polda Trough is limited (Fig. 2). Nine wells: Jerboa-1 and Potoroo-1 (Bight Basin), Apollo-1 (Eucla Basin), Duntroon-1, Echidna-1, and Platypus-1 (Duntroon Basin), and Gemini-1, Mercury-1, and Columbia-1 (Polda Trough), provide the basis for the region's stratigraphy.

Previous workers (Lowry, 1970; von Sanden & Barten, 1977) provide the framework for the Cretaceous sequence, supplemented by seismic interpretation of key marker horizons between existing well control by Fraser & Tilbury (1979). A summary of the revised stratigraphy, incorporating the revised stratigraphic nomenclature of Hill (1989) and the revised palynological zonations of Morgan (1986), is presented in Figure 5.

There is an uncertainty with respect to age relationships between units across all basins, resulting from the lack of cored sections and the reliance upon drill-hole cuttings which, inevitably, can be grossly contaminated. Palynological investigations to date, excluding the work by Morgan (1986) on Duntroon-1, must be viewed with considerable caution, owing to revised palynological zonations for the Mesozoic (Helby & others, 1987). The absolute reliance upon palynological data for correlation and interpretation of the Mesozoic section in the Great Australian Bight by previous workers must also be treated cautiously, because of marked facies changes across the basins. The acceptance of palynological interpretations as an indicator of absolute time, irrespective of the fact that revisions in zonation and taxonomy occur periodically, casts doubt on previous burial history plots and predictions of continental breakup.

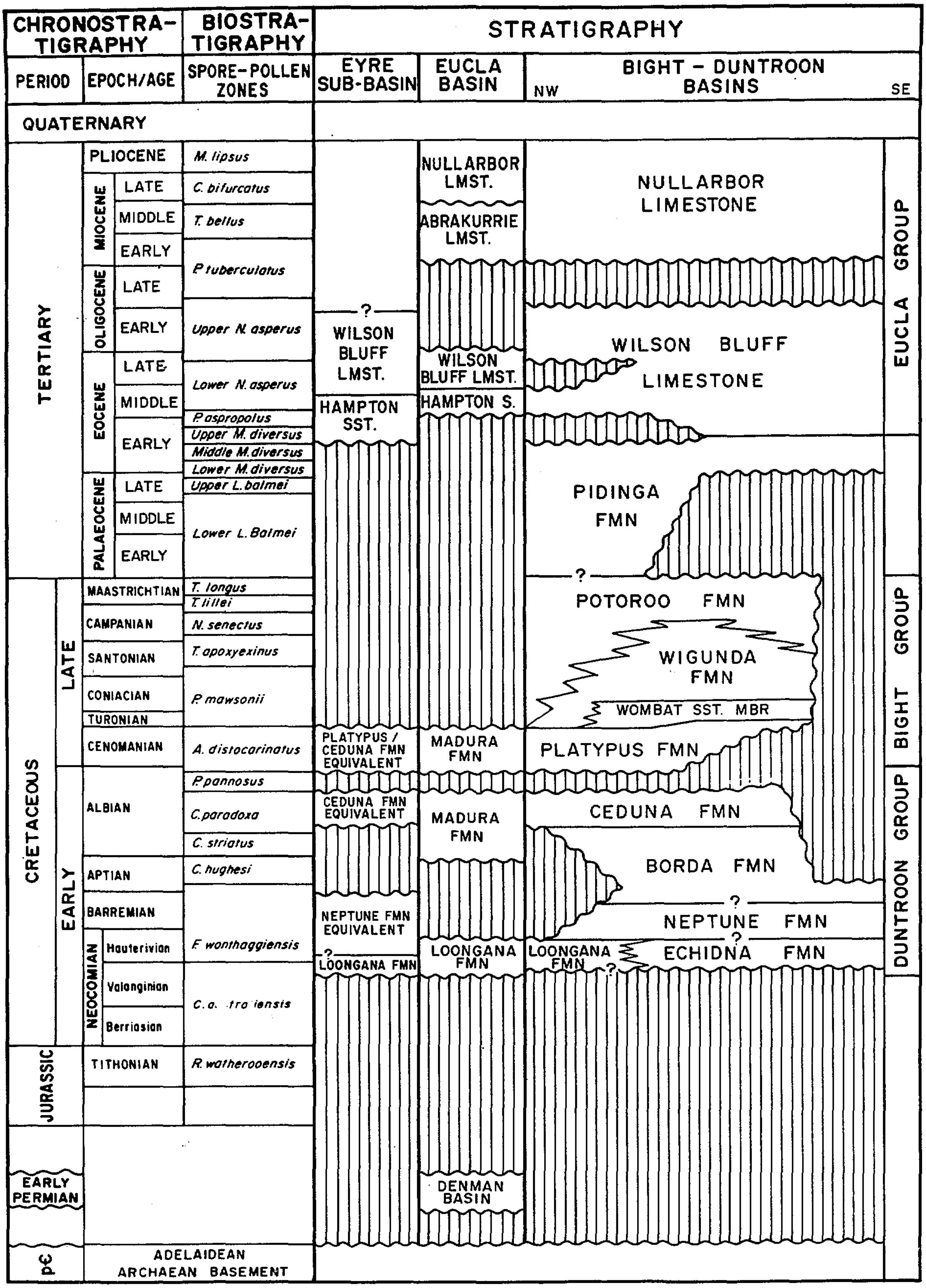

Figure 5. Summary of Great Australian Bight stratigraphy (after Stagg & others 1990).

PALEOZOIC AND OLDER ROCKS

Jerboa-1 intersected a dark grey, dense, micro-crystalline, amphibolitic basement, tentatively correlated with the Archaean Yilgarn Block of eastern Western Australia. Apollo-1 intersected a granitic gneiss of possible Archaean or Early Proterozoic age, whilst Potoroo-1 intersected a granodiorite; both these units show close affinity with the nearby Gawler Craton.

Both Columbia-1 and Mercury-1 reached TD in a thick succession of ?Cambrian redbeds (?Kilroo Formation equivalents), underlain by massive white sandstone and siliceous siltstone, although at Mercury-1 the succession was dominated by massive halite. Permo-Carboniferous sediments of the Coolardie Formation are recorded in the three offshore Polda Trough wells. Unnamed Permo-Carboniferous sediments of the Denman Basin also underlie sediments of the Eucla Basin in Apollo-1, Mallabie-1, and Nullarbor-8 Bore.

MESOZOIC SEDIMENTS

The first indication of Mesozoic sedimentation occurs in the Polda Trough. Fluviatile and lacustrine sediments of the Upper Jurassic **Polda Formation** have been intersected in the three offshore Polda Trough wells, and may represent early syn-rift deposition.

