DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA

BASINS OF THE GREAT AUSTRALIAN BIGHT

CONTINENTAL MARGINS PROGRAM

FOLIO 5: TEXT

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS
DEPARTMENT OF MINES & ENERGY, SOUTH AUSTRALIA

Department of Primary Industries and Energy

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Department of Mines and Energy, South Australia

OIL GAS, AND COAL DIVISION

BASINS OF THE GREAT AUSTRALIAN BIGHT REGION: GEOLOGY AND PETROLEUM POTENTIAL

CONTINENTAL MARGINS PROGRAM

FOLIO 5

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AUSTRALIAN GOVERNMENT PUBLISHING SERVICE
CANBERRA

ISSN 1031-6558
ISBN 0 644 12323 0

DEPARTMENT OF PRIMARY INDUSTRIES & ENERGY
Minister for Resources: The Hon. Alan Griffiths, MP
Secretary: G.L. Miller

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS
Director: R.W.R. Rutland, AO

DEPARTMENT OF MINES AND ENERGY, SOUTH AUSTRALIA
Minister: The Hon. J.C. Klunder, MP
Director-General: R.K. Johns

This report should be referenced as:

Stagg, H.M.J., Cockshell, C.D., Willcox, J.B., Hill, A.J., Needham, D.J.L., Thomas, B., O'Brien, G.W., & Hough, L.P., 1990. Basins of the Great Australian Bight region: geology and petroleum potential. *Bureau of Mineral Resources, Continental Margins Program Folio* 5.

Printed in Australia by Alken Press Pty. Ltd. – Smithfield

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PREFACE

In 1986, the Bureau of Mineral Resources (BMR) set out to rekindle exploration interest in the Great Australian Bight and to answer some of the perceived geological problems of the area, by conducting a regional framework multichannel seismic survey with follow-up sampling and heatflow work using the R/V *Rig Seismic*. At about the same time, the South Australian Department of Mines and Energy (SADME) commenced a project that involved re-interpreting existing company seismic data in the Duntroon Basin and other areas in South Australian waters, with a view to promoting a new round of exploration. In 1987, it was decided that BMR and SADME should pursue a joint study, with the aim of covering as much of the Great Australian Bight as possible. Areas of responsibility were allocated such that SADME concentrated on the shallow water Duntroon and Denman Basins, while BMR studied the deeper water Great Australian Bight Basin (including the Eyre Sub-basin), the Polda Trough, and the Bremer Basin further west. This folio is the principal product of the joint study.

Since this report is the combined effort of two widely separated organisations, it is inevitable that there will be some differences in interpretation and style of presentation. While the editors (Stagg, Cockshell, and Hill) have endeavoured to produce a final document that is devoid of internal inconsistencies, no doubt some will still remain.

CHAPTER 1: INTRODUCTION

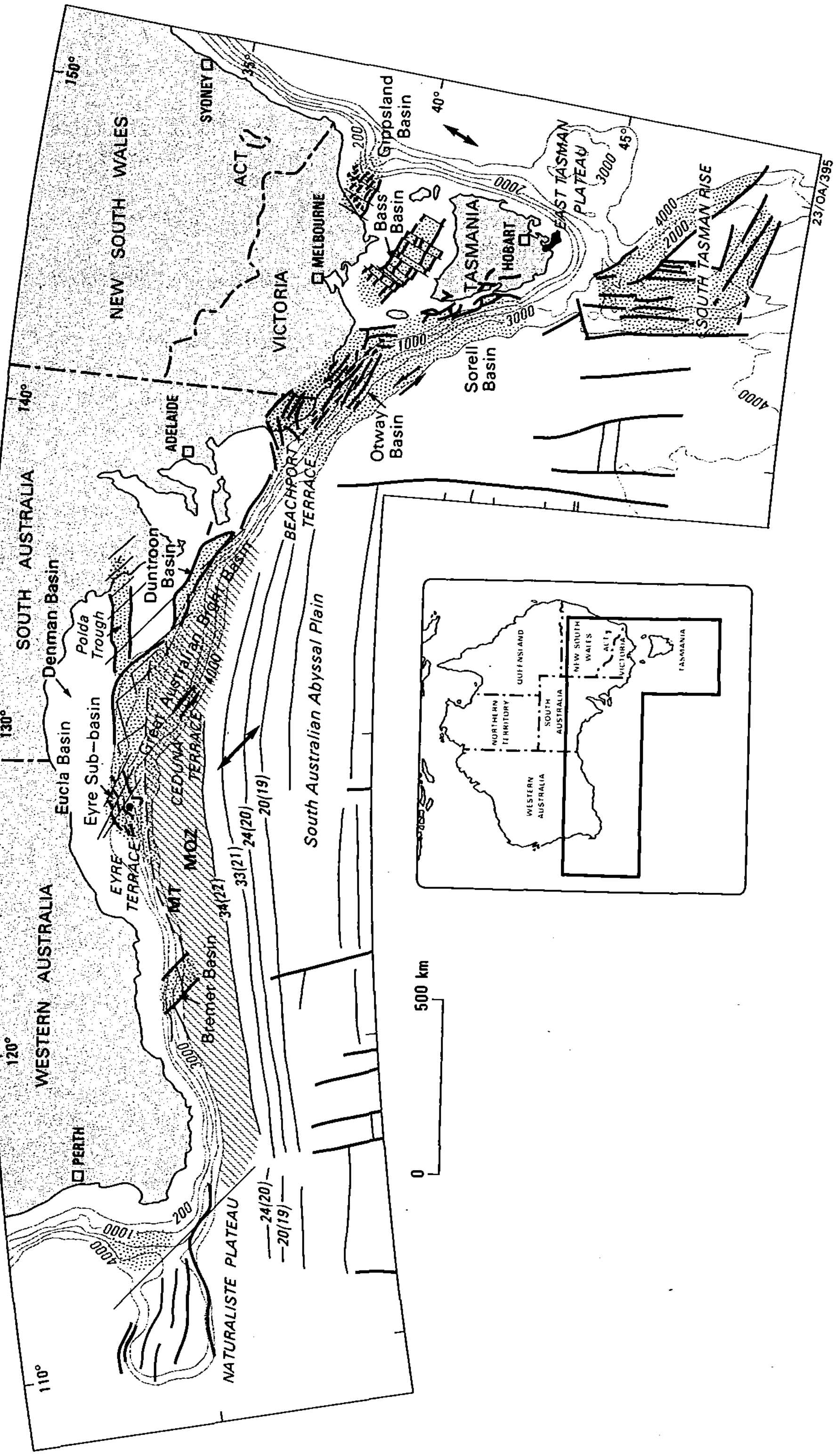
a) PREAMBLE

The Great Australian Bight (GAB) region of southern Australia, from Kangaroo Island off Adelaide to Cape Leeuwin in the southwest (Text Fig. 1), contains a number of primarily Mesozoic sedimentary basins ranging in area from 5000 to 180000 km^2, containing from 5 to 12 km of sediments, and lying in water depths from 60 to 5000 m. Despite the very large area and volume of sediments, the GAB region is inadequately explored for hydrocarbons.

Exploration of the GAB region commenced in the mid 1960s, peaked in the mid 1970s, and has been almost dormant in the 1980s (Figs 2.1-2.4). Approximately 50000 km of industry-standard multichannel seismic data were recorded from 1966-86; of this total, less than 14000 km have been recorded since 1980 (Figs 3.1-4.1). Most of the 1980s vintage seismic data have been recorded as detailed surveys over restricted areas, with the only exception being BMR's 1986 regional framework study of the central Great Australian Bight Basin. (For the sake of brevity, the Great Australian Bight Basin will be referred to as the 'Bight Basin' in the remainder of this report.) Only nine exploration wells have been drilled on the continental margin (Fig. 5.1), of which eight are in South Australian and one is in Western Australian waters. Six of these wells were drilled in two relatively small basins (the Polda Trough and Duntroon Basin), and all were unsuccessful. This drilling activity, spread over 14 years, represents one well every 18 months and for every 20000 km^2 of sedimentary basin.

The density of exploration coverage in the GAB region varies widely - from relatively high in prospective shallow-water areas (such as the Duntroon Basin), through low-density and frequently low-quality in frontier areas (Ceduna Terrace, Bremer Basin), to very sparse in areas of long-term strategic interest (*eg* continental rise). This range of exploration knowledge is reflected in the structure and contents of this report, both text and plates, and in the discussion of individual basins and sub-basins.

The organisation of the text and plates of this folio is such that the early sections consist of regional studies of the margin as a whole, while the later sections concentrate on the detailed structure, stratigraphy, evolution, and hydrocarbon potential of the individual basins and sub-basins. The study is strongly oriented towards hydrocarbon aspects of the GAB. However, considerable emphasis is placed on the tectonic development of the margin, as a whole (Chapter 5), since these authors consider that an adequate understanding of this development (and particularly of the unsolved problems in its evolution) is critical to an understanding of the geology and hydrocarbon potential of the individual basins.



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

b) ACKNOWLEDGEMENTS

A report of the scale of this folio requires a major effort from many people, apart from the authors. We would particularly like to place on record our appreciation of the efforts of the following people:

Bureau of Mineral Resources
Data Processing: P. Napier, J. Bedford, K. Revill, I. Roach
Drafting of Plates: G. Scott, L. Hollands, D. O'Donoghue, A. Murray, B. Pashley, J. Convine, N. Kozin.

SA Department of Mines & Energy
Drafting of Plates: E.R. Calabio, M.H. Ross, D. Simpson-Lyttle, L.A. Way.
Typing: D.J. Woods, H. Georgief, M.V. Scioscia, L.J. Taylor

The authors also appreciate the efforts of J.B. Colwell, R.A. Gerdes, D.I. Gravestock, and J. Hibburt in critically reading this report.

The cover photograph of the limestone cliffs of the Great Australian Bight was provided by Yvonne Bone, Department of Geology and Geophysics, Adelaide University, to whom we express our appreciation.

c) EXPLORATION HISTORY

i) History of Petroleum Exploration - South Australia

Petroleum tenure in the South Australian portion of the study area began in 1954 with the granting of Oil Exploration Licence (OEL) 7 to R.F. Bristowe and Santos Ltd (Appendix I). This licence covered most of northeast South Australia with only the southwest extremity of the licence partially covering the Polda Basin (Fig. 2.1). The licence was converted to OELs 20 and 21, granted to Santos Ltd and Delhi Australian Petroleum Ltd in 1959. No exploration was carried out the offshore part of the area and the licences converted to wholly onshore Petroleum Exploration Licences 5 and 6 in 1969.

Hematite Exploration Pty. Ltd were granted OEL 26 in 1961 covering the Otway Basin and extending into the study area. A reconnaissance aeromagnetic survey flown in that year (Fig. 10.1) indicated shallow basement south of Kangaroo Island beneath the continental shelf. Further work in this licence did not extend into the study area and the licence was surrendered in 1968.

In 1961, H.F. Blacker, P.L. Brady and T. Turner were granted OEL 27 over southern Eyre Peninsula and adjacent waters (Fig. 2.1). In 1963 they were granted OEL, 32 expanding outside the area covered by OEL 27. No offshore exploration was carried out in either licence and OEL 32 was surrendered in 1965.

A syndicate headed by Outback Oil Co. NL were granted OEL 33 over the Eucla Basin in 1964. OEL 38, covering most of the Bight and Duntroon Basins, was granted to Shell Development (Australia) Pty Ltd in 1966 (Fig. 2.1). In 1965-66 a gravity survey was conducted over the more prospective onshore areas of OEL 33. In 1966, a regional aeromagnetic survey of 16000 km was flown over OELs 33 and 38 covering most of the Eucla, Bight, Denman, Polda and Duntroon Basins. This survey indicated the shallow nature of the Eucla Basin, up to 2500 m of sediment in the Polda Trough, and magnetic basement depths exceeding 6000 m adjacent to the continental slope. OEL 33 was subsequently surrendered in the same year. Later that year, Shell carried out a reconnaissance seismic reflection and refraction survey in OEL 38, which resulted in substantial areas of shallow basement and very deep water being relinquished in 1967. Further seismic reconnaissance work was carried out in 1968. During 1968 and 1969, OEL 38 was converted into five Exploration Petroleum Permits (EPP) which covered most of the previous licence area plus a substantial area in deeper water regions of the Bight Basin (Fig. 2.2). Within these EPPs (5, 6, 7, 10, and 11) Shell carried out ten seismic surveys totaling 23172 km of reflection data, covering most of the region between 1969 and 1976 (Fig. 4.4). Along most deep water seismic lines, magnetic data were also recorded. In 1972, Platypus-1 and Echidna-1 wells were drilled in the Duntroon Basin, and in 1975 Potoroo-1 was drilled in the Bight Basin. During the life of these permits numerous partial relinquishments occurred; these are detailed in Appendix I. Following the drilling of the three dry wells, interest in the area waned and the permits were surrendered between 1975 and 1977.

In 1968, EPPs 1 and 3 were granted to Hematite Petroleum Pty Ltd in the western Otway/eastern Duntroon Basin area (Fig. 2.2). An aeromagnetic survey in that year indicated shallow basement in most of the licence area, deepening to 4000 m to the south and west. In 1970, a seismic survey in the southwestern permit (EPP 1) indicated shallow basement, rapidly deepening at the continental slope. Both permits were surrendered in 1971.

In 1968, Outback Oil Co. NL were granted EPP 4 in the Eucla and Denman Basins (Fig. 2.2) following two reconnaissance surveys in the previous year (Fig. 4.6). In 1969, EPP 12 was added to Outback's acreage in the Denman Basin. In 1972, two seismic surveys, totalling 3194 km of data were recorded detailing the Permian Denman Basin. In 1975, the dry Apollo-1 well was drilled into relatively shallow basement. This dampened interest in the area, and both permits were surrendered by 1977.

EPP 13 was granted to a syndicate headed by Bridge Oil NL over the Polda and northern Bight Basins in 1969 (Fig. 2.2). Seismic surveys in 1970 and 1971, totalling 2133 km, extensively covered the basin (Fig. 4.8). The permit was surrendered in 1974. A similar area was granted to a syndicate headed by Outback Oil Co. NL as EPP 15 in 1975 (Fig. 2.3). Immediately after the permit was granted, Gemini-1 was drilled on the results of the two previous seismic surveys. The hole was abandoned after intersecting apparently shallow basement. In 1978, a more detailed aeromagnetic survey was flown by Outback Oil, centred on the Gemini-1 well. Magnetic interpretation indicated that a considerable sedimentary section existed beneath the well total depth (TD), and re-examination of cuttings indicated that the well had bottomed in a large Jurassic volcanic boulder. Interest was rekindled in 1981, with 3214 km of marine seismic, magnetic, and gravity data extensively detailing the basin (Fig. 4.9). This was followed by the drilling of Mercury-1 and Columbia-1 wells in 1982. Both wells were dry and the permit was surrendered in 1983.

EPP 16 was granted to BP Petroleum Development Pty Ltd and Hematite Petroleum Pty Ltd in 1980 in the central-eastern Bight Basin (Fig. 2.3). 2188 km of seismic data were recorded over five main prospects in 1981 and 1982 (Fig. 4.10); however, interest waned and the permit was surrendered in 1982.

In 1980, EPP 17 was granted to a syndicate headed by Stirling Petroleum NL (Fig. 2.3); however, no work was carried out, and the permit was surrendered in 1983.

Outback Oil Co. NL was granted EPP 19 covering the Western Duntroon Basin in 1981 (Fig. 2.3). In 1982, 539 km of seismic data were recorded in the permit. The contractor for this survey, Geophysical Service Inc., also recorded 827 km of data in the adjacent permits on a non-exclusive basis (Fig. 4.7); however, interest in the area was low at that time and virtually all of the data was left unprocessed. EPP 19 was surrendered in 1984.

In 1982, a syndicate headed by Getty Oil Development Ltd was granted EPP 21 in the central Duntroon Basin (Fig. 2.3). An extensive reconnaissance seismic and geochemical survey totalling 2035 km was carried out in 1983 (Fig. 4.11). In 1984, a further 1017 km of seismic data were recorded. Several large prospects were defined and in 1986 BP Petroleum Development Ltd drilled the Duntroon-1 well. The well was dry, which, together with a worldwide downturn in oil prices, precipitated the surrender of the permit in the same year.

ii) History of Petroleum Exploration - Western Australia

The Western Australia portion of the GAB region has been only sparsely explored. The history of exploration leasing in this area will not be detailed in this section (as a number of leases have been held with no seismic data being shot), rather, it will concentrate on the specific areas where surveys have been conducted.

In 1967, Tenneco shot a total of 2062 km of seismic data across the offshore Eucla Basin, including some lines offshore from Eyre township. During 1970-71 a group of companies, including Genoa Oil and Hartogen Exploration, conducted the Twilight Cove and Offshore Eucla Seismic Surveys, during which a total of 1696 km of seismic data were recorded offshore from Eyre. These surveys indicated a maximum of 2200 m of ?Palaeozoic-Mesozoic sediments within a basement trough and channel system. No further work has been done in this area since 1971, with the exception of a few sparker seismic lines shot during the BMR Continental Margin Survey (CGG, 1975).

Esso Australia held the leases WA-125P and WA-126P over the Eyre Sub-basin from 1979 to 1983 in waters deeper than the Twilight Cove Survey. During this period, they recorded a total of 4073 km of good-quality seismic data on both regional and detailed grids (Fig. 4.5), and drilled one unsuccessful exploration well, Jerboa-1, in 1980. To date, Jerboa-1 is the only exploration well drilled into the continental margin between the WA/SA border and the southwest corner of the continent.

Permit WA-47P on the continental shelf adjacent to the Archipelago of the Recherche, was held by Continental Oil from 1972-73. In 1972, Continental recorded 957 km of seismic data in the permit. As the maximum indicated sediment thickness was only 1000 m at the shelf edge, no further work was done in this area. At the western end of the study area, Esso held permits WA-50P and WA-51P over the offshore Bremer Basin from 1974 to 1977. In 1974, Esso acquired 2224 km of moderate-quality seismic data on a regional grid extending from the inner continental shelf out to deep water. The survey indicated an areally-restricted continental slope basin, containing up to ?10000 m of highly-structured ?Mesozoic-Tertiary sediments. Because of the considerable water depths (typically 700 to 3000 m), no further activity was undertaken.

Since 1983, there have been no active exploration leases in Western Australian waters of the GAB region.

iii) Research and Government Surveys

Large volumes of magnetic and analogue/low-quality seismic reflection data were recorded by research institutions and government agencies between 1960 and 1976. The SADME and BMR also carried out various onshore magnetic and gravity surveys adjacent to the study area between 1954 and 1970.

The first geophysical investigation in the offshore study area was carried out in 1960 by BMR, Australian National University, and Lamont-Doherty Geological Observatory of Columbia University, who recorded isolated deep seismic refraction stations and magnetic and gravity profiles (Hawkins & others, 1965). In 1967, Atlantic Oceanic Laboratories recorded isolated magnetic and shallow seismic reflection profiles aboard the R/V *Oceanographer* (Conolly & others, 1970). Both surveys indicated thick sediments beneath the continental slope.

Between 1969 and 1972, the Lamont-Doherty Geological Observatory recorded approximately 190000 km of magnetic, gravity, and shallow reflection seismic data in a major southern hemisphere research project, with a significant proportion recorded within the study area (Talwani, 1969, 1972). Between 1970 and 1973, approximately 187000 km of seismic reflection, magnetics, and gravity data were recorded by the BMR over all the continental margins of Australia (CGG, 1975); Surveys 16 and 19 of this program were located in the Great Australian Bight region (Fig. 4.1). During 1972-73, Shell Development Pty Ltd carried out a reconnaissance seismic survey of much of the Australian continental margin with the M/V *Petrel* (Fig. 4.3). The data from this survey, though largely unprocessed, are of good quality and provide valuable information linking the continental shelf to the abyssal plain. In 1976, the Lamont-Doherty R/V *Vema* recorded shallow reflection seismic, deep-crustal seismic refraction probes, and gravity and magnetic data along profiles across the continental margin between southwest Australia and the Ceduna Terrace (Talwani & others, 1979).

In 1986, BMR recorded approximately 3500 km of high-quality seismic, gravity, magnetic, and geological data which provide the starting point for the interpretation of the Bight Basin and Polda Trough in this study (Fig. 4.2).

Areas adjacent to the Bight, Duntroon and Polda Basins were re-flown with magnetics, radiometrics, and VLF in the 1988 "Eyre Peninsula Aeromagnetic/Radiometric Survey" conducted by SADME in conjunction with BMR. 18969 km of data were recorded over the offshore Polda Trough and shallow basement areas adjacent to Eyre Peninsula in the survey.

iv) Summary

A summary of annual exploration activity in South Australian waters is included in Figure 2.4. This shows that the main exploration activity occurred between 1969 and 1975 followed by a 5 year period of very little activity. Exploration was renewed in 1981, but gradually declined until 1986.

A detailed listing of all seismic surveys is given in Appendix II, magnetic surveys in Appendix III, and gravity surveys in Appendix IV. To date a total of approximately 83350 km of seismic reflection data has been recorded in the study region. This includes 31210 km of research data. The 52140 km of company and 1986 BMR data comprise 8880 km in Western Australia and 43260 km in South Australia.

A complete line listing of seismic reflection and refraction data has been compiled as part of this study for the South Australian portion of the study area by SADME. A complete digital shotpoint database has also been compiled in conjunction with BMR. This used all available digital navigational information and was complemented by hand digitizing a further 17205 km of data. This digital database is available for purchase from BMR or SADME.

As part of this project, all magnetic data in the South Australia portion of the study area have been compiled on standard map sheets. Aeromagnetic and shipborne data from the Shell Development Pty. Ltd deep-water surveys (1969-1974) have been compiled onto 24 standard 1:250 000 map sheets with contours at 50 nannotesla intervals. These map sheets have been reduced to form five new 1:500 000 standard sheets. The location of these sheets is shown in Figure 10.1, which also shows a reduced version of all the contour data. To provide further magnetic coverage over the magnetic quiet zone and seafloor spreading anomalies, shipborne profiles from the 1969-1973 surveys of the BMR, Lamont-Doherty Geological Observatory and Shell Development Pty Ltd were used. These profiles were superimposed onto subdued magnetic contours for the southern three 1:500 000 sheets. All of these magnetic maps are available from SADME.

Since June 1986, all South Australian offshore acreage west of 138^{o}30'E (*ie* west of the Otway Basin) has been vacant. However, the onshore gas discovery at Katnook in PEL 32 in the Otway Basin has stimulated exploration in that region and initiated renewed interest in the Bight and Duntroon Basins, due to their tectono-sedimentary links with the Otway Basin.

d) PREVIOUS STUDIES

In broad terms, studies of the geology of the GAB region can be divided into three categories - regional, localised, and those related to sea-floor spreading/reconstructions. The following is a summary of the principal references in these areas.

i) Regional

Boeuf & Doust (1975) - interpretation of the structure and tectonic development of the GAB region based on reconnaissance deep-water seismic profiles acquired on the M/V *Petrel* in 1972.

Deighton & others (1976) - analysis of depositional environments and tectonic framework of the southern margin of Australia between the Naturaliste Plateau and the South Tasman Rise based on well and other data and models of continental margin formation.

Willcox (1978) - summary of the regional geology of the GAB and interpretation of seismic, gravity, and magnetic data acquired on the Continental Margin Survey (CGG, 1975).