The earliest firm evidence of rift-related sediments recorded ubiquitously across the Southern Rift System is the Neocomian **Loongana Formation**. In Jerboa-1, the sequence consists of non-marine, interbedded sandstones, siltstones, and dark brown to black pyritic shales, assigned a Late to Middle Jurassic age (M. florida Zone; Powis & Partridge, 1980). A fluvio-deltaic depositional environment with outbuilding of deltas into a deep lake that experienced localised anoxic conditions is envisaged. A similar but somewhat more condensed sequence occurs in Apollo-1 and Potoroo-1, where a basal sandstone and shale unit has been assigned to the Loongana Sandstone, but due to the strong affinities with Jerboa-1 is now referred to as the Loongana Formation; it represents a time equivalent of the Pretty Hill Sandstone of the Otway Basin.

In the Duntroon Basin, a sequence of dark brown to black shales interbedded with minor gritty sandstones, inferred to have been deposited in a proximal lacustrine environment, has been assigned to the **Echidna Formation** (Hill, 1989) and is a time equivalent of the Loongana Formation.

Non-marine conditions persisted across the region into the Barremian. A monotonous sequence of dark shales intersected in Echidna-1 is assigned to the **Neptune Formation** and is equivalent to a Neptune Formation equivalent in Jerboa-1. However, this unit was not penetrated, or was absent, in the remaining wells in the Duntroon Basin, and was absent in the Bight and Eucla Basins.

The first indication of marginal marine conditions is recorded within the Duntroon Basin during the Aptian. This involved the deposition of the **Borda Formation**, consisting of a thick sequence of shale with minor basal sands and coal. These sediments were deposited in a poorly drained floodplain that experienced minor marine ingressions, possibly resulting from the transgression of a shallow sea from the northeast (Veevers & Evans, 1975). No record of Aptian deposition is observed in the Bight and offshore Eucla

Basins; marine influence in the Otway Basin is similarly transitory during the Aptian.

Predominantly marine conditions persisted during the early Albian in the Eucla Basin at Apollo-1 (Madura Formation; Fig. 5), but are not recorded in the Bight Basin. A hiatus in marine deposition between the Eucla and Duntroon Basins is apparent, reinforcing the notion of a transgression from the northeast possibly via the Eromanga Basin.

Shales and minor coals of the upper Borda Formation in Duntroon-1 were deposited in a non-marine, fluvio-lacustrine environment with one notable marine incursion (M. tetracantha dinoflagellate Zone; Morgan, 1986). Widespread marginal marine sedimentation is apparent during the middle Albian.

In the Duntroon Basin, the **Ceduna Formation** conformably overlies the Borda Formation and consists of distributory channel sandstones and siltstones deposited in a tidally-influenced deltaic complex that extended laterally to Platypus-1 (Dodd, 1986). Within the Bight Basin, the Ceduna Formation occurs as a nearshore marine facies that passes into a condensed sequence in Apollo-1 (Madura Formation), possibly due to clastic starvation.

In the Eyre Sub-basin of the Bight Basin, Jerboa-1 contains a widely correlatable Albian section that comprises dark grey to black marine shales. It is assigned to the Ceduna Formation equivalent.

A regional hiatus is apparent in the late Albian extending from the Bight Basin to the Duntroon Basin (Fig. 5). The hiatus marks the boundary between the Early Cretaceous Duntroon Group and the Late Cretaceous Bight Group (analogous to the Otway and Sherbrook Groups of the Otway Basin) and is also coincident with the presumed Australia-Antarctica breakup at 96 ± 4 Ma (Veevers, 1988).

In the Duntroon Basin, a major Cenomanian regression led to non-marine conditions and the deposition of sandstone, siltstone, and coaly facies of the **Platypus Formation**. Meanwhile, in the Bight Basin, nearshore marine facies of the basal Platypus Formation were deposited, passing into brackish and non-marine facies at the top in Potoroo-1. In Apollo-1, a condensed sandstone and shale sequence (upper Madura Formation) was laid down under marine conditions, while in the Eyre Sub-basin, Jerboa-1 intersected a correlatable sequence comprising dark shales and a basal sand deposited in a nearshore environment (Platypus Formation equivalents).

The **Wombat Sandstone Member** of the Wigunda Formation is restricted to the Duntroon Basin where it represents a thin, but laterally-extensive shore-face unit deposited on a marine shelf (Morgan, 1986). Stable marine conditions existed in the Duntroon Basin from the Turonian to the Campanian with the deposition of the strongly diachronous **Wigunda Formation**. The unit comprises prodelta siltstones and claystones and is analogous to the Belfast Mudstone of the Otway Basin. The unit is absent in Jerboa-1, Apollo-1, and Mallabie-1, suggesting that the proximal portions of the Eyre Sub-basin and Eucla Basin acted as a major bypass margin in the Late Cretaceous. Deighton & others (1976) and Fraser & Tilbury (1979) interpret this change to signify a probable eastwards encroachment of the sea along the floor of the rift valley. It is coincident with a major global sea level rise in the Turonian (Vail & others, 1987). The merging of the Platypus and Potoroo Formations is likely as the Wigunda Formation becomes more condensed to the north of the Bight Basin.

In the southwest part of the Ceduna Sub-basin, a thick prograding sequence with large-scale foreset beds (**Potoroo Formation**) was deposited in the Santonian-Campanian. The unit is equivalent to the Timboon Sand of the Otway Basin. Significant upbuilding of topset beds is indicative of relative sea level rise which Fraser & Tilbury (1979) attribute more to sediment loading than to eustacy. The formation is strongly diachronous (Fig. 5), ranging in age from Cenomanian to Maastrichtian in the west to late Campanian to Maastrichtian in the east (Forbes & others, 1984). Depositional environments were paralic in the northeast and bathyal in the southwest.

Within the Duntroon Basin, the Potoroo Formation is divisible into a basal nearshore marine sand, middle massive brackish-water shale, and an upper interbedded sand and shale sequence deposited in a delta plain environment. Fraser & Tilbury (1979) suggest a high rate of terrigenous influx as being a contributing factor for this regression. A similar sequence is encountered in Potoroo-1 in the Ceduna Sub-basin. Seismic data indicate that the Potoroo Formation regression was followed by a transgression resulting in a seaward thinning wedge of paralic facies sediments cutting across the top of the prograded sequence and extending over most of the Ceduna Sub-basin (Willcox, Stagg, Davies & others, 1988).