Talwani & others (1979) - study of the deep crustal structure of the GAB region between southwest Australia and the Ceduna Terrace based principally on seismic refraction data (see also Konig & Talwani, 1977; Mutter, 1978; and Konig, 1980).

Willcox, Stagg, Davies, & others (1988) - summary of the principal results of BMR *Rig Seismic* Survey 65 in the central GAB in 1986.

Davies & others (1989) - summary of geological sampling carried out on board the *Rig Seismic* in the central GAB in 1986.

Stagg & others (1989) - Werner interpretation of a set of 50 magnetic profiles across the GAB and production of an interpreted magnetic basement structure map.

Willcox & Stagg (1990) - interpretation of the extension history of the southern margin to include a Jurassic-Early Cretaceous phase of northwest-southeast extension (see also Willcox, 1990).

ii) Localised

Cooney & others (1975) - brief (and to date the only) interpretation of multi-channel seismic data from the Bremer Basin.

Whyte (1978) - historical summary of Shell Australia's exploration effort in the eastern GAB from 1966-76.

Fraser & Tilbury (1979) - detailed structural and stratigraphic interpretation of the Ceduna Terrace region based primarily on the Shell regional seismic data set.

Bein & Taylor (1981) - interpretation of the structure and stratigraphy of the Eyre Sub-basin based on *ca* 4000 km of Esso multi-channel seismic data and the Jerboa-1 exploration well.

Nelson & others (1986) - summary of exploration in the Polda Trough from 1970-81 and revised interpretation of multi-channel seismic, well, and magnetic data.

Stagg & Willcox (1988) - interpretation of nature and distribution of seismic facies in the deep-water central GAB.

Stagg & Willcox (1989) - summary of interpreted hydrocarbon play types in the Bight Basin.

iii) Sea-floor Spreading and Australia-Antarctic Reconstructions

Weissel & Hayes (1972) - history of sea-floor spreading between Australia and Antarctica based primarily on magnetic data recorded on board the *Eltanin* in the 1960s; age of Australia-Antarctic separation interpreted as Eocene (55 Ma).

Cande & Mutter (1982) - re-interpretation of the oldest magnetic spreading anomalies and revision of Australia-Antarctic opening date to 110-85 Ma (see also Mutter & others, 1985).

Veevers (1986) - re-analysis of Cande & Mutter's work to refine the timing of Australia-Antarctic opening to 95 +/-5 Ma (Cenomanian).

Veevers (1987) - study of the conjugate margins of southern Australia and Wilkes Land, Antarctica, using a new multichannel seismic and magnetic data set from Wilkes Land and pre-existing data and interpretations from southern Australia.

Veevers (1988) - analysis of the oldest magnetic spreading anomalies off the Otway/west Tasmanian margins, and subsidence history of the area.

Veevers & Eittreim (1988) - reconstruction of Australia-Antarctica prior to rifting (160 Ma) and at breakup (95 Ma).

Veevers & others (1990) - analysis of the interpreted series of magnetic spreading anomalies during the period of slow spreading (95-44 Ma).

CHAPTER 2: REGIONAL SETTING

a) BATHYMETRY

The bathymetry of the Great Australian Bight region (Fig. 1.1) has been described by Conolly & von der Borch (1967), Conolly & others (1970), and Willcox (1978), while a detailed bathymetry map of the Ceduna Terrace was described by Tilbury & Fraser (1981). This section summarises the results of the latter two of these reports. The margin west of the Great Australian Bight (GAB) is described for the first time here.

i) 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 GAB, 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 GAB has been extensively modified by the Pleistocene courses of the Murray River.

ii) 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 GAB, gradients are up to 6°. Canyon development is extensive, particularly to the west of Esperance, though individual canyons are poorly defined due to the paucity of lines parallel to the slope. In the Bremer Basin area, in particular, canyon development appears to be structurally controlled, with many canyons formed along fault-block boundaries (including transfer faults); this predominantly structural control means that a number of major canyons are oblique to, and sometimes parallel to the continental slope. An areally-restricted terrace at about 1000-2000 m depth has developed above the central Bremer Basin between 119°E and $120^{\circ}30'$E (Fig. 62.1). The base of the slope lies at about 4000 m depth in the Bremer Basin area, and at about 3600 m in the western side of the GAB.

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° south-southwestwards 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. 39.1). 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 70000 km^2 in area, and up to 200 km in width and 600 km in length (Fig. 26.1). 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^{o}, compared with an average of 2^{o} 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; 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 GAB, with gradients of up to 8^{o} and extensive canyon development. The slope here extends down to about 4600 m. It is extensively incised by the numerous palaeo- 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.

iii) 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 (continental slope and the Diamantina Zone in the west). The upper boundary of the rise varies from about 4000 m off from Albany, to about 3000 m below 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^{o}. By contrast, south of the Ceduna Terrace, the rise is only about 50 km wide with a gradient of up to 2^{o}.

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.

b) CLIMATE AND ENVIRONMENT

The Nullarbor Plain, overlying the onshore parts of the Eucla and Denman Basins, is a karst plain underlain by Tertiary limestone which was uplifted during the Pliocene. In the central GAB, the coastline is dominated by a spectacular line of limestone cliffs, while high dunes form the coastal fringe in the east. The principal sedimentary basins of the GAB lie entirely offshore.

Climatic conditions in the GAB are largely controlled by the seasonal northward and southward movement of an east-west oriented high-pressure belt through the area, and by the continuous easterly procession, within this belt, of anticyclones and intervening troughs.

The average annual rainfall ranges from 250 mm at Head of Bight to 800 mm off the western coast of Kangaroo Island. Average summer and winter temperatures are 18°C and 14°C respectively with the greatest temperature range recorded at Eucla (50°C to -2°C).

For areas within about 30 km of the coast, the prevailing wind is southerly to easterly in summer and northerly to westerly in winter. Strong offshore breezes predominate in the late afternoon. For areas more than about 30 km from the coast, winds are highly variable due to the easterly procession of anticyclones from November to April. Wind strength is generally moderate, though highly variable, and gales recorded near the coast are only of moderate frequency, even in winter. For the period 1962-1988, the average number of days recording gale force winds ($\geq$34 knots) varied from 3 in winter to 1 in summer. Sea and swell has been recorded on 80% of all days, and about 40% of the time is recorded as moderate. Rough seas may persist for several days, particularly from June to September.

The optimum weather window in the Great Australian Bight for seismic and drilling activity is considered to be from November to March. Weather records from geophysical operations reports in the region indicate that ideal recording conditions are not, as would be expected, during a 'flat calm'. Rather, a slight sea running tends to reduce the effects of swell, so that the best recording conditions are at sea states 1-2.

More detailed records of climate can be found in Russell (1973).

c) HISTORY OF SEAFLOOR SPREADING

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

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

More recently, Veevers (1986, 1988) has 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 now quite widely accepted, these authors 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 will be alluded to later in this folio, 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 COB on some Survey 65 seismic lines;
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 GAB (*eg* Jerboa-1; Fig. 71.1);
5) The existence of a major tectonic event in the Late Cretaceous-Early Tertiary, reflected in seismic records margin-wide and discussed elsewhere in this report; these authors do not believe this event can be ascribed to eustatic sea-level changes or to deep ocean currents.

While this report will make reference to these problems, their solution requires considerable additional study. Such study is quite critical to a full understanding of the tectonic evolution of the southern margin.

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

This section will be illustrated by two maps. The Tectonic Elements map (Fig. 9.1) has been compiled by combining the interpretations of all the basins of the GAB that have been made for this report. The Magnetic Basement map (Fig. 11.2) has been compiled from magnetic profiles in the GAB that have been interpreted using the technique known as 'Werner deconvolution' (Aero Service Corporation, 1974; Hsu & Tilbury, 1977). A brief description of this technique and an interpretation of selected profiles and the magnetic basement map are included in Appendix XII.

In this report, the name 'Southern Rift System' (SRS) is proposed to describe the broad zone that has been affected by the Jurassic-Tertiary rifting and spreading event along the southern margin of Australia. Within the SRS, 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. In this section an attempt is made to rationalise the subdivision and nomenclature of sediment bodies within the western half of the SRS.

Typical guidelines for the recognition of basins and sub-basins within a rift system run into problems in the SRS. In particular:

1) Use of depocentres alone can be misleading where they are defined by poor or sparse data which inadequately define total sediment thickness or distribution. The presence of large basement high blocks can further divide depocentres into "troughs" or "zones", therefore adding a scale factor to the problem.

2) Use of the distribution of rock units alone is impractical for the Southern Rift System due to the very widespread occurrence of most units.

3) Division on the basis of structural styles is often complicated by the range of scale of various structural features and the paucity of control in deeper water.

However, in the SRS, zones of varying structural style or orientation occur which align with major basement offsets. These basement offsets are likely to be caused by independent nucleation of normal faults at a number of locations along the embryonic rift (Etheridge & others, 1988). As these normal faults propagate along strike as the extension increases, offsets must be taken up or accommodated. These 'accommodation' zones then become concentrated into narrower zones with increasing stress from rifting and spreading, ultimately developing into transfer or oceanic transform faults (Etheridge & others, 1988). In other rifted passive margins of the world (eg. Atlantic margin of North and South America, Grand Banks of Alaska), these accommodation zones or transfer faults are used to subdivide the margin into basins. Several such 'accommodation zones' have been identified in this study, and they can be of assistance in delineating the basins of the western half of the Southern Rift System.

In the east, the **Duntroon Basin** (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 (EDAZ and WDAZ, respectively). The EDAZ, 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 WDAZ marks the junction of the Duntroon and Bight Basins. Both of these accommodation zones may have expression in the Polda Trough to the north, as shown in Figure 9.1.

The **Bight Basin** occurs almost exclusively beneath the continental slope and rise which underlies most of the GAB 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' for this report. The Eyre Sub-basin is a discrete extensional basin 'perched' high on the continental slope on the western side of the GAB, 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 GAB, 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 (SCAZ); this feature is informally named the 'Recherche Sub-basin' here. The western limit of the Recherche Sub-basin is ill-defined, and it may continue well to the west of the GAB.

To the west of the GAB, the only easily-identified extensional basin is the Bremer Basin, which underlies the continental slope approximately between Albany and Esperance (Figs 62.1 & 63.1). 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 more 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 (Fig. 9.1). This fault system marks the northern limit of thick Cretaceous sediments. The southern boundary of the SRS 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 SRS 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^{o}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.

Underlying the Eucla Basin, in part, is the Permian Denman Basin. This basin occupies a north-south elongate depression between approximately 31^{o}S to 33^{o}S latitude and 130^{o}E and 131^{o}E longitude (Fig. 9.1). It appears to be coincident with the deepest depressions within the Eucla Basin and is probably related to an earlier zone of weakness. Definition of underlying Lower Palaeozoic or Upper Proterozoic features is beyond the scope of this report.

The Polda Trough (or Polda Basin) is an east-west oriented elongate intracratonic basin, approximately 350 km long by 40 km wide. It extends onshore to 136^{o}E and westward to $132^{o}45'$E where it debouches into the Bight Basin. Its geographic location and structural trend and the 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.

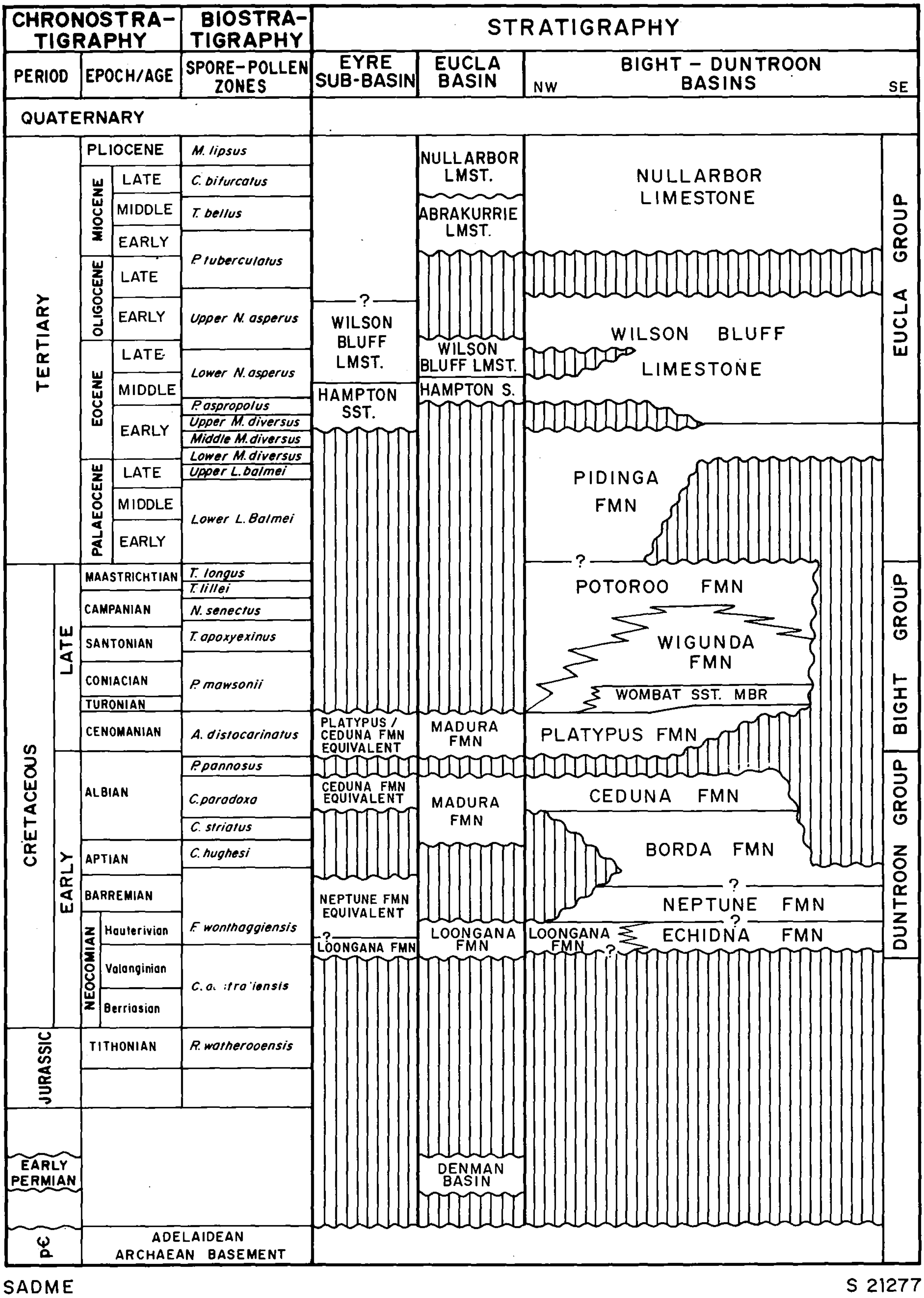
In the nearshore areas on the eastern flank of the GAB, large areas of shallow basement are covered by a thin veneer of Cainozoic (mainly Tertiary) sediments. Robertson & others (1979) used the term 'Eyre-Encounter Bay Shelf' to describe these sediments. However, the seismic data in this area is both 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.

e) REGIONAL STRATIGRAPHY AND PALAEOENVIRONMENTS

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. 5.1). 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 stratigraphy of the region.

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 review of the stratigraphy is presented below, reinforced by the revised stratigraphic nomenclature of Hill (1989), and incorporating the revised palynological zonations of Morgan (1986). A summary of the revised stratigraphy is included in Text Figure 2.

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 GAB by previous workers must also be treated cautiously, because of strong



Text Figure 2: Stratigraphic summary diagram for the Great Australian Bight 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.

While the formations of the Early and Late Cretaceous (Duntroon and Bight Groups) comprise the major units studied in this review, a brief description will also be given here of the pre-Mesozoic rocks.

Jerboa-1 intersected a dark grey, dense, micro-crystalline, amphibolitic basement, tentaively 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 a 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.

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 SRS is the Neocomian **Loongana Formation**. In Jerboa-1, the sequence consists of non-marine, interbedded sandstones, siltstones, and dark brown to black pyritic shales, formerly assigned to an unnamed Late to Middle Jurassic age (M. florida Zone; Powis & Partridge, 1980) and informally referred to as units JF-JJ by Huebner (1980). A fluvio-deltaic environment of deposition 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 (Fig. 13.1), 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 deposited in a proximal lacustrine environment, has been assigned to the **Echidna Formation** (Hill, 1989) and is a time equivalent of the Loongana Formation (Fig. 13.2).

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 Unit JE in Jerboa-1 (Huebner, 1980), which is referred to here as a Neptune Formation equivalent (Fig. 13.3). 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** (Text Fig. 2), 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 deposition in the Aptian is observed in the Bight and offshore Eucla Basins (Fig. 13.4). 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. 14.5) but are not recorded in the Bight Basin. A breakdown in marine conditions 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; Fig. 13.5). 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 has a correlatable Albian section that comprises dark grey to black marine shales. It is assigned to the Ceduna Formation equivalent (unit JD of Huebner, 1980).

A regional hiatus is apparent in the late Albian extending from the Bight Basin to the Duntroon Basin (Text Fig. 2). 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 breakup at 96 ± 4 Ma (Veevers, 1988) of Australia and Antarctica.

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** (Fig. 14.1). Meanwhile, in the Bight Basin, nearshore marine facies of the basal Platypus Formation were deposited, passing to 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 drilled a correlatable sequence comprising dark shales and a basal sand deposited in a nearshore environment (Platypus Formation equivalents; units JA-JC of Huebner, 1980).

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 (Fig. 14.5). 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 (Text Fig. 2). The unit is equivalent to the Timboon Sand of the Otway Basin. Significant upbuilding of topset beds is indicative of sea level rise which Fraser & Tilbury (1979) attribute more to sediment loading than to eustacy. The formation is strongly diachronous, 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 (Fig. 14.4), 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. In Potoroo-1 in the Ceduna Sub-basin, a similar sequence is encountered, although the unit is interbedded at the base with a massive sand at the top. 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).

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 close of the Tertiary (Text 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).

CHAPTER 3 DETAILED STRUCTURE AND STRATIGRAPHY

a) DUNTROON BASIN

i) Introduction

The Duntroon Basin is located in the centre of the Southern Rift System between the Bight and Otway Basins. It is bound to the north by the Archaean Gawler Craton, and to the east by Cambrian sediments which crop out on Kangaroo Island. The eastern and western margins of the basin are defined by north-northwest trending accomodation zones (Fig. 9.1) which offset the Southern Rift System (see Chapter 2 [d]). Sedimentation across these zones, from the Bight Basin in the west to the Otway Basin in the east, is generally continuous.

Structurally, the Duntroon Basin is divided into an inner half-graben zone, bounded to the north by west-northwest trending faults, and an outer zone contiguous with the continental slope (Figs 15.1 and 17.1). Unfortunately, due to poor data quality, the division between the zones is indistinct in some areas. The inner zone comprises a series of offset half-grabens, while the outer zone is faulted almost monotonously to the southwest.

A set of 1983 and 1984 seismic lines covering the inner zone (Fig. 16.1) have been interpreted by Thomas (1990). A selection of seismic lines extending southwestwards from this zone have been interpreted by Cockshell (1990a) and are also shown in Fig. 16.1. These lines comprise the principal seismic coverage of the Duntroon Basin, and are tied eastwards to lines in the Otway Basin (interpreted by Cockshell, 1986) and westwards to lines in the Bight Basin (interpreted by Fraser & Tilbury, 1979).

ii) Stratigraphy

The stratigraphic framework for the Duntroon Basin is derived from three wells: Echidna-1 (Shell, 1972a), Platypus-1 (Shell, 1972b), and Duntroon-1 (Templeton & Peattie, 1986). A well cross-section from Platypus-1 to Echidna-1 (Fig. 12.2) provides correlation of discrete mappable units that were formerly assigned to informal units proposed by von Sanden & Barten (1977) and discussed below. A summary of formation tops is given in Appendix VI.

A near-complete record of Early and Late Cretaceous deposition is recorded within the basin. A regional hiatus in the Cenomanian separates a predominantly fluvio-lacustrine Lower Cretaceous sequence (Duntroon Group) from a fluvio-deltaic to marginal-marine Upper Cretaceous sequence (Bight Group). These sequences have close affinities with the Otway and Sherbrook Groups, respectively, of the Otway Basin, and are overlain by open-marine sandstones of the Tertiary Pidinga Formation and Eucla Group carbonates.

The earliest drillhole evidence of rift-related sedimentation in wells in the basin is recorded by the Echidna Formation in Echidna-1. A Neocomian age has been assigned to the 228+ m sequence of interbedded grey to dark grey shales and siltstones that become sandy towards the base of the sequence. Fine to coarse sandstones are texturally immature, suggesting lacustrine deposition proximal to a land mass (von Sanden & Barten, 1977). Seismic data indicate extensive syn-rift sedimentation concentrated in half-graben depocentres; although undrilled, these sediments are assumed to be ?Jurassic-Neocomian in age.

The Neocomian Neptune Formation conformably overlies the Echidna Formation only in Echidna-1, where it has undergone tectonic uplift. Formerly assigned to the Madura Formation, it consists of a monotonous sequence of dark grey carbonaceous and slightly pyritic shale deposited in a possible graben lake. The formation attains a maximum thickness of 579 m, and is assumed to be present also in the deeper, undrilled portions of the Duntroon Basin, and beneath the Aptian-Albian sequence intersected in Platypus-1 and Duntroon-1.

The Barremian to Aptian Borda Formation conformably overlies the Neptune Formation and is present in all three wells drilled in the Duntroon Basin. Formerly assigned to the Madura Formation, it is a laterally-extensive unit, 1712 m thick in Echidna-1. It's maximum thickness is unknown due to the imprecise nature of overlap between the section in Echidna-1 and Duntroon-1, resulting from erosional truncation. The formation comprises an interbedded sequence of light- to medium-gray siltstone and shale, and minor coals. It can be distinguished from the underlying Neptune Formation by a pronounced irregularity in the gamma-ray and sonic-log traces, reflecting the heterogeneous nature of the sediments. Deposition in a broad, poorly-drained floodplain is envisaged.

The Borda Formation grades into the more sandstone-rich Ceduna Formation, with the top of the Borda Formation taken as the last major shale unit. The middle-upper Albian Ceduna Formation was drilled in Platypus-1 and Duntroon-1, but has been eroded in the region of Echidna-1, as a result of structural uplift. It is characterised by a coarsening-upward sequence which is reflected as an upward negative shift in the gamma-ray log trace. It reflects a transition from predominantly fluvio-lacustrine to fluvio-deltaic conditions, prior to continental breakup.

The overlying Ceduna Formation attains a maximum thickness of 505 m and consists of siltstone, claystone, and minor coals grading to well-sorted sandstones. The sandstones have units with excellent porosity at the top; these units are interpreted to be inter-distributory channel deposits of a tidally-influenced deltaic system.

The regional hiatus in the late Albian in the Eucla and Bight Basins is also present in the Duntroon Basin, although in Duntroon-1 its onset is delayed until the Cenomanian. This hiatus probably also coincides with the interpreted breakup age between Australia and Antarctica, and is reflected in seismic data as an abrupt change in character and structural style.

The Cenomanian to Turonian Platypus Formation of the Bight Group unconformably overlies the Ceduna Formation in Platypus-1 and Duntroon-1 but is absent in Echidna-1, presumably due to erosion. The formation has a maximum thickness of 394 m at Platypus-1, and consists of sandstones, siltstones, and coals that were deposited in an upper deltaic plain environment during a brief regression that terminated in the Turonian.