TERTIARY SEDIMENTS

The Potoroo Formation is unconformably overlain by the transgressive marine sands of the Tertiary **Pidinga Formation** in the Duntroon Basin, whilst no apparent unconformity can be recognised in the Bight Basin (von Sanden & Barten, 1977). Environments of deposition range from shallow sub-tidal to lagoonal. In the Eyre Sub-basin and the Eucla Basin, the **Hampton Sandstone** unconformably overlies the Upper Cretaceous Bight Group sequence and is considered to be a correlative of the Pidinga Formation.

Open marine conditions in the Early Eocene extended from the Eyre Sub-basin to the Duntroon Basin with the deposition of the **Wilson Bluff Limestone** of the Eucla Group which conformably overlies the Hampton Sandstone to the west and the Pidinga Formation to the east.

A regional hiatus, due to either non-deposition or erosion, is apparent across the region in the Lower Oligocene. Stable open marine conditions prevailed with deposition of the **Nullarbor Limestone** from the Early Miocene until the latest Tertiary (Fig. 2). Since their deposition, the limestones of the Eucla Group have been elevated and tilted gently to the east and south. At the Head of Bight, they are overlain by Pleistocene aeolinites (Ludbrook, 1969).

SUMMARY OF TECTONIC HISTORY

Stagg & others (1990) proposed the following speculative tectonic history for the Great Australian Bight region, and for the Southern Rift System in general:

(1) Lithospheric extension in the ?pre-Valanginian, and probably as old as the Permian, was on a NW-SE azimuth. This extension, which is well-documented on the western margin of Australia, probably reached at least as far east as Kangaroo Island, and may have affected the entire Southern Rift System. Movement would have been predominantly strike-slip or transtensional in the nascent Otway Basin, and in the Bass Strait/west Tasmania area.

(2) Permian to Jurassic sedimentary basins developed along the embryonic

Southern Rift System (for example, underlying the Recherche Sub-basin), and were filled largely by fluvial-lacustrine syn-rift sediments. The sediment fill was at least partially indurated.

(3) Neocomian 'breakup' lead to subsidence of the margin and the onset of marine deposition in the deeper parts of the rift basins. The developing ocean basin was underlain by crust which ranged from highly-extended continental, through mixed slivers of oceanic and continental material, to purely oceanic. Crust with greater oceanic affinity was probably more prevalent in the west. At about this time, lithospheric extension appears to have been taking place in the Gippsland Basin of southeastern Australia along a NNE-SSW azimuth, almost orthogonal to coeval extension in the west.

(4) A huge pile of clastic sediment (?3000 m thick) was rapidly deposited in the Ceduna Sub-basin and Duntroon Basin areas during mainly Barremian to Albian times: this was probably a shelf/slope deposit on the incipient continental margin.

(5) Continued breakup and the onset of thermal sag during the Cenomanian led to renewed block-faulting in the Ceduna Sub-basin and Duntroon Basin, and re-activation of deep-seated transfer fault zones. The pile of under-compacted sediment was put under transpression and/or slumped to create a zone of nappe and overthrust structures along the southwestern flank of the Ceduna Sub-basin. This covers an area of approximately 60,000 km^2.

(6) Gradual reduction in tectonic subsidence during the Late Cretaceous allowed the aggradation and outbuilding of massive delta complexes, particularly in the southwest Ceduna Sub-basin. Continued movement within the underlying incompetent sediment pile caused diapirism throughout the Late Cretaceous. In the Otway/Tasmania area, the proximity of the spreading-ridge thermal anomaly to the plate boundary (as a result of numerous ridge offsets) and contact between parts of the Australia and Antarctica Plates, led to transpression and uplift of some of the oceanward tilt-blocks.

(7) Extensive uplift and erosion appears to have taken place in the Late Cretaceous and ?earliest Tertiary when, for example, the 'outer high' formed in the Ceduna Sub-basin and the Echidna-Koala Structures (see Stagg & others, 1990) formed in the Duntroon Basin. Several thousand metres of sediment were probably eroded from the tops of these structures. Stagg & others (1990) could offer no satisfactory explanation for the origin of this uplift, since from calculations of the degree of extension and the rate of seafloor spreading, it would appear that the plates were separated by several hundred kilometres at this stage.

(8) The Tertiary was a period of minimal deposition, or deposition and subsequent erosion, in the Great Australian Bight area, with only a few hundred metres of Paleogene terrigenous sediment and Neogene carbonate being preserved. In the Otway area, Paleogene deltaic sediments were being laid down. During the Late Eocene and possibly earliest Oligocene, major wrench-related anticlines developed on the Otway continental slope, corresponding to the onset of fast seafloor spreading. These complexly-faulted structures occupy an inboard position on the slope (that is, away from the plate boundaries and contact), suggesting that they are caused by re-activation at the heads of major basin-forming detachment faults.

(9) Nearly all faulting and related tectonic movements ceased abruptly during the mid-Oligocene when the Australia and Antarctic Plates cleared each other in the South Tasman Rise area.

PROPOSED CRUISE PLAN

A summary of the proposed cruise plan is as follows (a more detailed description and time allocation table is given in Appendix 2). A map summarising proposed ship's track and sampling sites is presented in Figure 6:

1) Transit from Fremantle (departure 0000 hrs 12/6/91).
2) Dredging of northwestern ocean crust geochemistry site.
3) Shooting of two high-resolution seismic lines, together with short tie lines, across the Eucla Shelf and Eyre Terrace; a total of 650 line km.
4) Vibrocoring (in shallow water - <350 metres) and gravity coring (in deeper water - 350-1000 metres) on the Eucla Shelf and Eyre Terrace, at sites located on the high-resolution seismic lines.
5) Gravity coring for geochemical traverse from 500 - 3500 metres water depth.
6) Dredging and gravity coring of deep Ceduna Terrace sequence (>3500 m water depth).
7) Dredging of remaining three ocean crust geochemistry sites.
8) Transit to Fremantle (arrive 2330 hrs 10/7/91).

Summary:

	DAYS
Transit	: 10.0
Dredging (ocean crust geochemistry)	: 0.25
High-resolution Seismic (Cenozoic carbonates)	: 3.0
Vibrocoring/Gravity Coring (Cenozoic carbonates)	: 3.0
Gravity Coring (surficial geochemistry)	: 1.0
Dredging (deep Ceduna Terrace)	: 6.5
Dredging (ocean crust geochemistry)	: 0.75
Bad Weather	: 4.0
	28.5 days

EXISTING GEOPHYSICAL DATA

Proposed sample sites have been located on the basis of existing geophysical, primarily seismic data (Fig. 7). Where no seismic data exists, sampling sites are located on existing bathymetric data. The following compilation and quality assessment of existing data to be used for site location is based on Willcox, Stagg, Davies, & others (1988) and Stagg & others (1990).

SEISMIC DATA

(1) BMR Continental Margins Survey (1970-1973): Six-fold analogue seismic lines oriented N-S and E-W extend from the shoreward side of the continental shelf out to the abyssal plain at an average separation of about 35 km. These lines were recorded with a sparker source, and are of moderate to poor quality. Digital magnetic, gravity, bathymetry, and navigation data are also available.

(2) *M/V PETREL* (Shell Development Australia Pty Ltd) (1972-1973): Moderate to good quality, 24-fold, airgun array, digital data in the form of zig-zag lines extending across the margin from the continental shelf out to

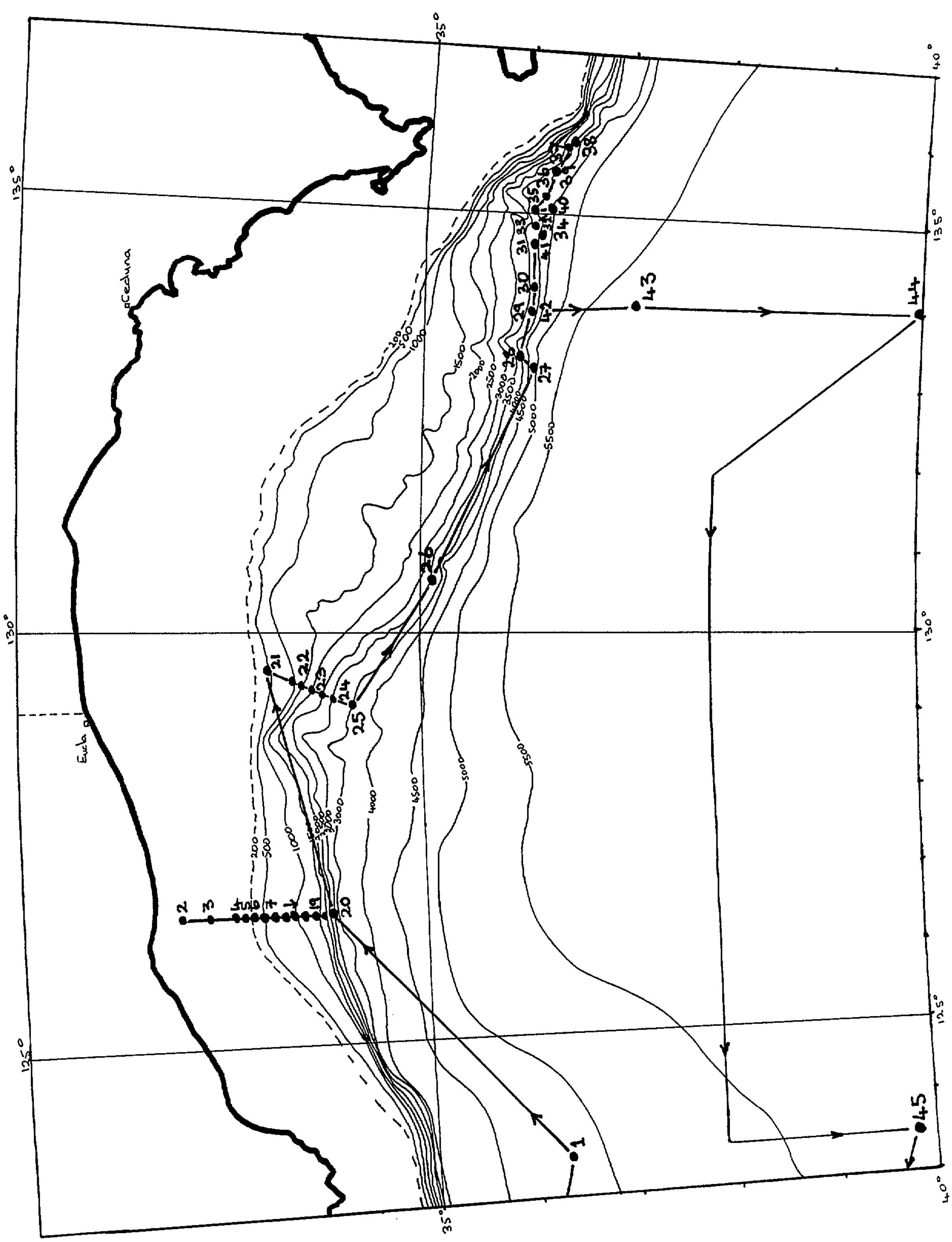

Figure 6. Map showing proposed *R/V RIG SEISMIC* ship's track and sampling sites. The approximate locations of sites are listed in Appendix 1.