The Platypus Formation is conformably overlain by the thin and laterally persistent Wombat Sandstone Member of the Wigunda Formation. This unit has a maximum thickness of 103 m in Platypus-1, and consists of interbedded delta-front sandstones and siltstones.

The remainder of the Wigunda Formation (analagous to the Belfast Mudstone of the Otway Basin) conformably overlies the Wombat Sandstone Member and attains a maximum thickness of 665 m in Platypus-1. The formation consists of carbonaceous and glauconitic prodelta mudstones, and becomes distinctly silty towards the base. It is strongly diachronous, younging to the southeast. It provides a regional seal within the Upper Cretaceous, although on the basement highs (as at Echidna-1) it has been removed by erosion.

The upper Campanian to Maastrichtian Potoroo Formation conformably overlies the Wigunda Formation in Platypus-1 and Duntroon-1, but is absent in Echidna-1. It consists of a thick sequence of interbedded sandstone, siltstone, and rare carbonaceous mudstone, 515 m thick in Platypus-1, and deposited in nearshore-marine to delta-plain environments resulting from a series of transgressive and regressive phases prior to the final marine transgression in the Paleocene.

The Potoroo Formation is unconformably overlain by the transgressive marine sands of the Pidinga Formation. These are, in turn, overlain conformably by the Eocene to Lower Oligocene Wilson Bluff Limestone of the Eucla Group. These limestones, up to 207 m thick in Echidna-1 and Duntroon-1, were deposited in open-marine conditions. After a hiatus in the Upper Oligocene, the Miocene Nullarbor Limestone was deposited across the basin.

iii) Horizons and Intervals Identified and Mapped

Open-marine conditions in the Duntroon Basin are not recorded until the Tertiary, hence most of the Mesozoic section was deposited in continental or paralic environments. Since continental sediments usually display a limited range of seismic characteristics and have low reflection continuity, the possibilities for seismic sequence and facies analysis are severely limited. Unconformities within the Mesozoic series are primarily the result of the combined effects of changes in sedimentation rates, sources and distribution, and tectonic influences.

Five horizons of structural and stratigraphic significance were selected for seismic-sequence mapping (Fig. 19.2). These are:

- top of basement
- top of the basal syn-rift unit (Near Base Cretaceous)
- top of Duntroon Group (Early Cretaceous)
- top of Bight Group (Late Cretaceous)
- seabed (top of Cainozoic)

Basement

The top of basement is usually well-defined in the inner part of the Duntroon Basin, and in the shallow basement area of the offshore Gawler Craton. Oceanwards, basement is down-faulted towards the continental slope. The combination of increasing sediment thickness and deterioration in seismic quality, reduces the confidence in mapping in the outer, deep-water part of the basin. Basement again becomes a prominent reflector beneath the abyssal plain, where it's strongly diffracting surface is probably indicative of oceanic crust. Where acoustic basement cannot be identified with confidence, estimates of depth to magnetic basement have been incorporated in the map of depth to basement (Fig. 20.1).

Near Base Cretaceous

This horizon (top of ?Jurassic-Neocomian section) is recognised in three isolated depocentres within the inner part of the Duntroon Basin. The horizon has not been drilled, and correlation between depocentres is based on seismic character similarities and structural relationship with the overlying sequences and basement.

Top of Duntroon Group

The top of Duntroon Group horizon is interpreted to correlate with southern margin breakup at about the Albian-Cenomanian boundary. The horizon is an unconformity everywhere except in the southern Duntroon Basin. The reliability of its identification varies from fair to good in the inner basin (except in the vicinity of diapir-induced faulted anticlines) to fair to poor in the outer basin, where faulting is intense, the overlying Bight Group sediments are thick, and data quality is poor.

Top of Bight Group

This horizon mark an unconformity between the eroded Upper Cretaceous Potoroo Formation and the marine Tertiary Pidinga Formation, and can be mapped reliably. This horizon coincides locally with the base of the Tertiary Wilson Bluff Formation carbonates, where the thin sandstones of the Pidinga Formation have been eroded or not deposited. At the northern margin of the basin, where sediments thin over the shallow Archaean basement platform, the horizon becomes more concordant, making identification less reliable.

Seabed

The seabed reflector is frequently not visible on seismic sections; accurate values obtained from echo-sounder charts have been used for map preparation in this report.

Seismic stratigraphic characteristics of the mapped horizons and intervals are shown in Table 1.

iv) Depth Conversion

For the Duntroon Basin, seismic horizon times were converted to depth to better portray the regional configuration of the basin. Time maps can give a distorted regional picture due to spatial velocity variations, especially that due to the rapid thickening of the low-velocity water layer over the continental slope.

In the northeastern part of the basin where the three wells and detailed seismic coverage (Fig. 15.1) provide the best definition of the geology, a single velocity function has been used to convert times to depths (Thomas, 1990). Data from well velocity surveys were used for the upper 3000 m of the sedimentary section whilst RMS stacking velocities from the 1984 seismic processing were used for the deeper section. Figure 18.1 displays all the well time-depth curves and the velocity function finally used (annoted 'BTs Duntroon curve'). The velocity data for the three wells are quite consistent, indicating that

TABLE 1: Duntroon Basin - Seismic Sequence Characteristics

Horizon	Upper Boundary	Lower Boundary	Internal Configuration	Age	Facies	Comments
Sea-floor						
	concordant - erosional	downlap	prograding wedge	Eocene - Recent	open marine carbonate	final clearance of Australian and Antarctic Plates
Tertiary						
	concordant	concordant to major unconformity	thin prograding basal sand	Paleocene - Late Eocene	marine sands	minor throws on normal faults
Top of Bight Group						
	erosional truncation	downlap - concordant minor unconformity	moderate continuity and frequency; intra-formational unconformities resulting from anticlinal growth	Late Cretaceous	marginal marine, fluvio-deltaic	mass-sliding in outer growth-fault zone; diapiric growth in inner zone
Top of Duntroon Group						
	concordant	downlap to concordant, slight unconformity	moderate continuity, medium frequency and amplitudes	Early Cretaceous	lacustrine shales, under-compacted at base of sequence, fluvio-deltaic at top	syn-rift sedimentation, regional decollement
Near Base Cretaceous						
	concordant	onlap - downlap on eroded basement	syn-rift wedge; high amplitudes, mixed continuity and frequency	?Jurassic - Neocomian	continental (?lacustrine), in isolated depocentres	syn-rift sedimentation
Basement						
	erosional		strong diffractions to coherent reflections	Archaean and Cambrian	crystalline rocks and metasediments	

depth conversion, at least for the upper part of the section, should be reasonably reliable. However, accuracy is likely to be considerably reduced deeper in the section.

Use of a single function over such a large area will mask any facies-related lateral velocity variations; a much more precise velocity analysis would be required for more accurate conversion. Such lateral variations are indicated by averaging RMS stacking velocities from 1982 seismic processing. Figure 18.1 shows that velocities increase from west to east across the basin. In view of the regional nature of this study, such velocity differences should not significantly distort the depth maps, and a second single velocity function was prepared for the outer Duntroon Basin. This function incorporated the 1982 seismic data, well velocity data (including Bight Basin wells), and seismic refraction data. The time-depth curve shown in Fig. 18.1 (annotated 'CDC best fit curve') is a power-curve described mathematically by:

$$\text{Depth (m)} = 0.1924 \times \text{Time (milliseconds)}^{1.2708}$$

The function origin is seafloor, thus removing the distortion of the low velocity water layer over the continental slope.

The use of a single function over a large area encompassing a range of geological terrains, limits the validity of the absolute depth values obtained; however, relative depths should be reliable in a regional study. Depth data for the data sets in the inner and outer Duntroon Basin derived from the velocity functions in Figure 18.1 were individually gridded and contoured, then merged to produce the depth maps shown in Figure 19.1 and Figures 20.1-22.1.

Isopach maps for the Neocomian-Jurassic, Lower Cretaceous, and Upper Cretaceous-Cainozoic sequences have also been prepared, using the same velocity functions. These maps are included as Figures 23.1-24.1 and in Cockshell (1990a) and Thomas (1990).

v) Structure and Evolution

Basement

The Duntroon Basin is characterised by two distinct tectonic regimes: a basement-involved extensional phase related to rifting and plate separation, and a shale mobilisation phase (growth faulting and diapirism) that affects the Cretaceous sediments. The shale mobilisation structures were developed in the Late Cretaceous above a decollement near the base of the Lower Cretaceous shales.

The general aspect of the Duntroon Basin is an extensional continental margin bound to the north by northwest-southeast to almost east-west trending faults. It is separated from the Southern Rift System basins to the west and southeast by north-northwest trending accomodation zones (Fig. 9.1). The extent of the Cretaceous rift sequence sediments defines the southern limit of the basin which abuts oceanic basement. Structurally, the basin has an inner half-graben zone which is separated from an outer faulted zone underlying the edge of the continental shelf and the slope by a series of *en echelon* basement ridges. These basement ridges are the crests of east-southeast trending basement fault-blocks that have been have been normal-faulted to the south-southwest and offset along northeast-trending faults. The inner basin zone broadens eastwards.

Smith and Kamerling (1969) proposed that the basement west of Kangaroo Island comprises two types of rocks of different velocity characteristics. They interpreted this difference to represent the boundary between the Archaean Gawler Craton to the north and the Cambrian Kanmantoo Group to the south. This boundary is collinear with the northern bounding faults of the Duntroon Basin.

The basement faults progressively coalesce and diminish in throw eastwards, and acoustic basement becomes a gentle monocline that shallows towards Kangaroo Island. The Mesozoic Duntroon Basin is thus inferred to be underlain by Cambrian meta-sediments of the Kanmantoo Group (Smith & Kamerling, 1969; Forbes & others, 1984).

Immediately west of Kangaroo Island is a 60 km-wide north-northwest trending zone of complex structure (Figs 15.1 & 20.1). West of this zone, the main structural fabric trends west-northwest, while to the east it trends northwest. Within the zone there is a strong north-northwest fault trend, with many faults appearing to bend to align with the fault trends on either side of the zone. There are also many smaller faults of varying orientations and a complex pattern of basement highs and lows. These are not dissimilar to the compressional highs and tensional structures associated with sinuous wrench faults (Lowell, 1985).

This zone is interpreted to be an accomodation structure or accommodation zone (Etheridge & others, 1988) and is annotated as the 'East Duntroon Accommodation Zone' (EDAZ) in Figure 9.1. It couples the independently-initiated and offset embryonic rift zones west of Kangaroo Island (west of the EDAZ), and 100 km south of Kangaroo Island (east of the EDAZ). With continued extension and eventual sea-floor spreading, concentration of this deformation zone is likely, with the ultimate formation of an oceanic transform fault. In this case, the broad EDAZ is believed to have produced two closely spaced transform faults, the Spencer and George V Fracture Zones.

West of Platypus-1 is a similar, though more subtle zone with similar orientation (Figs 9.1 & 15.1; West Duntroon Accommodation Zone, or WDAZ). West of the WDAZ, basement faulting in the Bight Basin is consistently down-thrown southwest or south-southwest into the basin, while east of the WDAZ, Duntroon Basin faults are down-thrown to the south (Fig. 20.1).

Beneath most of the abyssal plain, a strong basement reflector is observed, with a thin cover of flat-lying Cainozoic sediments. The basement surface is rugged, and occasionally forms ridges in the abyssal plain. In character, it has the appearance of oceanic crust, although magnetic lineations, typical of such crust, are poorly developed. Cockshell (1986) suggested that a transition zone exists between continental and oceanic basement in the Otway Basin, with this zone comprising continental rocks heavily intruded by oceanic material. This concept is also applicable to the Duntroon Basin. High-quality migrated seismic reflection data from a comparable location south of the Ceduna Sub-basin (Willcox & others, 1989; Chapter 5, this report) has also been interpreted to be either re-rifted oceanic crust, or an amalgam of both intruded continental and oceanic crust.

Syn-rift Sedimentary Sequences

The rift history of the Duntroon Basin can be divided into two distinct episodes of extension and subsidence, with two associated sedimentary cycles. The first cycle, of interpreted ?Jurassic-Neocomian age, is associated with typical syn-rift in-fill of three half-graben depocentres in the inner part of the basin. These depocentres are delineated by east-southeast and northeast oriented faults (Fig. 20.1). The two sets of faults have horizontal extensional components, and appear contemporaneous.

The ?Jurassic-Neocomian sequence contains isolated interpreted thick alluvial fans adjacent to the fault scarps, and has strong similarities to proximal alluvial fan deposits in the Neocomian Pretty Hill Sandstone within the Robe-Penola Trough of the Otway Basin (Gravestock & others, 1986). Localized channelling is also evident.

At the time of deposition, the depocentres were apparently relatively isolated and enclosed. Despite this, the unit is remarkably consistent in seismic character between depocentres, suggesting that the environment of deposition was similar throughout the area.

While Jurassic sediments have not been penetrated in the Duntroon Basin wells, support for a Jurassic age for at least part of this unit comes from the Polda Trough, where three wells encountered Jurassic sediments. The Polda Trough Jurassic section comprises poorly-consolidated and sorted, coarse to very coarse, feldspathic, non-marine fluviatile sands. The occurrence of Bajocian tholeiitic basalts on Kangaroo Island (Milnes & others, 1982) also supports a Jurassic age for the onset of rifting, and suggests that the early syn-rift unit in the Duntroon Basin may include volcanoclastics. Powis & Partridge (1980) interpreted a Callovian-Oxfordian to Kimmeridgian-Tithonian section to directly overly Archaean basement in the Jerboa-1 well in the Eyre Sub-basin to the west, although there is some controversy over this dating.

Movement on the basement faults within the inner basin ceased with the end of deposition of the first syn-rift unit, while the northern margin faults remained active and extended to the east during a second cycle of extension that began in the Early Cretaceous. This second cycle of rifting was accompanied by sagging of the southern edge of the basin towards the continental slope, which allowed thick Lower Cretaceous sediments to accumulate (Duntroon Group; Fig. 23.1).

In contrast with the restricted and localised ?Jurassic-Neocomian sedimentation, the Duntroon Group accumulated over a much wider area. The shales of the Duntroon Group were deposited at very high sedimentation rates (up to 40 cm/1000 years; Forbes & others, 1984) in fluviatile and lacustrine environments. Under-compaction and fluid over-pressuring are likely to result from such high sedimentation rates, explaining the tendency for shale migration which is observed in the Lower Cretaceous of the Duntroon Basin. Lower Cretaceous sedimentation was concentrated in the inner part of the basin, in two depocentres located in the southeast and northwest sectors (Fig. 15.1).

Post-rift Sedimentary Sequences

The end of rifting coincides with an abrupt decrease in the rate of subsidence in the mid-Cretaceous (Mutter & others, 1985; Hegarty & others, 1988). This decrease is interpreted to reflect the change from rapid fault-controlled subsidence to slower thermal subsidence following margin breakup. However, fault-controlled subsidence continued after breakup along the northern margin bounding faults (Fig. 20.1). This subsidence was probably due to sediment loading resulting from continuing high sedimentation rates, rather than to lithospheric stretching. Similar interpretations have been made in the Gippsland (Hegarty & others, 1986; Rahmanian & others, in press) and Otway Basins (Williamson & others, 1987), and in other parts of the world, such as the North Sea (Sclater & Christie, 1980).

The most dramatic manifestation of these post-rift movements is the Late Cretaceous uplift and tilting of the central ridge that separates the inner and outer Duntroon Basins (Fig. 17.2). Seismic interpretation suggests that it was structurally high in the ?Jurassic-Neocomian, as evinced by the thinning of the oldest sediments onto the ridge. However, the ridge was covered by a thick sedimentary sequence (Duntroon Group) during the Early Cretaceous. Reactivation of the northern basin margin faults in the Late Cretaceous resulted in basement tilting in the inner basin, and the consequent uplift of the central ridge. This tilting is particularly prominent in the western part of the inner basin, where it is accompanied by a considerable thickening of the Upper Cretaceous Bight Group (Fig. 24.1). As a consequence of the uplift, the Bight Group thins onto the central ridge, either due to erosion or non-deposition, and Tertiary sediments locally directly overlie the Duntroon group, as at Echidna-1.

Post-rift movement in the sedimentary section also resulted from the loading of the under-compacted shales of the Duntroon Group by the Upper Cretaceous sediments of the Bight Group. Similar Lower Cretaceous sediment-loading structures are also prominent along the southwest flank of the Ceduna Terrace, at the boundary between the Ceduna and Recherche Sub-basins. Mobilisation of the shales has produced domal Cretaceous structures with marked anticlinal dips. Two sets of faults (one set dipping seaward and the other dipping landward) typically cause collapse of the anticlinal crest (Fig. 17.2). The doming affects both the Duntroon and Bight Groups, and the crestal faults commonly extend through the Tertiary section, occasionally reaching the sea floor. These structures have a east-southeast trend, parallel to the basin axis, and vary from 80 km long and 40 km wide for the Koala-Echidna Structure, to about 30 km by 12 km for the Cockatoo Structure (Fig. 15.1).

The flanking faults of the shale anticlines die out or flatten out with increasing depth in a regional decollement zone immediately above the near base Cretaceous horizon. The decollement separates the arched and faulted Duntroon Group from the undeformed and underlying syn-rift ?Jurassic-Neocomian section. It is probably contemporaneous with a major decollement surface in the Recherche Sub-basin, to the west (Chapter 3d, this report). In the horizontal plane the flanking faults are essentially parallel to the anticline axis. Crestal faults, with either regional or contra-regional dip, are usually steeper and tend to be less continuous (Fig. 17.2) than the flanking faults and have large displacements.

The existence of a decollement in the ductile shales in the Duntroon Group also induced growth-faulting in the outer Duntroon Basin in the Late Cretaceous ('growth belt' or 'outer step faulted zone' of Forbes & others, 1984). The westward thickening of the Bight Group, from 757 m in Duntroon-1 to 1657 m in Platypus-1, reflects the westward increase in total overall fault throw in the 'growth belt' (Figs 17.1 & 24.1).

Initiation of the diapiric anticlines and associated withdrawal anticlines can be dated by the onlap of Platypus Formation (Bight Group) sediments along the southern flank of the Koala structure. This dates mobilisation and uplift as being in the Late Cretaceous (?Cenomanian). The growth of the diapiric anticlines and the variations in uplift along their axis have thus controlled the location of depocentres and probably locally influenced the distribution of depositional facies of the Bight Group (Platypus, Wigunda, and Potoroo Formations). The central part of the Echidna-Koala structure has been heavily eroded, and is totally bereft of Upper Cretaceous section, indicating that the structure acted as an effective sediment barrier between the northern and southern depocentres, at least during part of the Late Cretaceous (Cenomanian-Turonian). Sediments filled the southern syncline from both north and south, and from the eastern end of the basin. Progressive growth of the Echidna-Koala Structure generated local intra-formational unconformities within the southern syncline.

A strong angular unconformity at the base of the Tertiary marks an abrupt reduction in the rate of diapiric growth and up-lift, and probable cessation of rotation on the growth faults in the outer growth-fault belt. The measured angle of unconformity between the horizontal Tertiary and the underlying rotated Early Cretaceous reaches 20^{o} at Echidna-1, indicating that substantial erosion has taken place, as along the outer margins of the Ceduna and Eyre Sub-basins.

The overlying Eucla Group, comprising the Wilson Bluff and Nullarbor Limestones, marks the onset of open-marine conditions. This group gradually increases in thickness towards the shelf edge, with the characteristic form of a prograding wedge.

The major marine incursion in the Duntroon Basin occurs about 45 Ma after the onset of seafloor spreading between Australia and Antarctica. The absence of a decisive marine transgression at the time of Cretaceous breakup is possibly due to high continental sedimentation rates acting to counter marine incursions induced by post-breakup thermal subsidence, as Deighton & others (1976) have suggested in the Otway Basin. The timing of the marine trangression appears coincident with a slowing in the rate of growth-faulting and diapirism observed in the Tertiary, which probably due to a reduction in the rate of detrital supply.

b) BIGHT BASIN - CEDUNA SUB-BASIN

i) Introduction

The Ceduna Sub-basin comprises a major sediment accumulation underlying the Ceduna Terrace on the eastern side of the GAB in water depths ranging from 200 to 4000+ m (Fig. 9.1). The sub-basin is approximately 90000 km^2 in area and contains in excess of 10000 m of sediment, making it comparable in scale to the Exmouth Plateau. The greatest thickness of sediments is found in the water depth range 600-2000 m. The sub-basin is separated from the Duntroon Basin to the east and the Recherche Sub-basin to the west by inferred accommodation zones (the West Duntroon and Southwest Ceduna Accomodation Zones, respectively), and from the Eyre Sub-basin to the northwest by narrow continental slope at the head of the GAB.

Although the existence of the Ceduna Terrace (or Ceduna Plateau), which largely defines the limits of the Ceduna Sub-basin, has been known for a long time, the first seismic data were not recorded across the sub-basin until 1969. From 1966-76, Shell Australia shot approximately 25000 km of multichannel seismic data over the continental shelf and adjacent slope and terrace, before final permit relinquishment in 1977. During this period, a single well, Potoroo-1, was drilled in 1975 on the northernmost margin of the sub-basin; Potoroo-1 was plugged and abandoned as a dry well. During 1972, a series of reconnaissance-scale lines were recorded over the outer part of the sub-basin during the Shell *Petrel* roving scientific survey. Since 1977, exploration activity has been limited to a brief period in 1981-82 when BP/BHP reprocessed some of the original Shell seismic data and shot a further 2188 km of multichannel seismic data, principally in the northern half of the sub-basin. However, no further drilling was attempted. Since the early 1980's, the only new data acquired from the Ceduna Sub-basin was by BMR on the *Rig Seismic* in late 1986 (Willcox, Stagg, Davies, & others, 1988) when a number of lines were recorded, principally over the western flank of the sub-basin.

ii) Stratigraphy

To date, the only stratigraphic information on the Ceduna Sub-basin comes from Potoroo-1 exploration well and from some dredge samples collected on board the *Rig Seismic* during BMR Survey 66 (Davies & others, 1989).

Potoroo-1 (Shell, 1975)

Potoroo-1 was sited on a small fault-dip closure along an east-west trending basement fault on the northern margin of the Ceduna Sub-basin in the central GAB (Fig. 37.2).

The basal section above basement (?Precambrian Gawler Block equivalents) consists of 120 m of brackish water-bearing, sand-prone, Neocomian sediments (Loongana Formation) deposited in a possible braided-fluvial environment; thin siltstone and shale bands and a thin, coal-bearing sandstone are also present. Porosities in the unit vary from 13-25% in the lower part to 9-22% in the upper part.

The Loongana Formation is unconformably overlain by the Albian Ceduna Formation, comprising of 270 m of alternating dark shales, mudstones, glauconitic siltstones, and sandstone, with minor coal bands. The interpreted environment of deposition is restricted marine, which correlates closely with the equivalent unit (JD of Huebner, 1980) at Jerboa-1.

A regional hiatus in the late Albian separates the Ceduna Formation from the Cenomanian Platypus Formation, a 644 m-thick sequence of glauconitic siltstone and sandstone with dolomite bands throughout, and thin coal bands at the top (correlative of units JC-JA in the Eyre Sub-basin). Deposition was probably in a nearshore marine to brackish environment at the base, passing into non-marine at the top. In the Turonian, a 206 m thick unit of massive soft carbonaceous mudstone (Wigunda Formation) was deposited in a continental-paralic environment. The reduced thickness of this sequence, compared to the Duntroon Basin, is probably due to clastic starvation.