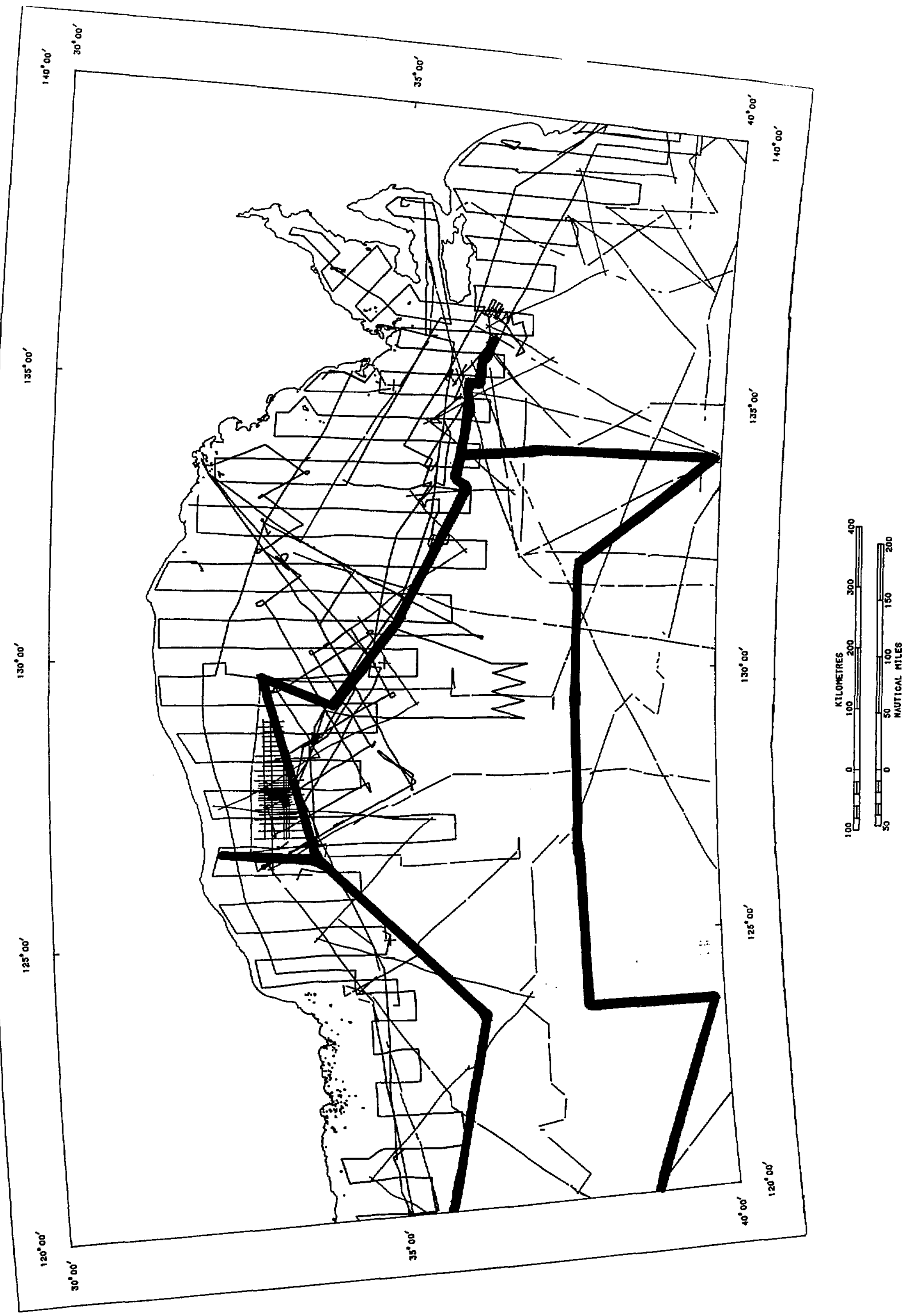

Figure 7. Track map showing existing geophysical data on which sampling sites will be located. Proposed *R/V RIG SEISMIC* tracks shown with heavy lines.

the abyssal plain, with an average separation of approximately 100 km between *the centre points of adjacent lines. Although recorded 24-fold, this material has not yet been stacked.

(3) Esso (1979): High quality, stacked 48-fold airgun array seismic data are available over much of the Eyre Terrace region.

(4) Japan National Oil Company (1989): JNOC recently collected seismic data over the Eucla Shelf-Eyre Terrace region. However neither this material, nor details of recording parameters and source type, were available when this proposal was being prepared. If possible, JNOC line location data will be used as the basis for locating the proposed high-resolution seismic component of the cruise, so that eventually the deep penetration data can be used to complement the higher resolution, but shallow penetration data.

BATHYMETRIC DATA

(1) L-DGO (1969-1972): Lamont-Doherty Geological Observatory collected magnetic and bathymetric data in relevant areas using the *USNS ELTANIN*.

SPECIFIC AREAS - BACKGROUND AND OBJECTIVES

AREA A: BIOSTRATIGRAPHY AND SEDIMENTOLOGY OF THE DEEP CEDUNA SUB-BASIN SEQUENCE (Joint BMR-University of Adelaide-South Australia Department of Mines and Energy-University of Sydney project).

The earlier *R/V RIG SEISMIC* cruises in the Great Australian Bight extended the existing seismic coverage in the Ceduna Terrace area (Survey 65), and carried out an extensive sampling program, using coring, dredging, and heatflow techniques (Survey 66) in the shallow Ceduna Terrace sequence. This earlier program was designed to further evaluate the hydrocarbon potential of an area considered to possess fair to good hydrocarbon prospectivity (Fraser & Tilbury, 1979). Fraser & Tilbury (1979) recognised two main possibilities in the Great Australian Bight Basin that may be favourable for hydrocarbon generation, migration, and entrapment:

(1) The top part of the faulted Lower to mid-Cretaceous sequence where structural entrapment may exist in tilted blocks by a combination of dip closure and faulting. While both source (marine beds within the blocks) and seal (fine-grained sediments of the Wigunda Formation) may be present, Potoroo-1 did not contain indications of appropriate reservoir facies. However Potoroo-1 was sited on the far northern edge of the Ceduna Terrace sequence, and cannot be considered a truly representative facies sequence.

(2) Juxtaposition of a thick Upper Cretaceous sequence, interpreted to contain interbedded sands and shales, directly above a probable fine-grained, shallow marine sequence. The deeper marine sequence provides a potential source, with any generated hydrocarbons having a simple migration path into sand bodies forming stratigraphic traps within the delta sequence. However Willcox (1981) suggested that the sand bodies may be too shallow for maturity, and that the delta shows no proximal downwarping or closure.

The existing biostratigraphic and sedimentologic facies information for the Ceduna Terrace sequence is based on the sequence encountered in Potoroo 1, lying on the northern margin of the terrace, and on dredge and core data from *R/V RIG SEISMIC* Survey 66, from the shallow outer margin of the terrace on the upper continental slope. The proposed sampling program would take a series of dredge samples from the deepest exposed parts of the Ceduna Terrace sequence, from deeply eroded submarine canyons primarily concentrated on the central and eastern parts of the terrace. If appropriate locations are identified following the dredging program, a series of gravity cores would also be collected. The objective of this program would be to describe the biostratigraphy and sedimentary facies of the interpreted Cretaceous sequence, in order to determine whether facies variations between Potoroo-1 and the southern margin of the sequence enhance the prospectivity of this sequence.

Biostratigraphic elements of this program will be co-ordinated by Dr S. Shafik (BMR), based on nannofossil (Dr Shafik; Dr N.F. Alley, South Australian Department of Mines and Energy) and foraminifer (Dr. B. McGowran, University of Adelaide) data. The sedimentary facies data will be collated and interpreted by Dr G. Birch (University of Sydney) and Dr D.A. Feary (BMR).

AREA B: SEDIMENTARY CHARACTERISTICS OF COOL-WATER CENOZOIC CARBONATE DEPOSITS ON THE EUCLA SHELF-EYRE TERRACE (Joint BMR-Queen's University-University of Adelaide project).