The Coniacian-Maastrichtian Potoroo Formation conformably overlies the Wigunda Formation at Potoroo-1, where it attains a thickness of 580 m. It consists of highly porous sandstones (25-30% porosity) grading to siltstone towards the base of the unit, and is interpreted to have been deposited in a delta plain environment.

As in the Eyre Sub-basin, Tertiary sedimentation at Potoroo-1 is in two distinct phases. The Paleocene and Early/Middle Eocene, is dominated by a sequence of unconsolidated and highly-porous sands and poorly-consolidated sandstones (Pidinga Formation) deposited in a marginal marine environment with periodic marine inundations. (While this sequence was not penetrated at Jerboa-1, it has been interpreted from the seismic data.) Since the Middle Eocene, open-marine carbonate sediments have dominated with some 600 m of marls, bioclastic and argillaceous grainstones, packstones, and wackestones being deposited under mainly low-energy, middle to outer neritic environments (Wilson Bluff and Nullarbor Limestones).

Dredge Samples

During BMR Survey 66 (Davies & others, 1989), three dredge sites (numbers 4, 6, and 7; Appendix X) were successful in recovering samples from the Ceduna Sub-basin. Due to equipment failure prior to the survey, only the section in water depths shallower than about 3500 m could be sampled. Deeper Cretaceous targets, which should be accessible to dredging in canyons, remain untested.

Dredge 4 recovered small fragments of friable, ?Lower Tertiary , siliceous wackestone on the flank of a small canyon on the northwest Ceduna Terrace. Dredge 6 recovered 50 kg of Lower to Upper Oligocene, fine-grained pelagic wackestone from Ceduna Canyon on the southern flank of the terrace. Dredge 7 recovered the most geologically interesting rocks - 20 kg of Maastrichtian and Upper Paleocene to Lower or Middle Eocene, organic-rich mudstone/siltstone, and Miocene interbedded wackestone and siltstone. The measured total organic carbon content of 2.0% in Upper Paleocene muddy siltstone was the highest recorded from Survey 66 dredge samples.

iii) Horizons and Intervals Identified and Mapped

BMR scientists A.R. Fraser and L.A. Tilbury digitised and mapped the principal seismic reflectors identified in the Ceduna Sub-basin in the late 1970s. Their data was incorporated in a paper (Fraser & Tilbury, 1979), but the maps were not otherwise publicly released. Their paper is an excellent and comprehensive summary of the geology of this part of the GAB, with the only substantial modifications required being those that take account of the revised (and still not definitive) extension/breakup history of the southern margin. This report has taken Fraser and Tilbury's digitised data set, and added an interpretation of the BMR Survey 65 seismic data. While the better quality BMR data have forced some minor modification of Fraser and Tilbury's interpretation of Late Cretaceous and Tertiary horizons, their interpretation remains largely intact, and it is acknowledged in the production of the maps accompanying this this report. The main difference these authors have with their interpretation is that we do not believe it is possible to reliably map any horizons older than their horizon D (our horizon d; approximately 90 Ma.

The location of Potoroo-1 on the northern basin flank, several hundred kilometres from the most-distant parts of the sub-basin, and the rapid thickening of the sedimentary section from <3 km to >10 km thick across the basin margin, makes dating of seismic reflectors over the entire area problematical, particularly in the deeper section. The following horizons have been identified, and their ages are estimated with moderate confidence; horizons shown in italics have been identified but not mapped in this report. The horizon identifications used by Fraser & Tilbury (1979) are shown in square parentheses, whilst a summary of seismic sequences is included in Table 2.

Horizon b *Top of Precambrian basement (Gawler Block equivalent), only identified reliably along the northern and northeastern margins; tentative identification of the top of the first rotated basement fault block below the northern basin margin fault on a few lines [= horizon H].*

Horizon n *?Top of the Valanginian-Hauterivian or ?Jurassic-Hauterivian syn-rift and early rift-fill section (top Echidna Formation); tentative identification at the northern and northeastern basin margins and the outer part of the Ceduna Sub-basin only, where the overlying section is not too thick [= horizon G].*

Horizon **d** ?Top of pre-breakup, rift-fill and early, post-breakup section (top Platypus Formation); extensive development of block faults in central and western sub-basin and growth faults in the east; best estimate of dating is about 90 Ma (*ca* 5 Ma post-breakup in Southern Ocean) [= horizon D].

Horizon **c** Base of major Santonian-Campanian delta (particularly well-developed in the southwest of the sub-basin) [= horizon C].

Horizon **td** Top of Santonian-Campanian delta [= horizon B].

Horizon **t** Major unconformity separating thick Cretaceous section from thin Tertiary; strong erosional surface in the outer part of the sub-basin where it also marks the upper limit of syn-sedimentary faulting [= horizon A].

Horizon e *Early Eocene horizon marking top of weakly developed thin prograding unit below shelf edge; difficult to identify in central Ceduna Sub-basin [= horizon A1].*

Horizon **wb** Seabed.

The following seismic intervals have been mapped for this report:

Horizons **d-wb** Post-Cenomanian section; total sediment thickness above major block-faulted horizon.

Horizons **d-c** Turonian-Santonian ?shallow marine fine-grained section between top of fault blocks and base of prograding unit (Wigunda Formation).

Horizons **c-td** Santonian-Campanian delta (within Potoroo Formation).

Horizons **td-wb** Total sediment thickness overlying delta.

Horizons **t-wb** Tertiary section (mainly open-marine carbonates).

iv) Structure and Evolution

Basement

Basement structures in the Ceduna Sub-basin can only be unambiguously identified along the northern and northeastern margins where the contact with the Gawler Block comprises a major basement scarp; tentative identification has been made of the first rotated basement block below the margin fault in the north (Fig. 37.4). Consequently, basement contour maps (Fraser & Tilbury, 1979, fig. 12) must be prepared from a combination of magnetic depth estimates and seismic refraction data. Since these data comprise sparse, spot estimates, such maps will be highly generalised and not provide any detailed basin-forming trends. Both basement maps indicate that magnetic/seismic basement is at a depth of at least 12 km below sealevel. The map produced by Fraser & Tilbury (1979) further suggests a WNW-ENE trending basin axis with the maximum thickness of sediments in the southeast, though this should be treated with considerable caution. While the broad structural subdivision of the Ceduna Sub-basin in Figure 9.1 (Northeast Ceduna Monocline; Central Ceduna Depositional Axis; Outer Margin High) probably reflects deeper basement structures, these structures have been so strongly affected by the extreme sediment loading (as much as 10000 m in the Cretaceous) that they cannot be used to infer original basin-forming trends.

The basement scarp along the north and northeast margins offsets basement by at least 4-6 km. The scarp is sometimes expressed as a single low-angle fault (eg Fig. 37.4), and sometimes as a complex monocline that may be down-faulted at depth within the sub-basin. The rapid sediment deposition in the Cretaceous has probably caused both flexure of the basement and strong erosion of the original fault scarp to produce a basin boundary along which individual fault segments are difficult to pick. However, three basic trends appear to be present: ENE-WSW along the crest of the deep rotated fault block in the extreme northwest (parallel to similar structures on the western side of the GAB); east-west along the northern margin, with some poorly-defined offsets; and WNW-ESE along the northeast margin (Fig. 9.1). While the exact nature of the structures producing these trends is ill-defined, they are not inconsistent with our model of northwest-southeast extension (Willcox, 1990; Chapter 5, this report).

Sedimentary Section

The Ceduna Sub-basin can be divided into three major structural elements that are manifested in the sedimentary column, and possibly also at depth. From northeast to southwest, these are (Fig. 9.1):

Northeast Ceduna Monocline - comprising the most rapidly thickening part of the basin between the edge of the continental shelf and the Ceduna Terrace proper. The monocline varies from 40-50 km in width and the sedimentary section thickens from less than 2000 m to probably more than 10000 m thick. All sequences thicken across this zone, except for the Tertiary section (t-wb). Faulting within the sedimentary section is relatively minor.

Central Ceduna Depositional Axis - a broad depositional trough in

TABLE 2: Ceduna Sub-basin - Seismic Sequence Characteristics

Horizon	Upper Boundary	Lower Boundary	Internal Configuration	Age	Facies	Comments
wb						
	concordant - erosional	downlap - concordant	prograding wedge at shelf edge; sheet drape on terrace; moderate-high amplitude; high continuity	Middle Eocene - Recent	open-marine carbonates	poorly-consolidated veneer
e						
	concordant	downlap - concordant	thin prograding wedge at shelf edge; sheet drape on terrace; mixed continuity and amplitude	Paleocene - Early Eocene	shelfal in NE; bathyal in SW	thin porous sand unit
t						
	erosional truncation	onlap - concordant	sheet drape; basin-fill beyond delta in c-td; low amplitude, variable continuity	Campanian - Maastrichtian	shallow marine in NE; bathyal in SW	
td						
	concordant	downlap - concordant	seaward-thickening wedge on N & NE margins; prograding delta in SW; mixed amplitude & low continuity in NE; medium amplitude & high continuity in SW	Santonian - Campanian	marginal marine in NE; bathyal in SW	major delta unit in SW Ceduna Sub-basin
c						
	concordant - mildly erosional	onlap - concordant	basin-thickening wedge at margins; sheet drape on Ceduna Terrace; mixed amplitude & variable continuity at base; low amplitude & high continuity at top	Turonian - Santonian	restricted and marginal marine	
d						

Table 2 (Cont.)

Horizon	Upper Boundary	Lower Boundary	Internal Configuration	Age	Facies	Comments
d						
	erosional truncation	?concordant - onlap	basin-thickening wedge; sheet drape on terrace; variable amplitude & continuity	Barremian - Cenomanian	?continental, rift-fill	marks top of major block-faulting
n						
	?mildly erosional - concordant	?onlap - concordant	?low frequency wedge; low continuity and variable amplitude	?Jurassic - Hauterivian	continental, syn-rift and rift-fill	top of syn-rift; too deep to distinguish individual sequences
b						
	erosional		acoustic basement	Precambrian	crystalline basement	

both Lower and Upper Cretaceous sections extending for some 350 km along the central Ceduna Terrace. The trough is some 80-100 m in width and the axis appears to migrate oceanwards with decreasing age. This area is characterised by high-angle, low-extension block faulting, frequently with throws of more than 200 m, in the centre and northwest, and growth faulting in the southeast.

Outer Margin High - a 15-40 km wide zone of uplifted section (or section which has been held high relative to the central axis) extending along the southwest flank of the Ceduna Sub-basin beneath the outer flank of the Ceduna Terrace. Horizons beneath the Outer High are elevated by as much as 1.5 s TWT (>2000 m) relative to the central part of the sub-basin. The latest Cretaceous section has been strongly eroded (as with the outer part of the Eyre Sub-basin and the central Duntroon Basin) and the entire zone has been subject to complex structuring, including wrenching and possible overthrusting. This zone partly overlies an interpreted transpressional zone (the "Southwest Ceduna Accommodation Zone").

The three zones described here all have a general WNW-ENE trend that appears to be the result of a copious supply of sediment that was derived from the northeast and has been dumped rapidly onto thinned crust.

The oldest sediments are probably of Jurassic and earliest Cretaceous age (pre-horizon n). The possibility of older (?Palaeozoic) sediments from an intracratonic basin cannot be precluded (see description of Recherche Sub-basin and Denman/Eucla Basins). The Jurassic-Neocomian sediments probably had syn-rift associations and may have been deposited over very thin crust, as appears the case in the Recherche Sub-basin. These sediments appear to in-fill the trough between the first major rotated basement block and the head-wall fault of the sub-basin (Fig. 37.4), similar to the Duntroon Basin (Chapter 3a), and form a thick blanket beneath the Ceduna Terrace. The actual environment of deposition is uncertain as the sequence is rarely identified, but we speculate that sedimentation was in a broad, subsided, flat-floored rift valley, that may have been subject to periodic marine inundations, particularly after the advent of seafloor spreading off Western Australia in the Neocomian (125-120 Ma). As is noted elsewhere in this report, it is possible that there may have been a phase of restricted seafloor spreading in the western half of the Southern Rift System, contemporaneous with that off Western Australia. If this is the case, then marine depositional environments may have been more prevalent than our interpretation has suggested. Fraser & Tilbury (1979) interpreted the seismic character immediately above and below horizon n as indicating the deposition of fine-grained material in a stable ?marine environment - this sediment consisting of shales, siltstones, and minor sandstones. Around the margins of the rift, sediments probably contained a higher proportion of coarse clastics, as drilled at Potoroo-1. The total thickness of sediments below horizon n cannot be reliably measured, but is probably in the range of 2000-4000 m.

The interval between horizons n and d was deposited during the Barremian-Cenomanian and is estimated to be at least 2 s TWT thick (>3000 m) in the central axis of the sub-basin. Seismic character and correlation with Potoroo-1 suggests that depositional environments in the central sub-basin were paralic in the Barremian, became restricted marine in the Albian, and, following a regression in the Cenomanian, became paralic again; conditions probably remained marine in the south and southwest. Horizon d is a strong reflector and has been correlated with coal bands near the top of the Platypus formation in Potoroo-1 and in Platypus-1 in the Duntroon Basin (Fraser & Tilbury 1979). Horizon d is the deepest reflector that can be confidently traced across most of the sub-basin, although it can still be too deep for positive identification in the deepest parts. It also marks the level of the major phase of faulting in the Ceduna Sub-basin, and appears to post-date Cenomanian breakup by approximately 5 Ma. Data quality is frequently poor at this level in the older seismic data, and consequently fault correlation is not straightforward. Maps of the Ceduna Sub-basin included in this report, which are based only on the Shell regional grid and the BMR Survey 65 data, are, therefore generalised in that the contouring does not include the faulting. Fraser & Tilbury (1979) are probably correct in their interpretation of a west-northwest - east-southeast trend for Cenomanian faulting. However, it must be emphasised that these faults, which are generally high-angle with throws commonly excess of 400 m, are probably at least partly due to differential compaction resulting from the high deposition rates, and are not basin-forming as has been interpreted, for example, by Veevers & Eittreim (1988).

The Turonian-Santonian section between horizons d and c can be considered in two parts, with a distinct change at about Fraser & Tilbury's (1979) horizon D1 (horizon d1 in this report). The section from horizon d to d1, is extensively faulted, although individual throws are less than at horizon d (typically less than 200 m). This unit is of fairly uniform thickness basin-wide, but thins over the margins. The upper part of the sequence (d1 to c) is a basin-thickening wedge. Fraser & Tilbury (1979) interpreted high reflection continuity and low amplitude as indicating predominantly fine-grained material deposited in a stable marine environment, perhaps contemporaneously with the restricted marine Belfast Mudstone in the Otway Basin. This sequence may correspond to a post-breakup transgressive sequence, seen here because of the relative proximity of the Ceduna Sub-basin to the COB compared to the Eyre Sub-basin. The sequence between horizons d1 and c is from 1-1.6 s TWT (approximately 1500-2500 m) thick in the Central Ceduna Depositional Axis, and probably constitutes a suitable source rock, at an adequate depth of burial for the generation of hydrocarbons.

The interval between horizons c and td (Potoroo Formation) is dominated in the southwest by a thick (0.5-1.3 s TWT; approximately 700-1700 m) prograding sequence, that may represent a shelf-edge delta. The delta extends for at least 250 km along the southwest margin of the Ceduna Terrace, with the direction of prograding indicating an abundant source to the northeast, presumably uplifted Gawler Block. The reflection character northeast of the delta changes from high-continuity and high-amplitude to low-continuity and variable-amplitude, which Fraser & Tilbury (1979) interpreted to indicate a facies change from shallow-marine sandstones and shales to interbedded, discontinuous sands and coals deposited in a delta plain or flood-plain environment. This facies change also appears to occur vertically within the delta, indicating a regression, presumably due to very high rates of terrigenous influx. Depositional environments in the far southwest were probably bathyal, as indicated by the height of the delta foresets.

It is interesting to note how the extremely high Late Cretaceous terrigenous influx was accommodated in different parts of the sub-basin. In the west, accommodation was principally by outbuilding of the delta, implying that post-breakup subsidence was retarded. Conversely, in the east, the sediments were accommodated by continued subsidence; the interval c-td is approximately 100% thicker in the east than it is in the west. This suggests that either heat-flow was much higher in the west (causing subsidence to be delayed), or that the crust in the west was in contact with crust perhaps on the adjacent Antarctic Plate, thus retarding its subsidence.

Post-delta sedimentation (td-t) started with a trangression, probably due to a marked reduction in terrigenous sediment supply, rather than to subsidence. The sequence td-t has the external form of a fairly simple basin thickening wedge. Reflection character again indicates probable shallow marine environments in the southwest, and continental-paralic in the northeast. Minor adjustment-faulting extends throughout the Upper Cretaceous section in the outer half of the Ceduna Sub-basin; while throws are rarely more than a few tens of metres, this faulting may have negative consequences for the entrapment of hydrocarbons.

The end of the Cretaceous is a time of major tectonic movements in the outer Ceduna Sub-basin; this period was originally interpreted as margin breakup. These movements are manifest in three ways -

- Major uplift of the Outer Margin High, a positive zone some 350+ km long, and up to 50 km wide extending along the southwestern and southern flanks of the sub-basin; the Outer High is elevated by up to 1500 m relative to the Central Ceduna Depositional Axis, and Upper Cretaceous sediments have been extensively eroded from its crest, in similar manner to the seaward half of the Eyre Sub-basin. The erosional unconformity is planar in appearance, and is interpreted as being due to wave-base erosion, rather than to the onset of deep oceanic circulation.

- Wrench faulting above deep-seated Early Cretaceous faults on the Outer Margin High; these faults have created 'positive flower' structures in the south and southwest, and appear to have an east-southeast strike. Some of these faults may have served as the stimulus and conduit for (?)shale diapirisim during the Tertiary (Fig. 37.5).

- Possible overthrusting of the Cretaceous section on the seaward flank of the Outer Margin High. Structuring in this area is highly complex and hard to resolve; however, evidence of overthrusting is difficult to refute. (This overthrusting is different in character and almost certainly different in age to the interpreted 'nappe' structures at the juncture between the Ceduna and Recherche Sub-basins; referred to in Chapter 3d)

- Emplacement of mound structures at the level of horizon t. These structures have been interpreted as volcanics extruded during margin breakup (Fraser & Tilbury, 1979). While volcanics are the most likely explanation, cold-water, ?carbonate build-ups cannot be totally discounted.

In the Tertiary, the Ceduna Sub-basin follows much of the rest of the southern margin in being sediment-starved (post-horizon t). As in the Eyre Sub-basin, sedimentation appears to have occurred in two phases. In the Paleocene-Early Eocene, a thin prograding sand sequence (Pidinga Formation) was deposited over the Upper Cretaceous section, principally in the vicinity of the present-day shelf edge; this unit is a correlative of the prominent Eocene prograding sand unit in the Eyre Sub-basin. Since the Middle Eocene, sedimentation has been dominated by open marine carbonates deposited in neritic to bathyal environments. This sequence is thin over most of the Ceduna Sub-basin (average thickness 200-500 m), and is completely absent from the outer edge of the Ceduna Terrace and the lower continental slope.

c) BIGHT BASIN - EYRE SUB-BASIN

i) Introduction

The Eyre Sub-basin forms a 'perched' extensional basin underlying the Eyre Terrace below the shelf break in water depths of 200-1200 m on the western side of the GAB (Figs 9.1 & 39.1). The sub-basin is approximately 8000 km^2 in area, comparable in area to the Polda Trough and the Bremer Basin. While the Eyre Sub-basin is bounded by basement highs to the north, west, and south, it is contiguous with the Ceduna and Recherche Sub-basins via the thick sedimentary section underlying the continental slope in the centre of the GAB.

The earliest seismic profiles recorded across the Eyre Terrace were acquired during the 1967 *Oceanographer* cruise. About 1000 m of sediments overlying a strong reflector (probably basement) were identified (Conolly & others, 1970). The Eyre Sub-basin was more fully delineated in Survey 16 of the BMR Continental Margin Survey, carried out from 1970-73. To date, the only industry exploration effort has been by Esso Australia from 1979-82. In 1979, Esso shot 3151 km of good-quality multichannel seismic data on both regional and detailed grids (Fig. 39.2). This enabled identification of the Jerboa prospect and the Jerboa-1 well was subsequently drilled in 1980 (Bein & Taylor, 1981); Jerboa-1 was plugged and abandoned as a dry well. In 1982, Esso shot a further 920 km of multichannel seismic over several leads, but no further wells were drilled. No additional data were recorded over the Eyre Sub-basin until late 1986 when parts of 6 multichannel seismic lines were recorded in the area by the R/V *Rig Seismic* during BMR Survey 65 (Willcox, Stagg, Davies, & others, 1988). These lines were of similar quality to the Esso data, but do not significantly change earlier interpretations.

ii) Stratigraphy

To date, the only information on the stratigraphy of the Eyre Sub-basin comes from the Jerboa-1 well and from some dredge samples collected on board the *Rig Seismic* during BMR Survey 66 (Davies & others, 1989).

Jerboa-1

Jerboa-1 was sited on the crest of a small fault block within a half-graben in the western half of the Eyre Sub-basin, to test a compaction-drape target in interpreted Cretaceous sediments above the fault block (Fig. 46.2). Permian sediments have been reported beneath the onshore Eucla Basin (Harris & Ludbrook, 1966) and may be preserved beneath parts of the Eyre Sub-basin, though not yet sampled. Seismic data from the western end of the sub-basin suggest parallel reflections conformable with the basement surface and cut by basement faults (Bein & Taylor, 1981, fig. 4). These sediments may be remnants of a Palaeozoic basin and possibly equivalent to part of the sedimentary fill of the Polda Trough.

In the well, the basal section, above Precambrian basement consists of 186 m of Valanginian non-marine sediments (units JJ and JI of Bein & Taylor, 1981; ages as revised in this report), which are assigned to the Loongana Formation. The earliest sediments are poorly-sorted sandstones interpreted to be weathering products and debris derived locally from basement which split off soon after basin initiation. The remainder of the sequence is largely shale-prone with interbedded sandstone units deposited in a lacustrine environment.

The Hauterivian section (units JH to JF of Bein & Taylor, 1981) is a 224 m-thick sequence of largely sand-prone non-marine sediments, which is also assigned to the Loongana Formation. Eastwards-prograding foresets in the west of the basin suggest probable deposition in a deep lacustrine environment. The upper and lower units (JF and JH) were considered by Esso to be the main exploration targets in the Eyre Sub-basin with average porosities of 20% and 17%, respectively. The intermediate unit, JG, comprises an 84 m-thick sequence of claystones and argillaceous siltstones. Burial, compaction, and cementation have destroyed much of the primary porosity of the sands; secondary pores, formed by dissolution of feldspar grains, now account for 30-60% of the total porosity.

The Loongana Formation is unconformably overlain by a succession of dark grey to dark brown shales with rare interbeds of siltstone (Madura Formation equivalent; unit JE of Huebner, 1980) deposited in a fresh or brackish-water lacustrine environment. The unit has strong similarities to the Neptune Formation of the Duntroon Basin. Because of the large distance between Jerboa-1 and the Duntroon Basin, the unit has been assigned to the Neptune Formation equivalent, until confirmed by seismic and drill data. While Powis & Partridge (1980) assigned a ?Neocomian-Aptian age, base on palynological evidence, it is now believed to be of Neocomian-Barremian age (Morgan, 1990). The formation is characterised petrophysically by a monotonous gamma-ray log signature and a corresponding smooth sonic-log trace, reflecting it's homogeneous nature.