In recent years there has been a growing appreciation that modern tropical carbonate systems do not constitute a universally applicable analogue for ancient carbonate hydrocarbon reservoirs (c.f. Nelson, 1988). Throughout much of the Phanerozoic, and especially the Paleozoic, carbonate deposition was characterised by the absence of the large metazoans capable of forming reef build-ups to produce rimmed shelves (James, 1983). Instead, non-rimmed platforms or distally steepened ramps (Read, 1986) appear to have been more common (Wilson, 1975). The best modern analogues for these non-rimmed carbonate deposits are carbonate shelves outside the tropics (James & von der Borch, in press). However lack of detailed information on the geometry and facies characteristics of such shelves, relative to the better known tropical shelf deposits, has meant that non-rimmed carbonate facies models have been little used. In addition, there is now an appreciation that studies of modern and Cenozoic shelf deposits can provide a record of past climatic variation, contained within the facies and isotopic characteristics of carbonate deposits (Marshall & Davies, 1978; Davies & others, 1988; Feary & others, 1991).

The Eucla Shelf is the largest modern contiguous area of cool water carbonate sedimentation, and has been the site of predominantly cool water carbonate deposition since Eocene time. Accordingly, this area provides the potential to make a significant contribution to our understanding of the origin, accumulation history, and diagenesis of cool water carbonate deposits; to enable the formulation of facies models of critical importance for the interpretation of cool water carbonates in onshore and offshore Australian Cenozoic basins; and to act as analogues for Paleozoic shelf and slope limestone deposits.

Reconnaissance work on the Eucla Shelf-Eyre Terrace and Lacapede Shelf areas (Conolly & von der Borch, 1967; Wass & others, 1970; Lowry, 1970; Davies & others, 1989; James & von der Borch, in press) have demonstrated the general characteristics of the modern southern margin shelf facies. The Eucla Platform is a high energy shelf with a relatively deep shelf-slope break. A sigmoidal prograding seismic signature visible on existing airgun seismic sections suggests that shelf margin accumulation rates exceed subsidence rates. The surficial sediments are dominated by bryozoans with accessory mollusc and foraminifer components. There is little terrigenous input, primarily because the platform borders the limestone karst Nullarbor Plain. The near shore sediments (down to 80 m water depth) are coarse-grained, rippled, bioclastic sediments reworked by long period storm waves. Deeper sediments are progressively finer grained and more poorly sorted, with proportionately greater planktonic foraminifer, sponge, and pteropod components.

The aim of this component of the program is to record a high-resolution seismic grid to define the geometry and seismic facies of the Cenozoic sequence on the Eucla Shelf and Eyre Terrace. This will be oriented to use and complement a recently collected Japan National Oil Corporation air gun seismic line which will show the deeper structure. Vibrocores and gravity cores collected across the width of the shelf, terrace, and upper slope will be used to provide biostratigraphic and sedimentary facies control, and to enable the compilation of a three-dimensional facies model for high energy cool water shelf and upper slope carbonate deposition. This data will provide a description of facies belts relative to energy, water depth, and substrate; an assessment of the role of relic components in shelf sediment dynamics; a determination of the intensity and style of sea floor diagenesis in bioclastic sediments; and documentation of the nature of the shelf margin bryozoan community and its history relative to Quaternary sea level fluctuations.

Descriptions of the bryozoan component within cores will be carried out by Dr Y. Bone (University of Adelaide). Seismic stratigraphic and facies analysis will be undertaken by Dr D.A. Feary (BMR), and the detailed sedimentological descriptions of cores will be carried out by Professor N.P. James (Queen's University, Canada).

AREA C: LATE QUATERNARY PALEOCHEMISTRY OF THE AUSTRALIAN CONTINENTAL MARGIN: BIOGENIC FLUXES AND CONTINENTAL WEATHERING RATES (Joint BMR-Flinders University of South Australia-Woods Hole Oceanographic Institution project).

The organic carbon cycle and the flux of biogenic elements in the ocean have important implications both for climatic change and for the accumulation of some seafloor minerals, e.g. phosphorites, manganese nodules. The rates of organic carbon production in surface water, organic flux to the seafloor, degradation of organic matter in surficial sediment and ultimate burial by sediment are key factors in these cycles.

Organic carbon burial in seafloor sediment is a long-term control on the oxygen content of the atmosphere, and organic carbon burial on continental margins, estimated to be 20-25% of primary productivity, is likely to be an important control on atmospheric carbon dioxide content. Glacial/interglacial changes in oceanic circulation patterns, on a 10^3-10^5 year timescale, have caused variations in sea surface temperature, nutrient concentration, oceanic primary productivity, organic carbon fluxes to the sediment, and the chemistry of the water column and the atmosphere. Furthermore, the occurrences and concentrations of seafloor minerals (e.g. phosphorites of Eastern Australia; metallic nodules and crusts on the South Tasman Rise and western Tasmanian margin), have been linked to the dynamics of major current systems, organic carbon flux to the seafloor, and the cycling of organic carbon and bioactive constituents in the sediments.

The Eucla slope geochemical sampling transect forms one component in a proposed series of transects around Australia designed to document the Late Quaternary paleochemistry of continental margin sediments. These coring transects will examine the effects of past climatic change, as reflected in sea-level variations, on the oceanic organic carbon cycle on Australia's continental margin. The Eucla slope transect will form part of a series of southern margin transects, with additional coring proposed for the Naturaliste Plateau, the South Australian - west Tasmanian margin, and the South Tasman Rise. Sediment on these margins has been influenced by variations in the location of the Sub-Tropical Convergence, by the Leeuwin and Flinders Currents, and by the West Wind drift. Specific objectives of this program are:

(1) To document Quaternary glacial/interglacial cycles within continental margin sediments.

(2) To determine bulk sedimentation rates, and accumulation rates of biogenic and terrigenous components.

(3) To document glacial/interglacial organic carbon sources and fluxes, and to determine the consequent implications both for paleoproductivity and nutrient flux, and for coastal upwelling and circulation pattern variations.

(4) To investigate the influence of glacial/interglacial cycles in ocean biogeochemistry and continental weathering on the accumulation and/or formation rates of seafloor minerals.

Results of analyses from Western Australian margin coring transects, including the Exmouth Plateau and Perth Basin, record interglacial minima and glacial maxima in calcium carbonate content, and document glacial/interglacial cycles in the oxygen isotopic ratios of planktonic foraminifer tests. These cores record variations in sediment accumulation rates, sediment composition (biogenic and terrigenous components and bioactive trace metals), and water column chemistry. Radiochemical studies indicate sedimentation rates of about 2.5 cm/kyr, and dramatic variations in authigenic uranium content indicate changes in organic carbon fluxes (McCorkle & others, 1990).

The proposed southern margin geochemical coring will collect cores at approximately 500 m intervals between 500 and 3500 m water depth. Sediment samples will be analysed for bulk calcium carbonate content in order to identify the approximate depths of glacial/interglacial cycles. Subsequent sampling will be conducted for detailed oxygen and carbon isotopic signatures of foraminifers; for organic carbon content; for proxy organic carbon indicators including biogenic silica, bioactive trace metals; and for radiochemical studies including U and Th isotopic contents. Detailed data analysis will be conducted by Dr D. Heggie (BMR), Dr H.H. Veeh (Flinders University of South Australia), and Dr D. McCorkle (Woods Hole Oceanographic Institution).

AREA D: GEOCHEMICAL SIGNATURES OF SOUTHERN OCEAN MAGMATISM (Joint BMR-University of Tasmania-Australian National University project).

Dredging of ocean crust basalts from south of Australia provides the unique potential to address significant questions concerning the composition and organisation of mantle reservoirs supplying ridge basalts during continental break-up and seafloor spreading. In particular, it has been proposed that the area south of the Great Australian Bight contains the only known boundary between mantle convection cells, and that the region should record whether the major change in seafloor spreading rates at about 45 Ma was associated with compositional variation of erupted basalts.

The Southeast Indian Ocean Ridge system extends from the Indian Ocean triple junction, across the Southern Ocean south of Australia, to the complex

Macquarie triple junction south of Macquarie Island. An area approximately 500 km wide of anomalously deep (>4000 m) crust characterised by rough seafloor topography lying approximately midway along the SE Indian Ocean Ridge, south of the western Great Australian Bight, is known as the Australia-Antarctic Discordance (AAD). Several authors (eg. Weissel & Hayes, 1974) have suggested that this complex bathymetric-geophysical province may result from downwelling convective mantle flow beneath this region. This should lead to depression of isotherms beneath the AAD, which might therefore be considered as a crustal 'cold-spot'. This hypothesis is supported by recent seismic (Forsyth & others, 1987), magnetic (Marks & others, 1990), and petrological-geochemical (Klein & Langmuir, 1987; Klein & others, 1988) studies. The latter work demonstrated that the isotopic composition of mid-ocean ridge basalts along the SE Indian Ridge changes over less than 200 km, within the AAD, from typical Indian Ocean values to values characteristic of East Pacific and Atlantic ocean crust. These analyses support the hypothesis that the AAD represents a profound discontinuity in mantle reservoirs; the only known example on Earth today of such a mantle 'cold-spot'.

An understanding of the organisation and longevity of mantle reservoirs offers the possibility of constraining models to explain the dynamics of mantle convection. At present, nothing is known of the longevity or compositional variation of the mantle reservoir boundary located at the AAD. Weissel & Hayes (1974) reviewed bathymetric data for the flanks of the SE Indian Ridge and the AAD, and concluded that the processes responsible for producing the AAD have persisted for at least 30 my. More recently Veevers (1982) proposed that the AAD has actually persisted since initial Southern Ocean rifting in the Cretaceous, based on a study of sedimentary basins along the margins of southern Australia and Antarctica. Only sampling of basaltic basement at sites south of the Great Australian Bight, between the continent-ocean boundary and anomalies 15-20, can provide the vital geochemical information required to determine how long the reservoirs feeding the ridge system south of Australia have existed, and whether spreading rate variations might be related to magma chemistry.

Accordingly it is proposed that *R/V RIG SEISMIC* occupy four dredge sites, located on either side of the AAD and on ocean crust representing both slow and fast spreading. Dredged rocks will be analysed for major, trace, and rare earth elements by Dr A.J. Crawford (Geology Department, University of Tasmania). Isotopic analyses (Nd, Sr, and Pb) will be performed by Dr S. Eggins (Research School of Earth Sciences, Australian National University).

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APPENDIX 1: APPROXIMATE LOCATION OF SAMPLE SITES

SITE	METHOD	AREA	LATITUDE	LONGITUDE	WATER DEPTH	
SITE 1	DR	D	36°20'S	123°30'E	5000 m	
SITE 2	VC	B	32°28'S	126°32'E	35 m	
SITE 3	VC	B	32°44'S	126°32'E	50 m	
SITE 4	VC	B	32°56'S	126°32'E	70 m	
SITE 5	VC	B	33°00'S	126°32'E	80 m	
SITE 6	VC	B	33°05'S	126°32'E	100 m	
SITE 7	VC	B	33°10'S	126°32'E	150 m	
SITE 8	VC	B	33°15'S	126°32'E	200 m	
SITE 9	VC	B	33°19'S	126°32'E	225 m	
SITE 10	VC	B	33°23'S	126°32'E	250 m	
SITE 11	VC	B	33°26'S	126°32'E	300 m	
SITE 12	VC	B	33°30'S	126°32'E	350 m	
SITE 13	GC	B	33°34'S	126°32'E	500 m	
SITE 14	GC	B	33°38'S	126°32'E	700 m	
SITE 15	GC	B	33°42'S	126°32'E	850 m	
SITE 16	GC	B	33°45'S	126°32'E	1000 m	
SITE 17	GC	B	33°49'S	126°32'E	1150 m	
SITE 18	GC	B	33°53'S	126°32'E	1300 m	
SITE 19	GC	B	33°57'S	126°32'E	1700 m	
SITE 20	GC	B	34°00'S	126°32'E	2000 m	
SITE 21	GC	C	33°17'S	129°41'E	100 m	
SITE 22	GC	C	33°30'S	129°38'E	900 m	
SITE 23	GC	C	33°45'S	129°34'E	1500 m	
SITE 24	GC	C	34°05'S	129°27'E	2500 m	
SITE 25	GC	C	34°26'S	129°20'E	3500 m	
SITE 26	DR	A	35°17'S	130°46'E	3800 m	Canyon C
SITE 27	DR	A	36°12'S	133°18'E	5000 m	Canyon D
SITE 28	DR	A	35°52'S	133°20'E	4000 m	Canyon D
SITE 29	DR	A	36°02'S	133°52'E	3600 m	Canyon E
SITE 30	DR	A	36°10'S	134°12'E	4500 m	Canyon F
SITE 31	DR	A	36°04'S	134°46'E	3700 m	Canyon G
SITE 32	DR	A	36°07'S	134°57'E	4000 m	Canyon H
SITE 33	DR	A	36°01'S	135°05'E	3600 m	Canyon H
SITE 34	DR	A	36°19'S	135°07'E	4500 m	Canyon J
SITE 35	DR	A	36°19'S	135°24'E	4000 m	Canyon K
SITE 36	DR	A	36°24'S	135°37'E	3800 m	Canyon L
SITE 37	DR	A	36°30'S	135°54'E	3900 m	Canyon M
SITE 38	DR	A	36°33'S	135°54'E	3800 m	Canyon M
SITE 39	GC	A	36°24'S	135°37'E	3800 m	Canyon L
SITE 40	GC	A	36°19'S	135°07'E	4500 m	Canyon J
SITE 41	GC	A	36°04'S	134°46'E	3700 m	Canyon G
SITE 42	GC	A	36°02'S	133°52'E	3600 m	Canyon E
SITE 43	DR	D	37°10'S	134°00'E	5560 m	
SITE 44	DR	D	40°10'S	134°00'E	5050 m	
SITE 45	DR	D	39°46'S	123°30'E	4990 m	

DR - dredge site; VC - vibrocore site; GC - gravity core site
Canyon references are to canyons named in Davies & others (1989).