The earliest marine influence, recognised by the first appearance of dinoflagellates, occurs in the Albian when a thin, shale-prone, prograding unit was deposited unconformably across the Hauterivian claystones. This unit (JD of Huebner, 1980) is only 35 m thick at Jerboa-1, and is assigned to the Ceduna Formation equivalent. After a depositional hiatus of approximately 3 Ma in the late Albian (possibly correlating with Southern Ocean breakup), marine sedimentation resumed in the Cenomanian with the deposition of a further 452 m of interbedded shales, claystones, and sandstones in an interpreted near-shore environment (units JC to JA of Huebner, 1980).

At Jerboa-1, the Turonian to Lower Eocene section is absent; this represents a gap in the sedimentary record covering approximately 40 Ma, and is seen as a major basin-wide unconformity. While some of this section may be preserved in the structurally-lower parts of the sub-basin, it is apparent that a major erosional event, probably combined with lengthy non-deposition, has affected the region.

Sedimentation at Jerboa-1 commenced again with the deposition of a 28 m-thick section of Hampton Sandstone in the latest Early Eocene. These sands were rapidly succeeded by calcilutites and marls of the Wilson Bluff Limestone and poorly-consolidated, open-marine, prograding carbonates which dominate the remaining 335 m of section at Jerboa-1.

With its central location within the sub-basin, Jerboa-1 penetrated a representative Cretaceous-Tertiary section, albeit abbreviated in the ?Jurassic-Neocomian. The only sequence apparently missing at Jerboa-1 is a thin southwards-prograding unit which stratigraphically lies between the Cenomanian and Eocene sequences at Jerboa-1. This unit is presumed to consist of prograding shelf-edge sands and to be of Paleocene or Early Eocene age.

Dredge Samples

During *Rig Seismic* Survey 66 (Davies & others, 1989), three dredges (DR01-03, Appendix X) were aimed at recovering rocks from the Eyre Sub-basin.

Dredge DR02 recovered moderately altered and sheared granodiorite of presumed Precambrian age from the lower slope basement scarp below the Eyre Terrace. Similar rocks are expected to underlie the Eyre Sub-basin.

Dredges DR01 and DR03 sampled the broad Eucla Canyon at the eastern end of the Eyre Sub-basin. This canyon is one of the rare locations in the central-western GAB where pre-Tertiary rocks are accessible to dredge sampling. Rocks recovered included Maastrichtian sandstone, siltstone, mudtsone, and conglomerate, Paleocene phosphoritic sediment, and Tertiary fine-grained limestone and siliceous carbonate. Fragments of amygdaloidal basaltic lava were also recovered. The abundance of large amygdules indicates eruption at a relatively shallow depth, and occurrence with Maastrichtian and younger sediments suggests a Maastrichtian or younger age.

iii) Horizons and Intervals Identified and Mapped

The principal geological sequences identified in Jerboa-1 can be reliably mapped over most of the Eyre Sub-basin. The horizons selected for mapping and their geological significance are as follows:

Horizon b Top of Precambrian basement; basement may also include some Palaeozoic or Proterozoic sediments in the west of the sub-basin.

Horizon j Top of Valanginian (?and older, perhaps Jurassic) syn-rift section.

Horizon n Top of Hauterivian sand-prone section identified as the principal exploration target in the Eyre Sub-basin; part of the rift-fill section; minor decollement surface.

Horizon a Top of the thick Barremian-earliest Aptian rift-fill section and end of the main phase of non-marine sedimentation.

Horizon t Major unconformity separating thick, eroded, mid-Cretaceous marine section (?early sag phase) from Tertiary prograding units; upper limit of sedimentary faulting.

Horizon e	Early Eocene horizon marking the top of a discrete prograding package; while this unit is probably of minor importance, it should be noted that it does contain a distinct 'flat spot' (Fig. 46.3).
Horizon **wb**	Seabed

The following seismic intervals were mapped:

Horizons **b-wb** -	Total sediment thickness
Horizons **b-a** -	Total ?pre-breakup, non-marine section
Horizons **a-wb** -	Total ?pre- and post-breakup, marine section
Horizons **b-j** -	Valanginian and older syn-rift section
Horizons **j-n** -	Hauterivian rift-fill section
Horizons **t-wb** -	Tertiary section (including Paleocene prograding unit); primarily open-marine carbonates

Seismic stratigraphic characteristics of the mapped seismic reflectors and intervals are shown in Table 3.

iv) Structure and Evolution

Basement

The Eyre Sub-basin is the only deep-water sediment accumulation in the GAB in which basement is mappable everywhere. Consequently, it is also the only area where basin-forming structures can be unmistakably identified.

As outlined previously, the Eyre Sub-basin developed over the most northerly of the half-grabens on the seaward side of a major crustal detachment fault. While the northern margin of the sub-basin has a gross east-west trend, it also displays northwest-southeast offsets at interpreted transfer faults. It is apparent from the structural elements map of the GAB (Fig. 9.1) that while the extension direction in the western GAB is NW-SE to NNW-SSE, the northern margins of the Eyre Sub-basin and Polda Trough are co-linear. We suggest that the eastern (Proterozoic-Palaeozoic) end of the Polda Trough developed along an old line of crustal weakness in the craton. Subsequent reactivation of this line of weakness in the ?Jurassic-Early Cretaceous may have then led to development of the western end of the Polda Trough, the Eyre Sub-basin, and the northern margin of the Ceduna Sub-basin. A corollary of this observation is that it is possible that eastern Polda Trough sediment equivalents may also floor the Eyre Sub-basin and the northern Ceduna Sub-basin (either deep within the half-grabens, or more likely, incorporated in the top of the basement blocks).

The southern flank of the Eyre Sub-basin is formed by a high-standing, east-northeast trending eroded basement block. The seaward flank of this block, interpreted to be the head-wall fault of the Recherche Sub-basin underlying the continental rise, has been postulated to be a fundamental branch of the main detachment fault (Etheridge & others, in press). The southern basement block becomes progessively

TABLE 3: Eyre Sub-basin - Seismic Sequence Characteristics

Horizon	Upper Boundary	Lower Boundary	Internal Configuration	Age	Facies	Comments
wb						
	concordant - erosional	downlap - concordant	continuous wedge; medium-high amplitudes	Middle Eocene - Recent	open-marine carbonates	
e						
	concordant	downlap - concordant	prograding wedge; high continuity and amplitude	Paleocene - Early Eocene	shelfal	thin porous sand
t						
	erosional truncation	downlap - onlap - concordant	sheet drape; thin prograding wedge at base; medium-high continuity; low-medium amplitude	Albian - Cenomanian	near-shore marine	onset of marine conditions
a						
	mildly erosional	onlap - concordant	sheet drape; mixed amplitude, variable continuity	Barremian	continental (late rift-fill)	
n						
	mildly erosional - concordant	concordant, some onlap	sheet drape; mixed amplitude, low continuity; prograding wedge in W	late Valanginian - Hauterivian	continental rift-fill (?lacustrine)	good reservoir section
j						
	mildly erosional - concordant	onlap - concordant	low-frequency wedge; low continuity, variable amplitude	Berriasian - Valanginian (?Jurassic in grabens)	syn-rift (?lacustrine)	potential source interval; major extension period
b						
	erosional		acoustic basement	Precambrian (?some Palaeozoic)	crystalline rocks	

narrower, more fractured by faulting, and deeper to the east. It is interpreted to merge with the head-wall fault on the northern margin of the Ceduna Sub-basin at about 130°E.

The western and eastern terminations of the Eyre Sub-basin are somewhat more difficult to define. In the west, the sub-basin first appears as a narrow half-graben within Precambrian basement; we postulate that it terminates at a series of transfer faults that are collinear with the NW-SE oriented transfer faults observed in the major head-wall fault above the Recherche Sub-basin (Fig. 9.1). To the east, the Eyre Sub-basin appears to be contiguous with the Recherche and Ceduna Sub-basins above the deepening basement of the southern flanking block; consequently, the boundary is somewhat arbitrary.

In map view (Fig. 40.1), several intra-basement trends and structures are readily apparent. The western two-thirds of the sub-basin is dominated by ENE-WSW trends, the interpreted strike direction for basin extension. These trends are offset by short, approximately NW-SE segments, interpreted to be the expression of transfer faults. The western sub-basin consists of two major half-grabens separated by a rotated and eroded basement block, the 'Wombat' Structure (Bein & Taylor, 1981). The southern flank of the Wombat Structure is a fault zone comprising a complex array of major and minor bifurcating faults, with a combined maximum throw of about 3 s TWT (*ca* 4000 m). The northern half-graben is narrower and shallower than that to the south, and contains a maximum of more than 2 s TWT (*ca* 3000 m) of sediment. It pinches out against the northern bounding fault at about line E79A-35, where the Wombat Structure merges with the northern shallow basement. This feature is analogous to the way in which the southern basement basement high appears to merge with the northern margin of the Ceduna Sub-basin.

The southern, major half-graben contains up to 3.5 s TWT (>5000 m) of sediment and is quite complex in detail, particularly in the west. The basement surface within this half-graben has been extensively splintered by relatively minor faulting with generally NE-SW to ENE-WSW trends. The Jerboa Structure is one of these splinters of basement that has been 'popped up'.

East of line E79A-25, the structure of the southern half-graben changes noticably. Here it becomes broader and less intensely faulted; conversely, the seaward flank of the southern basement high becomes more highly structured than it is to the west.

East of line E79A-45, a strong east-west basement trend becomes dominant. The southern basement high rapidly deepens and becomes incorporated in a generally highly-faulted, basement monocline at the eastern end of the basin. The reasons for this major trend change are not obvious; however, two observations can be made. Firstly, it coincides with an apparently major transfer fault/accommodation zone (the Southwest Ceduna Accommodation Zone; Fig. 9.1). Secondly, the character of the northern basin boundary changes markedly from a simple, and usually single normal fault in the west, to a basement hinge and a series of smaller, sown-to-the-south thrown faults to the east. It may be that the change is due to the merging of the Jurassic extensional fault direction with the strong east-west Polda Trough-northern Eyre Sub-basin lineament. The strong similarity in the pattern of basement trends with the Bremer Basin to the west should also be noted.

Sedimentary Section

The earliest syn-rift sediment in the Eyre Sub-basin is interpreted to be of ?Late Jurassic-Early Cretaceous (possibly older than the deepest sediment penetrated at Jerboa-1). This section is concentrated in two apparently discrete, elongate depocentres that follow the axes of the two underlying half-grabens in the west of the sub-basin (Fig. 43.2). The section is classically syn-rift in profile, thickening northwards, and onlapping the basement surface in the south and the fault plane in the north of each half-graben.

The syn-rift section is interpreted to have been deposited in two large (150x20 km and 80x15 km) ENE-trending ?intermontane rift lakes that were probably separated by a major geomorphic ridge (Wombat Structure), but may have been connected in the west. They appear to have drained to the east through the more southerly lake. The interpreted depositional environment (?deep lacustrine) and likely warm climate in this area during the Jurassic to Early Cretaceous, are considered to be propitious for source rock development. Other sedimentary facies present probably include coarse fluvial clastics adjacent to the fault scarp on the northern side of each lake and adjacent to orthogonal transfer faults. While such clastics are likely to be poorly-sorted, it is likely that they have some reservoir potential.

Continental extension appears from the seismic data to have been substantially complete by horizon j time. The section between horizons j and n (Hauterivian) is far more extensive than the underlying sequence and probably represents the first stage of rift fill (Fig. 44.1). Subsidence of the rift valley (?post-rift phase cooling plus sediment loading from the syn-rift section) allowed the deposition of a thin blanket of sand-prone sediments that have excellent reservoir properties at Jerboa-1. Erosion and/or subsidence led to the original two Jurassic depocentres coalescing across the western end of the Wombat structure, although the structure still provided an intervening ridge to the northeast (though more subdued than previously). The Hauterivian section is quite uniform in thickness at around 0.2 s TWT (250-300 m) except in the far west of the sub-basin where a 0.5 s thick section prograded eastwards from basement across the underlying horizon j.

During the Barremian (horizons a-n; Fig. 41.2), a thick, rift-fill sequence of non-marine claystones and siltstones was deposited over a continually subsiding rift valley. The section is areally more widespread than the Hauterivian, but is still absent from the high basement areas in the north, west, and south. For the first time, the Wombat Structure is completely buried. The depositional system was probably a broad (50 km-wide), rift valley with subdued topography surrounded on three sides by exposed basement that had been eroded down to be not much higher than the valley floor. Individual depositional environments are interpreted to include shallow lacustrine, and mature fluvial/floodplain. The structure map at early Albian time indicates that drainage continued to be generally eastwards, probably into a shallow sea overlying the Recherche Sub-basin to the south. The Barremian section varies in thickness from 0.2 s TWT (*ca* 300 m) in the west to a fairly uniform 0.5 s (*ca* 750 m) in the central and eastern parts of the sub-basin.

Isopachs of the total non-marine section (horizons a-b; Fig. 44.2) show a strong correlation of sediment thickness with the underlying basement topography. The section is thickest adjacent to the basement fault scarp (>2 s TWT; >3000 m) where the Wombat structure merges with the northern basin margin, and averages 0.5-1.5 s (700-2200 m)in thickness over most of the sub-basin.

From horizon a onwards, the section at Jerboa-1, and presumably throughout the Eyre Sub-basin, is exclusively marine. The base of this marine section throughout the sub-basin is a thin (~0.1 s TWT; 100-150 m) prograding sequence bound by strong reflectors (Fig. 47.1).

Between the Albian and the overlying and onlapping Cenomanian marine section is a time break of some 3 Ma. This break possibly correlates with the 95 Ma breakup age for the Southern Ocean interpreted by Veevers (1986), and it is tempting to refer to it as a breakup unconformity. In this report, the base of the Albian sequence has been mapped as it is more readily identified than the unconformity at the top of the sequence. However, the sequence is uniformly thin, and a structure map of horizon a is probably a close approximation to a breakup structure map.

Subsequent to the Albian transgressive sequence, a thick section of Cenomanian near-shore sediments was deposited. This section forms a seawards-thickening wedge across the monocline in the east of the sub-basin, ranging from 0.1-0.2 s TWT (150-250 m) thick in the north, where it onlaps basement, to about 0.6 s (*ca* 800 m) thick in the south (Fig. 46.4). In the west of the sub-basin it forms a blanket, onlapping basement in the north, that varies in thickness from approximately 0.3 s (*ca* 400 m) over the northern half-graben to ~0.6 s (*ca* 800 m) over the southern half-graben. This variation in thickness can be ascribed to differential subsidence, a notion which is strongly supported by the prolific small-scale faulting of the Cenomanian section. These faults, typically with throws of a few tens of metres, are most common above the crests of deep fault blocks, but can also be seen away from basement highs where they appear to sole out at about horizon n.

The top of the Cenomanian section is a major, basin-wide, erosional unconformity, particularly evident above areas of high basement (Fig. 47.1). Sediment dates at Jerboa-1 indicate that this unconformity spans about 40 Ma. While it has been suggested that this unconformity, which was once labeled as the breakup unconformity, may be due to deep ocean currents, its seismic expression is more suggestive of wave-base erosion. If this interpretation is correct, then it follows that a large part of the southern margin (including much of the Ceduna Sub-basin) was held at or above sea level for a long period in the Late Cretaceous subsequent to supposed margin breakup.

Tertiary sedimentation can be divided into two phases. In the Paleocene-Early Eocene a thin, shelfal, prograding unit of sandy facies was deposited across the northern half of the sub-basin. This sequence averages 0.1-0.2 s TWT (100-200 m) in thickness, and frequently shows a mounded high (?bar) at the palaeo-shelf edge. As previously alluded, a distinct flat spot is seen at the top of this sequence above a basement fault on one line (Fig. 46.3). An erosional phase, interpreted as Early Eocene to early Middle Eocene age by Bein & Taylor (1981), resulted in channels cutting through the Paleocene prograding unit and deep into the Cretaceous section at the eastern end of the sub-basin. Carbonate sedimentation subsequently became dominant in the Middle Eocene, and has continued throughout the Tertiary and Quaternary.

d) BIGHT BASIN - RECHERCHE SUB-BASIN

i) Introduction

The Recherche Sub-basin comprises that part of the Bight Basin underlying the broad continental rise on the western side of the GAB in water depths ranging from 3000 to 5000+ m (Figs 9.1 & 48.1). Although the extreme water depths make the sub-basin of no direct exploration interest for a long time to come, it is included in this study as it provides valuable information on the evolution of the GAB as a whole, and hence on the formation of the basins of exploration interest. It is separated from the Eyre Sub-basin to the north by the outer basement block of that sub-basin, and from the Ceduna Sub-basin to the east by the Southwest Ceduna Accommodation Zone underlying the southwest flank of the Ceduna Terrace. The southern limit of the Recherche Sub-basin is taken as the continent-ocean boundary as defined by Veevers (1986) at about 35°30'S and its western extent is somewhat arbitrarily taken at 125°E. The total area of the sub-basin, east of 125°E is approximately 80000 km^2 (comparable to the Ceduna Sub-basin) and it contains up to 8000 m of interpreted sedimentary section.

The existence of a broad continental rise (*ca* 200 km wide) in the western GAB has been known for a long time, as has the presence of a thick sedimentary section underlying it (Willcox, 1978). Seismic coverage is sparse, with the best data available coming from the Shell *Petrel* roving scientific survey and BMR *Rig Seismic* Survey 65; the average spacing of these lines is about 35 km, and large areas of the sub-basin have no seismic coverage at all (Fig. 48.2). Other data include reflection seismic, gravity, and magnetic data from Surveys 16 and 19 of the BMR Continental Margin Survey (CGG, 1975) and from cruises of the Lamont-Doherty Geological research vessels *Eltanin* and *Vema* in the 1960's and 1970's, and a series of crustal refraction stations recorded during Vema Cruise 33, Leg 3 in early 1976 (Talwani & others, 1979).

ii) Horizons and Intervals Identified and Mapped

While a number of seismic horizons can be identified within the Recherche Sub-basin, estimates of their ages depend on very tenuous ties back to Jerboa-1 in the Eyre Sub-basin and Potoroo-1 in the Ceduna Sub-basin. Lithologies and environments of deposition can only be estimated on the basis of seismic character and interpreted tectonic evolution.

The following horizons have been identified; only horizon n has been mapped (Figs 48.3 & 48.4):

Horizon b Top of Precambrian basement; only identified along the northern margin where the Recherche Sub-basin abuts the basement scarp below the Eyre Sub-basin; tentative identification of the first rotated basement fault blocks south of the scarp.

Horizon j Top of ?Jurassic-Valanginian syn-rift section; identified at the northern margin of the sub-basin where it in-fills the trough between the basement scarp and first rotated block

(Fig. 49.3); fades out about 50 km into the sub-basin.

Horizon **n** Prominent, basin-wide, flat-lying, south or southwest-dipping horizon that separates an underlying seismically featureless section from the overlying 'layer-cake' geology; major decollement surface around sub-basin margins; interpreted to be late Hauterivian age (as at Jerboa-1).

Horizon **a** Lies near the top of a broad band of reflectors of high continuity, interpreted as shallow-marine sediments of Albian age; tentative identification over limited areas.

Horizon **d** Prominent regional reflector; erosional surface above positive structures in the east of the sub-basin.

Horizon **c/td** Top of layer-cake geology with prominent onlapping, semi-transparent section above; correlative of entire Santonian-Campanian delta in southwest Ceduna Sub-basin.

Horizon **t** Base of Tertiary unconformity; frequently crops out at seabed, and dating is uncertain.

Horizon **wb** Seabed.

The only seismic interval mapped in this report is from wb-n, corresponding approximately to the post-western margin breakup interval. Most intervals between n and t have a 'layer-cake' appearance and show little variation in thickness, except around the margins of the sub-basin where slump, nappe, and rift in-fill structures cause major thickness variations; however, the line separation of the available data does not permit meaningful mapping.

Seismic stratigraphic characteristics of the seismic horizons and intervals are shown in Table 4.

iii) Structure and Evolution

It is believed that the Recherche Sub-basin formed over extremely thinned crust when the Antarctic 'upper plate' margin was pulled off the Australian 'lower plate' margin, probably in the Jurassic to earliest Cretaceous. Continental extension of 200-400% in this area has been computed (Etheridge & others, in press). Evidence for this extensional episode can be seen along the northern margin of the sub-basin where the first rotated basement fault block of interpreted upper crustal origin lies down-dip of the major fault scarp underlying the lower continental slope (Fig. 49.3). Etheridge & others (in press) interpreted the lower slope fault to be a fundamental branch of the main detachment fault that currently lies at about 15 km depth. Although basement blocks to the south are only expressed as 'shadow' zones in the seismic data, they are interpreted to become progressively more strongly rotated to the south. In the extreme case, beneath the southern half of the Recherche Sub-basin, these upper crustal blocks are either lying on their sides or have been completely stripped off. Also visible along the northern margin of the sub-basin are a number of orthogonal transfer faults (Fig. 49.4); these have a strong local controlling effect on the syn-rift and rift-fill sedimentation. At the southern margin of the sub-basin, basement gradually shallows, and in places crops out at seabed at a basement hummock that Veevers (1986) has interpreted as the continent-ocean boundary (COB). While this hummock is shown as the southern limit of the Recherche Sub-basin in Figure 9.1, we are by no means confident that it can be interpreted as the COB.

The first phase of sedimentation in the sub-basin saw the deposition of a widespread seismically-featureless unit that is assessed to be from 2000-4000 m thick (pre-horizon j; Figs 49.3 & 49.5). Where it is seen to fill in the structural lows between basement blocks and the northern boundary scarp, this sequence has definite syn-rift affinities. It is likely that the sequence was deposited while rapid extension was proceeding, and that a combination of underlying basement movements and high heatflow through extremely thin lower crust caused induration of the sediments and hence their almost reflection-free character. An alternative, but probably less-likely interpretation is that the pre-horizon j section is the remnant of an older intra-cratonic basin, somewhat akin to the basins of central Australia. In this case, the seismic character of the sequence may be ascribed to the antiquity of the sediments.

The most prominent seismic horizon throughout the Recherche Sub-basin is horizon n. On the basis of tenuous seismic ties back to Jerboa-1 and Potoroo-1, it is interpreted to be of Hauterivian age, as in the Eyre and Ceduna Sub-basins. This horizon is remarkably flat and unstructured and has a gentle south or southwestwards dip over the entire sub-basin. To the north it onlaps the basement scarp, while to the east it appears to continue into the Ceduna Sub-basin, with some disruption across the Southwest Ceduna Accommodation Zone. To the south, the horizon appears to onlap the basement hummock at the interpreted COB, and is interpreted to be present within the sedimentary column south of this hummock. This has profound implications for the interpretation of the 'continent-ocean boundary'. There are two main possibilities -

1) The interpretation of the basement hummock (and associated magnetic anomaly) by Veevers (1986) is incorrect, and the crust south of the 'COB' is actually highly-extended continental crust. This finds support in migrated seismic data from south of the Ceduna Terrace (lines 65-14P2 and 65-15P1 & 2) that we believe show evidence of a metamorphic core complex south of Veevers' COB (Willcox & others, 1989).

2) Sea-floor spreading in the Great Australian Bight actually took place in two distinct phases, with the first phase being very limited spreading that started at the same time as spreading off west and southwest Australia (Neocomian, 120-125 Ma). This notion is supported by the observations that the extension direction in the western GAB is similar to that off Western Australia (implying that the extensional phases in the two areas may have been due to the same stress regime), and that horizon n, dated as approximately 120 Ma in the Eyre Sub-basin, obviously marks a major geological boundary in the seismic data throughout the western GAB. In addition, these authors believe that the current interpretation of the oldest magnetic spreading anomalies in this area is far from definitive, with many anomalies being very poorly defined. In this interpretation, horizon n could be equated with a western margin 'breakup' unconformity.

It is possible that the interpretation of horizon n as being of Hauterivian age may be incorrect. However, it does not appear possible

TABLE 4: Recherche Sub-basin - Seismic Sequence Characteristics

Horizon	Upper Boundary	Lower Boundary	Internal Configuration	Age	Facies	Comments
wb						
	probably erosional	onlap - concordant	erosional remnants (mounds); low amplitude, moderate continuity	Tertiary	pelagic (siliceous ooze)	largely absent, either due to submarine erosion or non-deposition
t						
	erosional truncation	onlap - concordant	sheet drape; low amplitude, moderate continuity	Campanian - Maastrichtian	paralic - shallow marine	
c/td						
	mildly erosional	onlap - concordant	sheet drape; variable amplitude & continuity	Turonian - Santonian	paralic - shallow marine	
d						
	erosional - concordant	onlap - concordant	sheet drape; low amplitude, moderate continuity	Albian - Cenomanian	paralic - shallow marine	
a						
	erosional - concordant	onlap - concordant	sheet drape; low & high amplitude, high continuity	Barremian	rift-fill; possibly shallow marine	top of interval may equate with Southern Ocean breakup
n						

TABLE 4 (cont.)

Horizon	Upper Boundary	Lower Boundary	Internal Configuration	Age	Facies	Comments
n						
	mildly erosional	?onlap	basin-thickening wedge; variable amplitude, high continuity	Hauterivian	?syn-rift - rift-fill	top of interval may equate with western margin breakup
j						
	?concordant - erosional	onlap at northern margin; obscured elsewhere	?basin-thickening wedge; very low amplitude & continuity	?Jurassic - Valanginian	syn-rift (possibly also infra-rift or intra-cratonic	?indurated; possible old ?Palaeozoic basin
b						
	erosional		acoustic basement	Precambrian	crystalline basement	

to ascribe to it an age younger than 95 Ma (Cenomanian), which is necessary if the crust south of the 'COB' is indeed oceanic crust emplaced during slow spreading subsequent to Cenomanian breakup.

The environment of deposition for the pre-horizon n sequences is difficult to assess, as there are no obvious present-day analogies of the western Bight Basin. Our interpretation that continental extension was substantially complete by horizon j time indicates that the northern margin of the Recherche Sub-basin was a major scarp, several thousand metres in height, and that the Eyre Sub-basin was therefore formed as an intermontane basin. Given the extreme thinning of the crust beneath the Recherche Sub-basin, it is entirely possible that depositional conditions were shallow-marine during the Neocomian, particularly considering the onset of western margin seafloor spreading.

The sedimentary section from horizons n to c/td is quite uniform in seismic character, except at the sub-basin margins. This section, some 3-4000 m thick, comprises 'layer-cake' geology in a gross, basin-thickening wedge, with individual sequences generally showing only minor variations in thickness. The internal seismic character of the sequences indicates that deposition was probably largely continental-paralic with periodic marine incursions represented by areally-extensive bands of high-continuity, moderate-amplitude reflectors. These interpreted incursions are particularly prominent immediately above and below horizons n and a, and are possibly related to western margin and Southern Ocean breakup, respectively. It is envisaged that sedimentation was taking place within a broad (300-400 km wide) rift valley, probably with a narrow and restricted ocean basin at its centre extending as far east as the western Otway Basin. A possible present-data analogy is the Red Sea. Subsidence of the rift floor was at a fairly steady rate due to sediment loading and possibly due to thermal sag following the western margin-early Southern Ocean spreading.

The only exception to the layer-cake character of the section is around the sub-basin margins, where horizon n has acted as a decollement surface upon which the sequences between horizons n and d have slipped. South of the Eyre Sub-basin, this slippage appears as highly rotated listric faults in the sequence n-a above a southwards-inclined horizon n (Fig. 49.3). Adjacent to the bounding basement fault scarp, the slippage is so extensive that the sequence n-a may be entirely absent. Adjacent to the Southwest Ceduna Accommodation Zone, the slippage is expressed as a broad (up to 100 km wide) belt of 'nappe' structures underlying the lower slope below the Ceduna Terrace (Figs 9.1 & 49.2). Individual nappes are oriented approximately northwest-southeast, indicating compression from the northeast. Movement of the sediments started at about horizon a time (Albian) and continued until about horizon d (Cenomanian) when the tops of the most elevated nappes were eroded off, apparently at wave base. We suggest three alternatives for formation of the nappe structures:

1) They are toe-thrusts of listric faults that originate on the Ceduna Terrace (Boeuf & Doust, 1975). Against this it can be argued that the average trend of the nappes (NW-SE) is at variance with the trend of the Cenomanian faults that presumably give rise to them (WNW-ESE; Fraser & Tilbury, 1979).

2) The nappes have formed by the gravity sliding or compression of incompetent ?marine sediments above a hard sub-strate (horizon n). This sliding may be due to a southwestwards

incline on horizon n (gravity sliding) or to compression caused by the excess Upper Cretaceous sediment load within the Ceduna Sub-basin. Arguments against this alternative are, firstly, that horizon n is currently deeper beneath the Ceduna Sub-basin than it is beneath the Recherche Sub-basin (though this may change when sediment loading effects are removed) and, secondly, that movement of the nappes was substantially complete by horizon d, at which time sediment thickness beneath the Ceduna and Recherche Sub-basins was comparable.

3) The nappes may have formed as the shallow expression in incompetent sediments of transpressional left-lateral motion along the proposed Southwest Ceduna Accommodation Zone, both prior and subsequent to Cenomanian Southern Ocean breakup. This finds some support in the dual observations that the most intense overthrusting occurs above the presumed location of the accommodation zone, and that the nappe belt follows the accommodation zone for a considerable distance.

Subsequent to horizon c/td (correlative to the entire delta sequence of the Ceduna Sub-basin), two distinct sequences have been deposited in the Recherche Sub-basin. Between horizons c/td and t (Early Tertiary) is a *ca* 500 m-thick flat-lying sequence that onlaps the underlying inclined strata and has all the hallmarks of a pelagic ooze section. It is likely that a substantial part of this sequence at the sub-basin margins is derived from erosion of the contemporaneous section that was eroded from the Eyre Sub-basin and the outer part of the Ceduna Sub-basin. During the Tertiary, the entire southern margin has been relatively sediment-starved. This is particularly evident in the Recherche Sub-basin where the entire Tertiary section is represented by thin and erratically-distributed mounds of pelagic sediments (sequence t-wb).

e) POLDA TROUGH

i) Introduction

The Polda Trough (also known as the Polda Basin) is an elongate east-west trending trough that extends for at least 350 km from the Eyre Peninsula in the east to the centre of the Great Australian Bight in the west, where it debouches into the Ceduna Sub-basin of the Bight Basin. The trough ranges from 10-40 km in width (an average of 30 km), has an overall area of about 10000 km, and contains at least 5000 m of Proterozoic-Tertiary sedimentary fill. Water depths are generally from 50-100 m, with a maximum depth of 200 m at the western end of the trough. Although the Polda Trough is basically an intra-cratonic feature, its antiquity is such that it bears the marks of several phases of tectonism, with the most recent phase being the separation of Australia and Antarctica in the Cretaceous.

The Polda Trough was first recognised as a geological entity in 1966, following an aeromagnetic survey flown for Shell Development (Australia) and Outback Oil. Initially, the feature was known as the Elliston Trough, to distinguish it from the previously identified 'Polda Basin', an onshore infra-basin containing Jurassic-Tertiary sediments.

This report will follow Nelson & others (1986), in referring to the total area of sedimentation, onshore and offshore, as the Polda Trough.

From 1966-69, Shell shot approximately 2100 km of reflection and refraction seismic data in the general area, before deciding to concentrate their efforts on the deeper water GAB to the south. Bridge Oil was granted the Polda Trough lease in 1969, and two further seismic surveys, totaling 2131 km, were recorded in 1970 and 1971. Although drilling targets were identified, no drilling took place until 1975, when Outback Oil took over the lease and drilled Gemini-1; this well reached a TD of 894 m in a volcanic boulder, that was at the time interpreted as basement.

In 1978, Outback Oil carried out a detailed aeromagnetic survey, re-processed some of the 1970-71 seismic data, and re-interpreted all the available data. As a result of this re-appraisal, Australian Occidental farmed into the lease and subsequently shot a further 3213 km of relatively good-quality seismic data in 1980-81 and drilled the wells Mercury-1 and Columbia-1 in 1981-82. Both wells were plugged and abandoned as dry holes at TDs of 3251 and 2168 m, respectively, in sediments of ?Proterozoic age. Since 1982, exploration in the Polda Trough has been dormant, with the exception of 7 reflection seismic lines recorded across the western end of the trough on the R/V *Rig Seismic* during BMR Survey 65 in late 1986.

ii) Stratigraphy

The stratigraphy of the offshore part of the Polda Trough is known from three wells - Gemini-1, Mercury-1, and Columbia-1. Gemini-1 and Mercury-1 were drilled on anticlinal closures induced by salt mobilisation at depth, while Columbia-1 tested the pre-Jurassic sediments of a horst-like structure. As noted previously, Gemini-1 was prematurely terminated at a TD of 894 m on encountering a large volcanic boulder. Gemini-1 penetrated a thick Upper Jurassic sequence of poorly-consolidated clastics, including coals, and a thin underlying sequence of sand to grit, interpreted to be of Permo-Carboniferous age. Mercury-1 and Columbia-1, however, while not reaching basement, did penetrate a thick sequence of ?Proterozoic sediments before being abandoned; these wells are considered to have sampled a representative Polda Trough section (Figs 57.1 & 57.2; McClure, 1982a, 1982b).

Although correlation of the older part of the section between Mercury-1 and Columbia-1 is tentative, due to the intense sedimentary structuring and the frequently indifferent quality of the seismic data, it appears that both wells bottomed in sediments of similar age. From TD to 771 m KB in Columbia-1 and to approximately 900 m in Mercury-1, the section consisted largely of a thick sequence of red beds, underlain by massive white sandstone and siliceous siltstone. The major difference between the sections at the two wells is the presence of approximately 1270 m of massive halite, in the form of salt pillows, at Mercury-1; no halite was encountered at Columbia-1. Red beds, interbedded with the halite, are interpreted to have been 'rafted in' at the time of salt mobilisation (McClure, 1982a). The highly-oxidised nature of the red beds precludes definitive dating. However, comparison of the section with that onshore (*eg* at CRA 83 KD1A, Fig. 56.2) suggests that the section consists of equivalents of the Kilroo Formation, and is therefore of Late Proterozoic age.

At both Columbia-1 and Mercury-1, the top of the red bed sequence is marked by a prominent unconformity with an overlying sequence of Permo-Carboniferous glacigene sediments of the Coolardie Formation. This sequence, 65 m thick at Mercury-1 and 87 m thick at Columbia-1, consists of siltstone, claystone, and conglomerate and can be termed a diamictite. The Coolardie Formation forms a widespread veneer in the Polda Trough, but is typically difficult to separate from the overlying section in the seismic data.

The Upper Jurassic Polda Formation is about 450-500 m thick at both Columbia-1 and Mercury-1, but is highly variable in thickness throughout most of the Polda Trough, due to the strong relief at the top of the underlying Proterozoic red beds. The lower part of this unit is largely sand-prone, with some interbedded coal units, while the upper part consists of claystone, siltstone, and fining-upwards sandstone. Depositional environments at Mercury-1 are considered to be fluviatile, while the westwards-prograding character of the sediment package east of the well is suggestive of a shallow lacustrine environment (Fig. 56.1, line AP81-02).

The base of the flat-lying Tertiary section (Poelpena Formation) is marked by a strong angular unconformity with the underlying Upper Jurassic section. While the Tertiary section was not sampled at either well, by comparison with the same interval elsewhere, it is likely to consist of poorly-consolidated, open-marine carbonates.

iii) Horizons and Intervals Identified and Mapped

The principal geological sequences identified in Mercury-1 and Columbia-1 can be mapped throughout the Polda Trough, with varying degrees of confidence. The horizons selected for mapping and their geological significance are as follows:

Horizon b — Top of crystalline basement; this horizon is extremely difficult to pick within the Polda Trough and basement maps must be considered somewhat speculative.

Horizon lp — Intra-Late Proterozoic - this horizon may be mapped with higher confidence than basement over most of the trough. The horizon is a fairly strong, continuous reflector except in areas of intense structuring in the central basin deep and areas of post-horizon lp salt tectonism, which together have given rise to processing velocity problems and out-of-the-plane reflections due to high dips.

Horizon pc — Top Precambrian (Top Kilroo Formation); this is the most prominent basin-wide erosional unconformity, separating the strongly-oxidised Precambrian red beds from overlying Permo-Carboniferous glacigene sediments of the Coolardie Formation.

Horizon t — Base of Tertiary; major erosional unconformity separating terrestrially-derived, moderate- to high-energy, Upper Jurassic sediments from quiescent, shallow marine, sediment-starved, carbonate platform deposits of Tertiary age. This reflector is often masked by the water bottom multiple.

The following seismic intervals have been mapped:

Horizons b-lp - Late Proterozoic and older continental sediments; probably equivalent to Blue Range Beds onshore.

Horizons lp-pc - Late Proterozoic continental sediments, including the massive and interbedded halite interval.

Horizons b-pc - Total Precambrian section (Kilroo Formation).

Horizons pc-t - Palaeozoic-Mesozoic section, consisting of a thin veneer of Permo-Carboniferous glacigene sediments (Coolardie Formation) and a thicker Upper Jurassic fluvial and lacustrine section (Polda Formation).

Seismic-stratigraphic characteristics of the mapped seismic reflectors are shown in Table 5.

iv) Structure and Evolution

While Precambrian basement can readily be identified beneath most of the continental shelf in the northeast GAB, it is extremely difficult to map beneath the Polda Trough. A combination of complex basement tectonics, highly structured sediments (including salt mobilisation), ringing from the shallow-water bottom and base Tertiary unconformity, and complex off-side basement reflections does much to disguise basement reflections. As a consequence, the maps and profiles showing basement in the Polda Trough in this report, while broadly correct, should be viewed with caution.

Although most hitherto published maps of the gross architecture of the Polda Trough portray it as a relatively simple east-west trending fault-bounded graben, careful mapping shows that this is not the case. In north-south profiles (Fig. 56.3), east-west profile (Fig. 55.1), and map view (Figs 50.2 & 51.2), the trough is seen to consist of several discrete depocentres bound by a complex of faults of varying style and orientation.

In east-west profile (Fig. 55.1), the Polda Trough appears to comprise three distinct depocentres, referred to here as the eastern, central, and western Polda Troughs. This section will concentrate primarily on the central and western depocentres. Very briefly, the eastern Polda Trough lies almost entirely onshore, where it contains 1500-2000 m of Proterozoic-Upper Jurassic sediments at its eastern and western ends, but only about 500 m above shoaling basement in the centre. The eastern end of the eastern Polda Trough has been referred to as the Lock Sub-basin. The eastern end of the feature appears to be a monoclinal sag, while its western termination appears to be at a fault system just to the west of the shoreline. This fault system may be collinear with the East Duntroon Accommodation Zone (Fig. 9.1).

The central Polda Trough contains the major sediment body in the basin, with a maximum of ca 5000 m of Proterozoic-Tertiary sediments being interpreted to the west of Mercury-1. This part of the basin is the most intensively explored for hydrocarbons. It is separated from the eastern and western Polda Troughs by faulted shallow basement at a cross trend to the main structural grain (Figs 50.2 & 51.2). The structure of the western Polda Trough is relatively poorly defined as very little modern seismic data is available in this area. The western limit of the Polda Trough is taken as its confluence with the Ceduna Sub-basin of the Bight Basin. However, the prominence of the east-west Polda Trough trend across the northern margins of the Ceduna and Eyre Sub-basins suggests that these Mesozoic features may be underlain by

TABLE 5: Polda Trough - Seismic Sequence Characteristics

Horizon	Upper Boundary	Lower Boundary	Internal Configuration	Age	Facies	Comments
wb						
	concordant	concordant - ?some downlap	high continuity; moderate amplitude; parallel reflectors	Tertiary	open marine carbonates	not sampled in wells
t						
	erosional; rarely concordant	onlap - concordant	low continuity, low-moderate amplitude	Permian - Jurassic	glacial veneer at base; fluvial and lacustrine in remainder of interval	Coolardie Formation; poorly consolidated.
pc						
	erosional - concordant	?concordant - onlap	low continuity, moderate amplitude; some diapirism with internal chaotic reflections	?Late Proterozoic	red beds; massive halite	'upper' Kilroo Formation
lp						
	?erosional - concordant	obscured by multiples	low continuity, mixed amplitudes	?Middle-Late Proterozoic	red beds	'lower' Kilroo Formation (?Blue Range Beds equivalents)
b						
	obscured by multiples		acoustic basement	Archaean	crystalline rocks	Gawler Block

older Polda Trough equivalents (Stagg & others, 1989).

In cross-section, the western and central Polda Troughs have markedly different character. The western Polda Trough is apparently bound by a relatively simple fault system to both north and south (Fig. 56.4), and appears to form a simple graben. The ENE-WSW trend of the major faults (Fig. 50.2) is approximately parallel to the basin forming-trend in the Eyre Sub-basin to the west, leading us to postulate that this part of the trough formed during the Jurassic-Cretaceous extensional episode prior to the breakup of Australia and Antarctica, and hence probably contains a mainly Mesozoic section.

The central Polda Trough has in most previous studies been shown as normally and symmetrically faulted. In this interpretation, only the southern margin seems to fit this picture (Fig. 56.3). The structure of the northern margin is complex, and it appears to be an amalgam of a monocline with normal and wrench faulting; in places, wrenching may have produced reversal on faults. In simplified form, it can be thought of as a half-graben, hinged to the south, and fault-bounded to the north. In map view, while both northern and southern flanks show a strong east-west trend, they also show strong northwest-southeast offsets along interpreted accommodation zones. It is possible that the area of shallow and complex-structured basement at the junction of the western and central Polda Troughs may be a continuation of the East Duntroon Accommodation Zone to the southeast (Fig. 9.1).

Nelson & others (1986) have provided the most comprehensive tectonic history of the Polda Trough, drawing on the previous work of Thompson (1970), Lambeck (1984), and Veevers (1984). We combine their work with an analysis of the structure and isopach maps and interpreted seismic sections presented here (Plates 50-56) to summarise the tectonic and sedimentary history of the Polda Trough as follows.

It has been suggested that the Polda Trough is a member of the family of basins that also includes the Ngalia, Amadeus, and Officer Basins, which are characteristically elongate east-west and, with the intervening areas of uplift, form a series of basins and highs (Thompson, 1970; Nelson & others, 1986). It appears that sedimentation commenced with the deposition of Middle-Upper Proterozoic red beds of the 'lower' Kilroo Formation (possible equivalents of the Blue Range Beds onshore). This sequence is up to 1.4 s TWT (*ca* 2000 m) thick in the eastern half of the central Polda Trough, adjacent to the southern bounding fault. Trends within the sequence appear to largely reflect the underlying east-west basement trend, particularly in the east of the central Polda Trough (Fig. 53.1).

At some time early in the history of the Polda Trough (?Petermann Orogeny; Austin & Williams, 1978; Veevers, 1984), a new stress regime produced northwest-southeast oriented dextral wrenching that gave rise to positive 'flower' structures (Nelson & others figs 17 & 18), offsets in the southern bounding fault (Figs 50.2 & 51.2), and apparently to *en echelon* offsetting of depressions in magnetic basement (Nelson & others, 1986, fig. 3a). These wrench structures have probably been re-activated at later stages in the history of the trough, perhaps as recently as during the Jurassic-Cretaceous rifting.

Sedimentation continued through the Late Proterozoic with the continued deposition of redbeds and the introduction of evaporites. While the original deposition of this sequence (horizons lp-pc; 'upper'

Kilroo Formation) was initially basin-wide, subsequent salt mobilisation has radically altered distribution, with the bulk of the sequence being concentrated in a northwest-southeast trending belt of sediments up to 1.3 s TWT (*ca* 2000 m) thick across the central Polda Trough (Fig. 53.1). The massive salt deposits appear to be restricted to areas where the total thickness of the 'upper' Kilroo Formation is greater than 0.9 s TWT (*ca* 1400 m).

Mobilisation of halite appears to have taken place over quite a long period of time, and possibly in two phases. Since most of the relief at the top Kilroo (horizon lp) level is salt-induced and the structural highs are strongly eroded, we suggest that the first and major mobilisation phase took place prior to deposition of the Coolardie Formation. However, structuring within the overlying Coolardie and Upper Jurassic Polda Formations also appears to be due to halite movement, and we conclude that mobilisation continued during the deposition of these units.

A major basin-wide erosional hiatus occurs between the top of the Precambrian section and the thin glacigene sediments of the Permo-Carboniferous Coolardie Formation. These sediments are uniformly thin, and consist of a veneer of coarse glacigene sediments up to ~100 m thick, that are correlatable with those of the St Vincent and Arckaringa Basins (Nelson & others, 1986). The Upper Jurassic Polda Formation has subsequently filled in the structural lows in the Kilroo-Coolardie Formations and is as much as 1 s TWT (*ca* 1500 m) thick, though the average is nearer 0.5-0.6 s TWT (700-800 m). While this sequence was largely of fluviatile origin in the wells, low-relief westwards-prograding foresets (*eg* line AP81-02, SPs 700-900, Fig. 56.1) suggest shallow lacustrine conditions. These Jurassic sediments are probably correlatable with the oldest syn-rift sediments of the Ceduna and Eyre Sub-basins, and possibly constitute a major part of the sedimentary fill of the western Polda Trough.

No younger Mesozoic sediments have been penetrated in the wells, and the seismic data suggest that the Cretaceous is probably entirely absent from the central Polda Trough. The Mesozoic sediments are terminated by a major erosional unconformity, as in the outer parts of the Ceduna and Eyre Sub-basins, with the Tertiary forming a thin (<0.2 s TWT, <200 m) veneer of carbonates and sands, blanketing both the trough and the adjacent basement.

f) DENMAN AND EUCLA BASINS

i) Introduction

In the offshore platform area north of the Bight Basin at approximately 33°N (Fig. 9.1), the rifting and separation events of the Southern Rift System have had no apparent effect. Here the basement is shallow, dips gently to the south, and is generally highly eroded. Within this area gentle sags or depressions have formed, with enhanced local relief due to faulting. In the deepest trough/depression, at approximately 31-33°S and 130-131°E, Permian sediments have been deposited, as intersected in the Apollo-1 and Mallabie-1 wells. The extent of these sediments defines the Denman Basin.