APPENDIX 2: DETAILED CRUISE PLAN

The proposed cruise plan, with a detailed time allocation, is as follows (see Figure 6).

1)	Depart Fremantle 0001 hrs 12th June 1991.		
2)	Transit to site 1 at 36°20'S 123°30'E -	650 nm	54 hrs
3)	Dredging at site 1 -		6 hrs
4)	Transit to seismic start at 34°00'S 126°32'E -	225 nm	19 hrs
5)	Deploy streamer -		12 hrs
6)	High-resolution watergun seismic lines -	650 nm	72 hrs
7)	Recover streamer -		6 hrs
8)	Vibrocoring at sites 2 to 12 -	60 nm	48 hrs
9)	Gravity coring at sites 13 to 20 - (finish at 34°00'S 126°32'E)	35 nm	24 hrs
10)	Transit to site 21 at 33°15'S 129°40'E -	195 nm	16 hrs
11)	Gravity coring at sites 21 to 25 - (finish at 34°25'S 129°15'E)	70 nm	24 hrs
12)	Transit to site 26 at 35°17'S 130°46'E -	95 nm	8 hrs
13)	Dredging and gravity coring at sites 26 to 42 - (finish at 36°02'S 133°52'E)	494 nm	156 hrs
14)	Transit to site 43 at 37°10'S 134°00'E -	72 nm	6 hrs
15)	Dredging at site 43 -		6 hrs
16)	Transit to site 44 at 40°10'S 134°00'E -	182 nm	15 hrs
17)	Dredging at site 44 -		6 hrs
18)	Transit to site 45 at 39°45'S 123°30'E	625 nm	52 hrs
19)	Dredging at site 45		6 hrs
20)	Transit to Fremantle - (arrive 2300hrs 10th July 1991)	791 nm	66 hrs
	Allowance for bad weather -		93 hrs
	TOTALS	4144 nm	28 days 23 hrs

APPENDIX 3: EQUIPMENT TO BE UTILISED DURING CRUISE

GEOLOGICAL SAMPLING EQUIPMENT

- Deep-sea winch with 9000 m of 19 mm wire
- Hydrographic winch with 9000 m of 5 mm wire
- Vibrocorer with 6 m core barrel
- Gravity corer with 10 m core barrel
- Chain bag and pipe dredges
- Benthos time-depth recorders
- Bottom sediment photographic camera and assembly
- Core splitting and X-Ray equipment

SEISMIC EQUIPMENT

- Digital seismic acquisition system designed and built by BMR; 16-bit floating point, SEG-Y output at 6250 bpi; 1 millisecond sampling
- A-300 Price compressor, providing 300 scfm at 2000 psi (62 litres/min. at 14 MPa)
- FJORD Instruments seismic receiving array: 6.25 m groups, 144 channels, 900 m active streamer length
- Syntron RCL-3 cable levellers; individual remote control and depth read-out
- single SSI-80 (80 cu.in.) and SSI-15 (15 cu.in.) waterguns

OTHER GEOPHYSICAL EQUIPMENT

- Geometrics G801/803 magnetometer
- Bodenseewerk Geosystem KSSS-31 marine gravity meter

NAVIGATION AND ECHO-SOUNDER EQUIPMENT

- Non-seismic data acquisition system built around Hewlett-Packard 1000 E-series minicomputer, with tape drives, disc drives, 12" and 36" plotters, line printers, and interactive terminals
- Racal Differential GPS system and Marisat datalink
- Magnavox T-Set stand-alone GPS receiver
- Magnavox MX1107RS (dual channel) and MX1142 (single channel) transit satellite receivers
- Magnavox MX610D and Raytheon DSN450 dual axis sonar dopplers; Ben paddle log
- Sperry, Arma-Brown, and Robertson gyro-compasses
- Raytheon deep-sea echo-sounder, 3.5kHz (2kW) 16-transducer sub-bottom profiler
- Raytheon deep-sea echo-sounder, 12kHz (2kW) precision echo-sounder

APPENDIX 4: SCIENTIFIC AND TECHNICAL CREW

D. Feary	Chief Scientist
S. Shafik	Micropaleontologist
E. Chudyk	Systems Scientist
P. Petkovic	Systems Scientist
G. Birch [1]	Visiting Scientist
T. Boreen [2]	Visiting Scientist
R. Lanyon [3]	Visiting Scientist
C. Buchanan	Marine Technician
P. Butler	Marine Technician
L. Hatch	Marine Technician
G. Sparksman	Marine Technician
J. Stratton	Marine Technician
P. Vujovic	Marine Technician
C. Saroch	Electronics Technician
U. Reike	Electronics Technician
C. Dyke	Mechanical Technician
J. Roberts	Mechanical Technician
D. Sewter	Mechanical Technician
S. Wiggins	Mechanical Technician

[1] - Department of Geology & Geophysics, University of Sydney
[2] - Department of Earth Sciences, Queen's University, Ontario, Canada
[3] - Geology Department, University of Tasmania

APPENDIX 5: ORGANISATIONS CONSULTED DURING PROPOSAL PREPARATION

The following organisations were contacted prior to preparation of this cruise proposal, with an invitation to either provide input at the cruise planning stage, or to participate in the cruise (* indicates that the organisation responded):

Petroleum Exploration Companies:
- *BHP Petroleum Pty Ltd
- Conoco Australia Ltd
- Esso Australia Ltd
- *Japan National Oil Corporation
- Marathon Petroleum Aust. Ltd
- Mobil Exploration Aust. Pty Ltd
- Sagasco Resources Ltd

State and Commonwealth Government Organisations:
- *Australian National Parks & Wildlife Service
- *CSIRO Antarctic Division
- *South Australian Department of Mines and Energy
- *Western Australian Department of Mines
- Western Australian Geological Survey

Universities:
- Curtin University of Technology
- Flinders University of South Australia
- *James Cook University of North Queensland
- National Centre for Petroleum Geology & Geophysics
- *Queens University, Canada
- *University of Adelaide
- *University of Sydney (including Ocean Sciences Institute)
- *University of Tasmania
- University of Western Australia