Overlying the Denman Basin is a more extensive sequence of Cretaceous and Tertiary sediments which complete the infilling of the depressions in the platform basement rocks and defines the Eucla Basin. The Cretaceous sediments are condensed in character due to their deposition on a persistent shallow platform quite different from the Cretaceous rift sequence of the Bight Basin

Due to the superimposed nature of the Denman and Eucla Basins, they are discussed together here to provide a more complete picture of the offshore platform geology.

ii) Stratigraphy

Permo-Carboniferous glacial sediments underlying Mesozoic sediments of the Eucla Basin have been assigned to the Denman Basin. These sediments unconformably overlie either Precambrian crystalline basement or ?Cambro-Ordovician sediments.

In Apollo-1, an unnamed succession of interbedded brown- to buff-coloured claystone over the interval 633-858 m has been dated as Permian (Stage 3; Partridge, 1976). Mallabie-1 also intersected 89 m of Lower Permian (Stage 2) sandstones and siltstones. Furthermore, claystones in Nullarbor No 8 Bore have also been dated as Permian (Stage 3; Harris & Ludbrook, 1966).

Cretaceous sediments of the platformal Eucla Basin comprise a condensed unit with only minor palynological breaks, deposited in a by-pass margin as sediment, derived from the interior basins, was dumped into the developing rift valley to the south.

In Apollo-1, the Cretaceous section comprises the 86 m-thick Loongana Formation, which consists of fluvial sandstones and conglomerates with minor carbonaceous shale interbeds, overlain unconformably by the Albian to Cenomanian Madura Formation, which consists of a 153 m-thick succession of paralic to marine sandstone, claystone, and shale. A minor hiatus in the late Albian (Fig. 19.2) may, in fact, result from poor palynological control in the condensed sequence.

The occurrence of dinoflagellates (E. Ludbrookii) confirms a marine influence at Apollo-1 (Forbes & others, 1984). The Madura Formation is therefore equivalent to the condensed Duntroon Group and lower Bight Group in the rift-valley basins. The Madura Formation is, in turn, overlain unconformably by the Middle Eocene Hampton Sandstone and younger carbonates of the Eucla Group.

iii) Seismic Horizons

The area covered in this investigation is shown in Figure 58.1, extending offshore to 33°S latitude between 129°E and 132°E. The lines selected for interpretation (Fig. 58.1) constitute about 75% of the available seismic data in the basin.

The only offshore well in the area to provide geological control is Apollo-1. However, information from Mallabie-1, 6 km onshore, has been used to extrapolate control for the northern part of the area. Drilling data from other onshore wells (Youngs, 1974) have been used to indicate the likely extent of the various rock units.

From Apollo-1, four seismic horizons were selected for mapping to delineate the geometry of both basins, as indicated in Figures 19.2 and 59.2.

Top of Basement - This horizon is clearly seen on all sections as a strong reflection. On some lines, a poor signal wavelet combined with shallow water ringing makes it difficult to pick the horizon to within one cycle. Where Cretaceous and Tertiary sediments onlap basement the angular unconformity is much reduced due to reduced basement relief and very gently dipping nature of the sediments.

Top of Permian - This horizon is characterized by a fair to moderately-strong reflector, with reduced erosional relief, except for a strong Cretaceous erosional channel through the centre of the area. This channel provides a moderately-strong angular unconformity with the overlying Cretaceous reflectors. The horizon occurs within the deeper depressions of the basement. In the southern part of the area, relatively flat-lying reflectors occur in more isolated depressions which could represent either Permian or basal Cretaceous sediments. Due to lack of geological control, the latter interpretation is preferred, but the possibility of a more extensive distribution of Permian sediments cannot be discounted.

Top of Cretaceous - Due to the flat-lying, condensed, and sandy nature of the Cretaceous and Tertiary sediments at this level, the reflector corresponding to this boundary is often difficult to correlate with accuracy. A very thin veneer of Upper Cretaceous sediments occurs in Apollo-1; however they are seismically indiscernible from the Lower Cretaceous sediments. The horizon has very little relief and so any mis-picks were limited in this study to one or two cycles and corrected during mistie analysis. This horizon is most difficult to pick on the early 1967 seismic lines (lines DE-H, J, K, & L in Fig. 58.1), due to poor data quality and ringing from the water bottom and Tertiary carbonates.

Sea Floor - This horizon corresponds to top of Tertiary in the area. The horizon is not visible in the 1972 lines as the processing techniques mute out the strong first breaks to minimize amplitude problems at the top of the section. However, accurate water depths can be obtained from echo sounder data, often annotated at the top of each seismic section.

Details of seismic sequence characteristics of the mapped units are shown in Table 6, whilst a summary of their stratigraphic position, relative to the other basins of the GAB, is included in Figure 19.2.

Correlation of Cretaceous reflectors with horizons mapped in the Bight Basin is hampered by the lack of suitable seismic ties between lines in the offshore Eucla and the Bight Basins. One line parallel to the south end of AP81-41 (Fig. 58.1) indicates that the Top Platypus Horizon (Horizon D of Fraser & Tilbury, 1979) converges with the base of Tertiary horizon (Horizon A) just south of AP81-26C, thereby wedging out most of the Upper Cretaceous sequence. However, it is likely that all units thin and become condensed northward into the shelfal Eucla Basin. Although data quality and ties are poor and the condensed nature of these sediments precludes accurate resolution of unconformities, a

TABLE 6: Offshore Denman/Eucla Basins - Seismic Sequence Characteristics

Horizon	Upper Boundary	Lower Boundary	Internal Configuration	Age	Facies	Comments
Sea-floor						
	?concordant - erosional	onlap - concordant	high-amplitude, parallel reflectors, with minor, low-angle prograding wedges	Eocene - Recent	open marine carbonates with basal marine sand unit	
Top Cretaceous						
	concordant to slight erosional	onlap	high-amplitude parallel reflections	Neocomian - Cenomanian	condensed shelfal and fluvio-deltaic; stronger marine influence at top	partial by-pass margin for sediments transported south into Bight Basin
Top Permian						
	erosional	onlap above erosional unconformity	generally low amplitudes; some moderate amplitude reflectors with limited internal continuity	Early Permian	lacustrine	deposition following glacial period
Basement						
	erosional		strongly diffracting; commonly masked by multiples	Archaean	crystalline rocks	possible Cambrian and Precambrian metasediments near- and onshore

Cretaceous hinge line appears to trend east-west at about 33°20'S.

iv) Depth Conversion

Due to the paucity of seismic velocity information in the area, an average time-depth curve was used to convert seismic travel times to depth. As there was no well velocity survey carried out in Apollo-1, data from Potoroo-1, Jerboa-1 and Mallabie-1 wells were used together with edited seismic reflection velocity analyses to construct an average function of time verses depth. This power curve is mathematically described by:

$$\text{Depth (m)} = 0.494 \times \text{Time (msec)}^{1.1304}$$

The origin for the function is taken at sea floor, whilst the curve is shown graphically in Figure 18.1, together with the well data.

Considering the flat nature of the sea floor and condensed nature of the sediments, use of such a function is considered to provide a reasonable to good spatial depth conversion for each horizon. Contoured depth maps of each horizon and isopach maps of each sedimentary unit have been prepared; pre-Tertiary maps are included as Figures 59.2-61.2, whilst all maps are included in Cockshell (1990b).

v) Structure and Evolution

The overall structure of the Denman Basin is shown by the depth to basement map (Fig. 59.2) and the Permian isopach map (Fig. 61.1). Figure 59.2 shows a north-northwest trending basement depression up to 50 km wide. Numerous faults have been interpreted with a similar north-northwest trend in this area, with most faults having a throw of less than 100 m; only faults with more substantial throw (up to 300 m) are shown in Figure 58.1. While it is difficult to determine whether basement has been faulted or severely eroded by glacial action in the Permian, evidence from other Permian Basins in Australia indicates that most are largely structurally-controlled (Wopfner, 1980). Our interpretation of the Denman Basin is consistent with this, indicating initiation by normal faulting followed by modification by glacial erosion. Considering the general northwesterly movement of Permian ice in southern Australia (Bourman, 1987), it seems likely that glaciers would have been funnelled north-northwestward along this Late Proterozoic-Early Palaeozoic basement low from the Antarctic ice sheet juxtaposed to the south. In the northern onshore part of the basin, Wopfner (1980) suggests that ice-flow was in a west to southwest direction. This was probably due to the influence of westward-flowing ice from an ice sheet located on the Gawler Craton highlands.

The basement is deepest 40 km south of Apollo-1 (1400 m), grading to 600 m in the axis of the Denman Basin close to the shoreline. The flanks of the structure are asymmetric, being less than 200 m deep 100 km east but around 400 m deep a similar distance westward. 10 km north of Apollo-1, a 10 km-wide basement high block causes local bifurcation of the trough which coalesces again 60 km north of the well.

On the western side of the high, the basement is more than 900 m deep, whilst the eastern side is 200 m shallower. The Permian sediments infilling the eastern side of the basin are generally 100-200 m thicker than in the west (Fig. 61.1). Furthermore, severe channeling of the Permian sediments, mainly in the eastern lobe, has occurred during the

Early Cretaceous (Figs 58.1 & 60.1). An example of this is shown on the seismic line DE-128 (Fig. 59.1). These facts indicate that the eastern side of the basement inlier was the main zone of erosional and depositional activity whilst subsequent broad basement sag of 200-300 m has occurred from east to west. The depth to Cretaceous map (Fig. 60.2) shows essentially east-west trending contours. The Cretaceous isopach map (Fig. 61.2) shows slight thickening to the west, indicating that the basement tilt occurred in the late Early Cretaceous and probably into the Late Cretaceous.

Figure 59.2 shows good correlation between seismic and magnetic basement depths, except in the northern part of the Denman Basin. Where the basement depths are in agreement, basement is likely to be Archaean as in Apollo-1. Where the depths differ, seismic basement is likely to be Upper Proterozoic/Lower Palaeozoic non-magnetic sediments while magnetic basement could be Upper Proterozoic/Lower Palaeozoic volcanics or Archaean gneisses, as in Mallabie-1. These discrepancies should be an indication of the thickness of non-magnetic Upper Proterozoic or Lower Palaeozoic sediments (up to 1700 m, 50 km east of Mallabie-1).

The depth map of the top of Permian shows a gradual north-south deepening (Fig. 60.1) from 450 m to 1000 m with little structuring other than Early Cretaceous channelling. The main channel is best-developed southward, from 35 km north to 20 km south of Apollo-1, along the eastern lobe of the basin (Fig. 58.1). 25 km south of Apollo-1, a slight basement rise apparently formed a southern barrier to the distribution of Permian sediments. The top of Permian horizon is little affected by faulting, with the faults present being due to minor re-activation of the underlying basement faults (Fig. 59.1).

Permian sediments of the Denman Basin continue onshore. However, extensive Early Cretaceous erosion may have removed much of these sediments and reduced their distribution to isolated depressions within the Upper Proterozoic-Lower Palaeozoic basement (Youngs, 1974).

The overlying Cretaceous sediments of the Eucla Basin show very little structure and no significant faulting. The flat-lying platform nature of these sediments precludes the determination of seismic stratigraphic characteristics. The top of this section dips gently from 250 m nearshore to 600 m in the south (Fig. 60.2). Approximately 50 km east of Apollo-1, the sediments onlap shallow basement (Fig. 61.2), while 100 km west of the well they become quite thin and appear to be absent in isolated areas (Fig. 61.2). Along the axis of the Denman Basin they gradually thicken from 150 m nearshore toward the south, being thickest (900 m) in the palaeo-channel incised into the Permian sediments. 30 km south of Apollo-1, this Cretaceous palaeo-channel splays outward from the slight basement rise, debouching southward into the developing Bight Basin.

The overlying Tertiary sediments also show a thickening to the south, being 200 m thick nearshore to 500 m in the south. The top of these sediments (seafloor) slopes gently southward to 100 m at 33°S.

g) BREMER BASIN

i) Introduction

The main sedimentary accumulation of the Bremer Basin is almost exclusively confined to the continental slope between 117°E and 121°E (Figs 62.1 & 63.1). The basin has an area of about 9000 km^2, excluding any extension onto the continental rise; this is comparable with the Eyre Sub-basin, with which it shares some common structural trends. While the basin is not, strictly speaking, within the Great Australian Bight, we have included it in this report for two reasons. Firstly, it almost certainly formed during the same extension/rift/drift phase that formed the Bight and Duntroon Basins and hence should have many structural and stratigraphic similarities to those basins. Secondly, in any study of the basins of southwest or southern Australia, the Bremer Basin seems to be omitted - partly because of the lack of data, and partly because of its relative isolation from other basins.

The earliest seismic survey of the Bremer Basin was conducted by Teledyne in 1970, using a sparker energy source with 12-fold CDP coverage; fair quality data were recorded. The nearshore eastern flank of the basin was explored by Continental Oil in 1972, using an airgun source with 24-fold CDP coverage. Sedimentary cover identified on this survey was thin, being no more than 1000 m at the edge of the continental shelf. Also in 1972, Shell Australia recorded portions of three high-quality 24-fold airgun array lines across the basin, while the BMR surveyed the entire area at a regional spacing during Survey 19 of the Continental Margins Survey (CGG, 1975); data quality from the latter survey was poor. The principal data set in the Bremer Basin is Esso's Bremer (R74A) Marine Seismic Survey, which recorded 2224 km of 24-fold seismic data in 1974 (Cooney, 1974; Cooney & others, 1975; Fig. 62.2). These data are of good quality, though the regional line spacing makes correlation of the complex structuring difficult. No seismic data have been recorded since 1974, nor have wells been drilled, and the Bremer Basin consequently remains a very poorly-explored area.

ii) Stratigraphy

The thin onshore sediments of the Bremer Basin are all related to a marine transgression in the Eocene. In the coastal region, these sediments comprise the Plantagenet Group, while further inland they comprise the Eudynie Group. The sediments of these groups consist of limestone, spongolite, clay, siltstone, sandstone, lignite, and carbonaceous siltstone (Robertson & others, 1979, table 1). They have no recognised hydrocarbon significance. Since no samples have been recovered from the offshore, the stratigraphy of the main part of the Bremer Basin can only be inferred from the structural interpretation.

iii) Structure and Evolution

It is the opinion of these authors that the complexities of the Bremer Basin combined with the sparse seismic data are such that confident correlation of seismic horizons across the basin is not possible. Consequently, we have restricted our mapping of the basin to the compilation of a tectonic elements map (Fig. 63.1). This map is grossly over-simplified in that many prominent individual structures are not shown since their trends cannot confidently be determined. This discussion will be limited to describing and attempting to interpret the features seen in the tectonic elements map and in some representative seismic sections (Figs 63.1-64.4).

In the Bremer Basin area, basement can only be unequivocally identified beneath the continental shelf. Here it is generally manifest as a relatively smooth or undulating surface at a depth of no more than 0.4 s TWT (*ca* 500 m) below seabed at the shelf edge. The only indication of a sedimentary depocentre on the shelf is a narrow, shallow, half-graben trending west-southwest from the shelf edge east of Albany; the sedimentary fill is probably of Palaeozoic age. While the magnetic signature of most of the shallow basement is very subdued, isolated areas on the continental shelf south and west of Albany have associated intense magnetic anomalies (Fig. 63.1); these anomalous areas are probably a function of variations in the basement composition or of later igneous intrusion.

The boundary between shallow basement and the Bremer Basin proper is typically a major high-angle fault scarp; this boundary is the most prominent feature of the tectonic elements map. The scarp shows several distinct trends along its length - from roughly east-west in the western segment, to ENE-WSW in the centre, and east-west in the east (Fig. 63.1). The western limit of the basin is complex and difficult to define, whereas the eastern termination at about 121°E at a pair of northwest-southeast trending transfer faults (Fig. 64.4) is clear-cut. Minor offsets in the basement scarp appear to be along transfer faults, also with a NW-SE trend. We note the strong similarity in change of basement trend from west to east through the Bremer Basin and the Eyre Sub-basin (ENE-WSW abruptly to E-W) and suggest that it is due to the strong NNW-SSE Jurassic-Cretaceous extension direction interacting with older (?Palaeozoic and older) east-west trending lines of crustal weakness. One of these older lineaments extends from the western end of the Eyre Sub-basin across the central GAB and through the Polda Trough, and a second underlies the continental slope from about 120°10'E to the eastern end of the Archipelago of the Recherche. A third, less well-defined east-west lineament, may underlie the margin south of Albany.

Beneath the Bremer Basin, basement is rarely identified because of the considerable thickness of sediments and the moderate quality of the 1974 seismic data. It can be unmistakably identified within some fault blocks (Fig. 64.2) and is inferred to shallow beneath the lower continental slope, as shown in the tectonic elements map. Basement beneath the continental rise lies at considerable depth (2.5 s TWT, or 3000-4000 m below seabed on Shell *Petrel* line N.400-401) as it does to the east in the Recherche Sub-basin.

The sedimentary fill of the Bremer Basin is restricted to a narrow highly structured belt beneath the continental slope between 117° and 121°E in water depths ranging from shelf edge to 3000+ m. The greatest sediment thickness, estimated to be at least 10000 m by Cooney (1974), occurs in water depths of 600-1500 m.

The western extremity of the Bremer Basin, here informally named the Denmark Trough, appears to be separated from the main part of the basin by a major erosional canyon, offshore from Albany. The trough is an areally restricted syncline containing more than 3 s TWT of sediment in water depths of 1000-1300 m. The complex bathymetry of this part of the margin appears to reflect the underlying structures (Fig. 62.1) with canyon development typically following major basement fault traces.

The main part of the Bremer Basin from 118°20' to 121°E, can be broadly divided into three units (Fig. 63.1). From west to east, these are:

a) A zone of complex block faulting in the west. Throws on the major faults are up to 3 s TWT, and the relationship of the sediments to the faults indicates some compression due to wrenching (Fig. 64.2). The trends of individual structures cannot be discerned with the 40 km line spacing.

b) A zone of relatively subdued structuring in thick sediments in the centre of the basin, underlying a narrow mid-slope terrace.

c) A zone of extensive high-angle faulting and wrench structuring in the east of the basin. This area contains some areally-large, high-relief anticlines that have been deeply eroded at the crests.

It is suggested that the complexities in zones (a) and (b) result from the interaction between the Jurassic-Cretaceous extension structures with the east-west Palaeozoic and older lineaments.

With the highly-structured nature of the sedimentary fill and the wide spacing of the seismic lines, it is difficult to make definitive statements about the seismic stratigraphy of the Bremer Basin. Four horizons have been identified in the interpreted seismic sections in Plates 63 and 64 (labeled horizons P, Q, R, and S, to avoid confusion of nomenclature with the Bight Basin); we are moderately confident of the correlation of these horizons between lines.

The most prominent unconformity within the Bremer Basin (excepting basement) is horizon R, a strong erosional surface generally 0.5-1.0 s TWT (700-1500 m) below seabed. At the margins of the basin on dip lines, the underlying steeply-dipping section is strongly truncated by horizon R, resulting in a strong character resemblance to the Neocomian 'breakup' unconformity in the South Perth Basin. This led Cooney (1974) to propose a Neocomian age for the unconformity; these authors agree that this is the most likely age given the proximity of the Bremer Basin to the Perth Basin and the prominence of a near top Neocomian reflector (horizon n) elsewhere on the southern margin.

Horizon S is a prominent reflector within the ?Lower Cretaceous section, approximately 1 s TWT below horizon R in the depocentres and truncated by horizon R at the outer basin margin (Fig. 64.1). Horizon S has high amplitude and continuity and is a mild unconformity in places. We propose an Early Cretaceous or Late Jurassic age for this horizon.

Horizons P and Q occur in the shallow section (<1 s TWT below seabed) and are the two most prominent unconformities in a section which is extensively mounded and channeled with a number of minor unconformities. Cooney (1974) also identified these unconformities and suggested ages of base of Late Tertiary and Middle-Late Eocene, respectively, with the interval from seabed to horizon P containing Upper Tertiary carbonates while the interval from horizon P to Q contains Eocene clastics. By analogy with prograding units elsewhere on the southern margin, Cooney further suggested that the interval between horizons Q and R consisted of Upper Cretaceous clastics. These authors believe, in the total absence of stratigraphic information from the offshore, that Cooney's interpretation is quite reasonable.

CHAPTER 4: HYDROCARBON POTENTIAL

Previous Work

The first geochemical analyses undertaken in the region were in the Duntroon and Bight Basins by Reiman & Dielwart (1972) for Shell Development Australia. These analyses encompassed simple fixed-carbon content determination (by percent weight), based entirely on the fixed-carbon content of the vitrinite present in the sample.

As part of a regional evaluation of Australian basins, British Petroleum carried out extensive vitrinite reflectance (R_v) and Rock-Eval pyrolysis work on core and cuttings from Potoroo-1 and Platypus-1 (Lowe & Wise, 1980; Lowe & O'Reilly, 1980).

The most comprehensive review of geochemical studies to date, was initiated by Getty Oil Development in 1983-1984. 150 samples from Echidna-1 and Platypus-1 in the Duntroon Basin, and samples from Mercury-1 in the Polda Basin, were analysed for total organic content (TOC), Rock-Eval pyrolysis, and R_v determination. These were coupled with maceral analysis, kerogen elemental composition, and rock extract (EOM) data for Platypus-1, Echidna-1, and Mercury-1, the results of which are summarised below. Additionally, bitumen analyses on cuttings from Platypus-1, Echidna-1, Mercury-1, and coastal bitumen samples collected between the Eyre Peninsula and southern Fleurieu Peninsula and Kangaroo Island, were carried out by McKirdy (1984).

In conjunction with the 1983 Getty Oil seismic program, a water-column hydrocarbon "sniffer" survey was carried out in the Duntroon Basin by Inter-Ocean Systems Inc. for Getty in 1983. This involved the acquisition of some 2000 km of geochemical data, on a rectangular grid. A geochemical study of Duntroon-1 was undertaken by Gibbons & Fry (1986), but remains confidential until July, 1991.

a) DUNTROON BASIN

i) Introduction

Geochemical studies of Platypus-1 and Echidna-1 wells provide the framework for predicting hydrocarbon generation and maturation in the Duntroon Basin. Due to the highly variable maturity of the Cretaceous sequence within the basin, maturity, source richness, source quality, and kerogen type will be discussed for individual wells, rather than on a wider formation basis.

ii) Reservoir and Seal Potential

Excellent reservoir potential exists within fluvial to paralic sandstones of the Duntroon and Bight Groups, and in marine sands of the Tertiary Pidinga Formation. Reservoir quality, distribution, and thickness are summarised in Table 7.

Good-quality cap rocks exist in the Lower Cretaceous Borda and Neptune Formations. Collectively, they provide up to 2800 m of seal.

Interbedded sandstones within the essentially claystone-dominated Borda Formation have intraformational trap potential. Similar sandstone

TABLE 7: Reservoir characteristics of formations in the Duntroon and Bight Groups

Formation	Total Thickness (m)	% Sand	Maximum individual sanstone bed thickness (m)	Porosity Range (%)	Porosity Average (%)	Sandstone geometry and environment of deposition
Potoroo	322 Duntroon-1	34	15	10-30	23	Transgressive/regressive sequence.
	515 Platypus-1	22	40	10-30	25	Laterally extensive. Excellent reservoir potential.
Wombat Sandstone Member	73 Duntroon-1	42	20	5-30	20	Marine Shelf - shoreface. Laterally
	103 Platypus-1	54	15	14-29	20	extensive. Excellent reservoir potential.
Platypus	49 Duntroon-1	48	17	5-30	20	Fluvial - upper delta plain. Thick,
	402 Platypus-1	35	14	2-30	16	locally extensive meandering stream deposits. Excellent reservoir potential.
Ceduna	393 Duntroon-1	42	25	10-28	18	Delta distributing channel sands.
	505 Platypus-1	53	20	5-23	14	Laterally continuous. Excellent reservoir potential, although increased shaliness towards base of unit decreases porosity.
Borda	533+ Duntroon-1	15	2-5	5-10	6	Meandering - fluvial. Thin, laterally
	1712 Echidna-1	12	2-5	5-10	6	discontinuous reservoirs of variable quality.

interbeds within the Lower Cretaceous Eumeralla Formation of the Otway Basin have proven gas reserves.

Prodelta claystones of the Upper Cretaceous Wigunda Formation provide an effective regional seal away from structural highs, such as the Echidna Structure, where they have frequently been eroded off. In the northwest part of the Duntroon Basin, at Platypus-1, the formation is more than 650 m thick, and provides and effective seal above the highly-porous sands of the Ceduna and Platypus Formations and the Wombat Sandstone Member. Laterally extensive claystone units up to 100 m thick within the Potoroo Formation provide excellent intra-formational seals. Interbedded marls within limestones of the Eucla Group have limited lateral and vertical continuity and therefore have poor potential as seals for the prospective Cretaceous Section.

iii) Hydrocarbon Generation and Maturation

Maturity

Platypus-1

Vitrinite reflectance data (Appendix IX) indicate that, with the exception of the basal Platypus Formation, the entire Upper Cretaceous sequence down to 3048 m is immature ($R_v \leq 0.5\%$). The well reached a total depth (TD) of 3881 m in the basal Ceduna Formation, just above the threshold of maximum oil generation ($R_v \leq 0.8\%$). Respective hydrocarbon thresholds for resinite-rich and resinite-poor, Type III terrigenous kerogen are shown in Table 8.

It can be presumed from isopachs of the Ceduna Formation and correlation with Duntroon-1, that maximum oil generation could be expected within the Borda Formation at the Platypus-1 location if the well had been drilled deeper.

Low C^{12} hydrocarbon yields, high pristane/n - heptadecane values and the elemental composition of the corresponding Type III kerogens, further testify to the fact that the Ceduna Formation (at least to 3834 m) lies above the zone of peak oil generation in Platypus-1 (McKirdy, 1984).

Echidna-1

Vitrinite reflectance data (Appendix IX) indicate that the Tertiary and Lower Cretaceous sediments are immature ($R_v \leq 0.5\%$) above 1554 m. Principal hydrocarbon thresholds for terrigenous organic matter are shown in Table 9.

The relatively narrow oil window, located entirely within the Lower Cretaceous Borda Formation, is a possible reflection of the erosional truncation of the mid- and Upper Cretaceous sequence. High production index values over the interval 1311-2042 m suggest the presence of migrated hydrocarbons in the section above the threshold for oil generation for resinite-poor Type III kerogen. This may account for high C_{12}+ hydrocarbon yields obtained between 1442-1472 m (McKirdy, 1984). Conversely, this inverted maturation trend may be an artifact of the immature inertinitic character of the kerogen in the upper Borda Formation.

Table 8: Hydrocarbon generation thresholds in Platypus-1

Threshold	R_v(%)	Depth (m)	Formation
Top oil window (resinite rich)	0.45	2774	Basal Wigunda
Top gas window	0.60	3475	Ceduna
Top oil window (resinite poor)	0.70	3764	Ceduna
Maximum oil generation*	0.80	4000	NP
Oil floor*	1.35	5319	NP

NP - Not Penetrated
* - Source: Lowe & Wise, 1980

Table 9: Hydrocarbon generation thresholds in Echidna-1

Threshold	R_v(%)	Depth (m)	Formation
Top oil window (resinite rich)	0.45	1402	Borda
Top gas window	0.60	1829	Borda
Top oil window (resinite poor)	0.70	2042	Borda
Oil floor	1.35	2317	Borda

Table 10: Source capacities for Platypus-1 and Echidna-1

Well	Form.	Lithology	TOC (Range)	TOC (Average)	S_1+S_2	S_1+S_2 (Average)
Platypus-1	Platypus	shale	1-19	5.6	2-32	8
		coal	30-60	43	29-144	74
	Ceduna	shale	1-22	3.22	1-53	5
		coal	24-62	41	31-178	81
Echidna-1	Borda	shale	0.49-17.9	1.73	0.4-27	3.5
		coal	19-47	31	50-117	81

Source Richness

The respective source capacities of shales, siltstones, and coals from the Upper Cretaceous Platypus Formation and the Lower Cretaceous Ceduna and Borda Formations in Platypus-1 and Echidna-1 are presented in Table 10.

The total organic content (% TOC) can be used as a guide to source richness. A TOC of <0.5% indicates negligible source capacity, while a TOC of ≥2% indicates good to excellent capacity. Source richness, as indicated by potential hydrocarbon yields (S_1 and S_2) can be considered poor if $S_1 + S_2 <2$ kg/tonne, moderate if $S_1 + S_2$ is up to 6 kg/tonne, and good if $S_1 + S_2 >6$ kg/tonne. Potential hydrocarbon yields are summarised in Table 10. Whilst source richness of the Platypus Formation shales is fair to very good, the underlying Ceduna Formation has fair source richness to approximately 3688 m, and good to very good potential below this depth (Appendix IX). Source richness of shales from the Borda Formation in Echidna-1 is mostly poor with the exception of a lignitic interval from 1441-1475 m. Source richness of coals of the Platypus, Ceduna, and Borda Formations is excellent (Table 10).

The deepest sediment fill in the inner and outer parts of the Duntroon Basin has not been reached by drilling. If it is assumed that these sediments are at least partly Jurassic in age, then lithological and maturity information can be derived from analysis of the closest time-equivalent deposits of the Polda Trough, some 250 km north of the Duntroon Basin. Geochemical analysis carried out on samples from the Mercury-1 well (McKirdy, 1984) indicate that the Jurassic Polda Formation has good source potential with a mean TOC of 2.56%. Rock-Eval pyrolysis confirms the good potential, with the genetic potential ($S_1 + S_2$) ranging from 2.97 to 22.42 kg/tonne. However, the section never entered the oil window in the Polda Basin, and R_v values do not exceed 0.38. The sediments of ?Jurassic-Neocomian age are buried to depths of up to 9000 m in the Duntroon Basin. If the TOC values are similar to those in the Polda Trough, then significant volumes of hydrocarbon may have been generated during the Cretaceous and Cainozoic.

Source Quality and Kerogen Type

Platypus Formation

Shales and siltstones of the Platypus Formation in Platypus-1 contain terrigenous organic matter of woody, herbaceous, Type III composition. However, up to 50% of the samples fall below the modal maturation pathway for Type III kerogen, indicative of Type IV organic matter, and are therefore capable of generating dry gas. Approximately 14% of the samples have hydrocarbon indices (HI) ≥150 mg/g TOC, indicative of liquid generating potential. HI values for coals in the Platypus Formation commonly exceed 150 mg/g TOC in 60% of samples analysed, and consequently are considered to have higher oil potential than the adjacent shales and siltstones.

Ceduna Formation

Down to approximately 3688 m in Platypus-1, the Ceduna Formation has HI values <150 mg/g TOC (*ie* the formation is gas prone). Shales and siltstones are mostly comprised of inertinite (55-85%), whilst coals are rich in vitrinite and exinite (V = 50-75%, E = 15-20%). Below 3688 m, HI values commonly exceed 150 mg/g TOC, and range up to 226 mg/g TOC (*ie* there is marginal to fair potential for liquid hydrocarbons). The HI average for the Ceduna Formation shales and coals is 103.06 mg/g TOC and 179.1 mg/g TOC, respectively (Appendix IX).

Borda Formation

The shale/claystone-dominant Borda Formation has a more consistent shale source quality (HI in the range 43-207 mg/g TOC, with an average of 110.24). Hydrogen Index values for coals of the Borda Formation, however, exceed 150 mg/g TOC and average 215.3, indicative of high liquid hydrocarbon generation. McKirdy (1984) noted a periodicity of hydrogen index with depth and suggested that this may have been in response to systematic fluctuation in organic input to the lacustrine-fluviatile depositional environment.

In conclusion, wet gas and waxy paraffinic oil are the likely products of the Type III organic matter that has a HI $\geq$150 mg/g TOC, as is seen in the Platypus, Ceduna and Borda Formations, where $R_v > 0.7\%$.

iv) Thermal History

All three wells from the Duntroon Basin have been the subject of geohistory analysis (Figs 65.1-69.1). Two of these wells, Platypus-1 and Duntroon-1, have undergone similar thermal, and very similar subsidence histories. In contrast, Echidna-1 shows a completely different subsidence and thermal history.

Platypus-1 and Duntroon-1

Subsidence in both Platypus-1 and Duntroon-1 has been fairly smooth and appears to have been almost totally thermally-driven (Figs 66.1D & 68.1C). Subsidence began at approximately 125 Ma and continued until the early Cenomanian, when there was a brief period of uplift and erosion. Basement at both well locations then subsided steadily until approximately 30 Ma, when non-thermal subsidence rates increased significantly, leading to a rapid increase in water depths from the Late Oligocene onwards.

The maturation histories of both Platypus-1 and Duntroon-1 are similar, with Duntroon-1 having experienced a slightly more intense thermal history. A thick, mature (undrilled) Duntroon Group was deposited by the early Late Cretaceous at both wells (Figs 66.1E & 68.1D). In fact, a significant part of the basal Duntroon Group was already over-mature by this time. Hydrocarbons generated from lacustrine and coally source rocks in the Duntroon Group could have had migration paths up the large growth faults which were initiated in the mid-Cretaceous and which gave rise to the structures at Platypus-1 and Duntroon-1. Following deposition of the Wigunda Formation seal (at approximately 88 Ma), these hydrocarbons could have charged Platypus Formation and Wombat Sandstone Member reservoirs. At the present day, these reservoir horizons are either immature or marginally mature.

The top of the oil window ($R_v = 0.65$) at Platypus-1 and Duntroon-1 is presently located at depths of 3250 m and 3100 m, respectively, while peak oil generation ($R_v = 0.80\text{-}1.3$) occurs in the depth ranges 3950-5500 m and 3450-4250 m, respectively (Table 11). The maturation history of Platypus-1 is probably more favourable to the entrapment of liquid hydrocarbons than that of Duntroon-1. The high-quality lacustrine source rocks which are probably present towards the base of the Duntroon

TABLE 11: Vitrinite Reflectance vs Depth at Exploration Well Locations

	VITRINITE REFLECTANCE									
WELL	0.45	0.50	0.60	0.65	0.70	0.80	1.00	1.30	1.60	2.00
Jerboa-1	2120	2370	2800	3050	3200	3550	4130	NC	NC	NC
Potoroo-1	2150	2450	2890	3050	3250	3500	3950	4600	5000	NC
Platypus-1	2450	2650	3000	3250	3500	3950	4650	5500	6150	6850
Duntroon-1	2350	2600	2900	3100	3250	3450	3800	4250	4600	4950
Echidna-1	1300	1300	1500	1600	1700	1950	2250	2700	3000	3300

NC - not calculated

Group (Echidna Formation) entered the oil window prior to structuring in Duntroon-1, whereas in Platypus-1 these source rocks matured after structuring. Moreover, fair- to good-quality source rocks have been found within the Ceduna Formation at Platypus-1 at depths below 3688 m (Appendix IX). These source rocks are now well within the oil window, and have been since about the Early Eocene (Fig. 68.1E).

Echidna-1

Echidna-1 is located on a faulted, central basin high, and experienced a period of normal, thermally-driven subsidence from the Early Cretaceous until the beginning of the Paleocene (Fig. 65.1D). This was followed by a period of intensive uplift and erosion in the latest Cretaceous to Early Tertiary. As much as 1600 m of Upper Cretaceous sediments were eroded at Echidna-1, and lowermost Eocene sediments now unconformably overlie lower Aptian shales. As with the other Duntroon Basin wells, subsidence rates increased significantly at about 30 Ma, and water depths increased rapidly from that time.

A combination of a high geothermal gradient and relatively shallow basement at Echidna-1 has produced a markedly different maturation history to Platypus-1 and Duntroon-1 (Fig. 65.1E). Much of the Duntroon Group had entered the oil window by the early Aptian. Strong uplift at the end of the Late Cretaceous elevated mature and over-mature sediments to shallow depths, with mature sediments being within 300-400 m of the surface. Any reservoired hydrocarbons were probably either spilled or biodegraded during this uplift. There has been relatively little further maturation since the end of the Paleocene, with the iso-vitrinite reflectance profiles actually deepening with subsidence and sediment accumulation. The Borda Formation is the only formation that is presently located within the oil window. In view of its apparent gas-prone nature, and the early maturation and over-maturation of the Duntroon Group at Echidna-1, it appears likely that plays such as Echidna-1 would be predominantly gas-prone.

The present day oil window (R_V = 0.65) begins at a depth of 1600 m at Echidna-1, with peak generation (R_V = 0.80-1.3) at depths of 1950-2700 m (Fig. 65.1E).

v) Play Concepts

Introduction

An evaluation of the petroleum potential of the basin based on well data is limited by the location of the wells. Duntroon-1 and Platypus-1 tested the outer growth-fault zone with very similar results. Echidna-1 was located on the central basement high, on the crest of a diapiric anticline, where it penetrated a reduced section and had a thermal maturity profile which differs greatly from that of the outer growth-fault zone. The inner basin has not been drilled, and an evaluation of its potential is derived by extrapolation from the existing wells and consideration of the tectonic and sedimentary history of the area.

Outer Growth-fault Zone

Platypus-1

Platypus-1 was drilled to test a broad roll-over structure defined on 1970 vintage seismic lines. The well was abandoned as dry at a TD of

3881 m, in shales of the Ceduna Formation. The Platypus structure is located on the major fault that separates the outer growth-fault zone from the central basement high (Fig. 15.1). The structure formed by the slippage and rotation of Lower Cretaceous sediments on a shallow-dipping fault plane at the time of deposition of the Cenomanian Platypus Formation. The roll-over provides dip closure to the north at the top of Duntroon Group. Dip closures to the south and laterally, along the axis of the roll-over, appear to be limited. The well penetrated adequate reservoirs in the Platypus Formation (334 m thick) and the Wombat Sandstone Member (103 m thick), and potential seals in the Wigunda Formation (665 m thick).

Duntroon-1

Duntroon-1 was located on the Numbat prospect, and was sited on the results of the 1983 and 1984 Getty Oil seismic surveys . The primary objective was to test the hydrocarbon potential of the Platypus Formation. The Numbat prospect is interpreted as a mid-Cretaceous structure generated by mass sliding on a ductile shaly substratum. The structure is bounded to the south by a growth-fault which was active in the mid-Cretaceous and affected the top of the Ceduna Formation (top of Duntroon group horizon). The deposition of the Platypus Formation appears to be controlled by the growth of this fault, whilst sealing of the fault should have occurred with the deposition of the Wigunda Formation.

The Bight Group penetrated at the well comprises the Potoroo Formation (172 m), the Wigunda Formation (313 m), the Wombat Sandstone Member (73 m), and the Platypus Formation. The Platypus Formation is relatively thin (49 m, from 2541-2590 m; Hill, 1989), since the deposition of the formation is interpreted as being synchronous with the structuring of the Numbat prospect. Geochemical analysis did not show any evidence of hydrocarbon migration in the penetrated Cretaceous section.

Summary

Assuming that the maturity profiles at Platypus-1 and Duntroon-1 are representative of the outer growth-fault zone, then the main factors affecting hydrocarbon prospectivity in this area are the immaturity of the section down to 3000 m, and the volumetric importance of the deposits in the deepest (un-penetrated) levels of the Duntroon Group and underlying sediments. Structuring is essentially related to growth-faulting, and commenced in the Cenomanian. If migration along these faults occurred, then hydrocarbons may have accumulated in the Upper Cretaceous section which contains potential reservoir sandstones (35% of the Platypus Formation and 22% of the Potoroo Formation, in Platypus-1). The zone of maximum oil generation was estimated to be at 4420 m by Forbes & others (1984). The prospectivity of the outer growth-fault zone is dependent on substantial vertical migration of hydrocarbons from the deepest levels of the Duntroon Group to fill Upper Cretaceous (and possibly Cainozoic) reservoirs. Such migration appears to have occurred in the Gippsland Basin, where vertical migration of up to 2 km and lateral migration of up to 15 km are suggested (James, 1983; Burns & others, 1984; Rahmanian & others, in press).

The abundance of shales in the Duntroon Group could constitute a regional seal for reservoirs in the unpenetrated basal Cretaceous section and trap any hydrocarbons generated below 3000 m. Active growth-faulting during the deposition of the shales of the Duntroon Group, could prevent the vertical migration of the hydrocarbons to the Upper Cretaceous reservoirs.

Alternatively, lateral migration of hydrocarbons from the deep mature Cretaceous levels of the outer zone, to the central basement high could have occurred. In this hypothesis, the traces of migrating hydrocarbons found in the Lower Cretaceous section at Echidna-1 (see later) would have originated in the outer growth-fault zone, and migrated to the Echidna Structure through lateral pathways within the Lower Cretaceous section.

Inner Half-graben Zone

Echidna-1

Echidna-1 was drilled on a structure defined by 1970 Shell seismic lines (Fig. 15.1). The well tested a rotated shale mass on the apex of the central basement high which forms the southern margin of one of the half-grabens of the inner zone of the Duntroon Basin. Unfortunately, the strong rotation of the Lower Cretaceous section induced by the mobilisation of shale, and the dense faulting, degrade the seismic data and reduce the level of confidence in the structure being closed.

The structure at Echidna-1 is the result of the superposition of a series of tectonic events - namely the ?Jurassic-Neocomian extensional rifting, the mid-Cretaceous shale mobilisation, and the Late Cretaceous post-rift uplift of the central basin high. The sedimentary section is characterized by a total erosion or non-deposition of the Bight Group, and incomplete preservation of the Duntroon Group directly below the base Tertiary unconformity. The seismic interpretation does not provide conclusive evidence to determine the respective influence of these factors.

Half-graben Depocentres

A maturation profile for the 'inner' half-graben depocentres is hard to predict since the structural setting differs significantly from the outer growth-fault zone or the central basement high (including the Echidna Structure). The existence of deep-seated tilted basement blocks in that sector also precludes a direct extrapolation of the thermal history from the outer growth-fault zone.

The increased thickness of the Bight Group in the withdrawal synclines consequently means that the sediments of the Duntroon Group are more deeply buried, particularly in the southeast sector of the Duntroon Basin where the Upper Cretaceous and Cainozoic sections are 3500-3800 m thick (Fig. 17.2), and the total sediment thickness can exceed 10000 m (Fig. 20.1).

Structures

Structures at the top ?Jurassic-Neocomian level are usually related to warping and normal faulting above the apices of deep basement blocks, and are found in the deepest parts of the inner zone.

Mid-Cretaceous structures in the inner zone of the basin are related to the development of the diapiric anticlinal features. The consequence of the doming-arching of the Early Cretaceous is the faulting of the competent part of the Cretaceous sedimentary section along the axis of the anticlinal features. Typically these crestal faults have an average length of 5 km and highly-variable vertical throws. The importance of these fractures is twofold. They may have created pathways for the migration of hydrocarbon generated in the lacustrine deposits of the Duntroon Group, and they may have produced the combination of structural and stratigraphic traps and seals within the Late Cretaceous.

b) BIGHT BASIN

i) Introduction

Discussion of such factors as source, reservoir, seal, and thermal history, and maturity in the Bight Basin must focus on the only two wells in the basin, Potoroo-1 and Jerboa-1, as these provide the only geological control. However, any analysis of play types, must be based primarily on interpretation of the seismic data, since data from the two wells located on the periphery of the basin have limited value when extrapolated basin-wide.

ii) Reservoir and Seal Potential

Reservoir characteristics within the Lower Cretaceous section are highly variable. At Potoroo-1, the upper 30 m of the 78 m-thick Loongana Formation consists of poorly-sorted, clean, quartz sandstone that has porosities in the range 9-22%. A thin coal-bearing sandstone unit separates this stacked sandstone from a well-sorted micaceous and pyritic sandstone which has porosities in the range 13-25%. The reservoir potential of the Upper Cretaceous Platypus Formation equivalent is reduced, due to the increased shale and siltstone content of the unit. Sandstone interbeds up to 4 m thick are poorly-consolidated, although often containing coaly laminae which produce anomalously high log-derived porosities. The Potoroo Formation consists of unconsolidated, clean, clear to milky quartz sandstones up to 50 m thick, which have excellent porosities of up to 30%.

A regional seal is provided by the Wigunda Formation (interval between horizons c and d in this report) which is 200 metres thick in Potoroo-1. Additional seals may also be provided by the Neptune Formation equivalent which, although thin at Potoroo-1 (44 m), is much thicker in the main part of the Bight Basin.

At Jerboa-1 in the Eyre Sub-basin, a number of good-quality reservoirs were identified in the basal sediments of the Loongana Formation. Average porosities in the best units were in the range 17-24%. Regional seals could be expected in the thick overlying claystones of the Neptune Formation equivalent. Within the shallow part of the section, it is expected that the thin prograding shelf-edge sands of the Paleocene Pidinga Formation equivalent may have suitable porosities, though the quality of the overlying seal is uncertain.

iii) Hydrocarbon Generation and Maturation

Maturity

Vitrinite reflectance studies have been carried out on 66 samples from the Neocomian to the Middle Miocene at Potoroo-1. These studies indicate that, while the Upper Cretaceous section is essentially immature, the Lower Cretaceous Ceduna and Loongana Formation sediments were intersected within the oil window, but above the top of the gas window. Hydrocarbon thresholds for Type III terrigenous kerogens are presented in Table 12. Lowe & O'Reilly (1980) noted that bitumen staining of the autochthononous vitrinite may account for a discrepancy between the R_v maturity trend and spore colour maturation trends, which indicate a more shallow maturation threshold. Consequently, the generation thresholds must be treated with caution.

A limited set of vitrinite reflectance data show that Jerboa-1 is thermally immature to total depth. The maximum R_v values recorded were 0.51 (at 2490 m) and 0.50 (at 2507 m), close to basement. Burns (1981) considers that the onset of maturity in this area corresponds to R_v = 0.65, would occur at depths of approximately 2900 m in the depocentres adjacent to Jerboa-1.

Source Richness, Quality and Kerogen Type

TOC measurements for 5 samples from Potoroo-1 showed moderate values of organic carbon for the Cretaceous, as summarised in Table 13. Although these values indicate moderate source capacity, their source potential is downgraded by to the presence of inertinitic material detected by pyrolysis and visual kerogen investigation.

Oil and gas yields from 25 samples range from 0.1-2.2 and 0.1-2.61 kg/tonne, respectively, for the entire Tertiary-Cretaceous sequence, indicating poor to marginal source richness. One notable exception at 2126-2130 m (in the Platypus Formation) gave a theoretical oil yield for a coal of 15.2 kg/tonne, indicating high liquid hydrocarbon potential. However, shales from the same interval gave only moderate total hydrocarbon potential and were predominantly gas-prone.

The presence of the coal maceral, inertinite, reduces the source potential of the predominantly near-shore marine Albian to Tertiary section, which has only moderate to poor gas potential (Lowe & O'Reilly, 1980). High oil potential from a coal in the Cenomanian Platypus Formation was found, but the coal has not reached the oil window. No analytical work on Hydrogen Index or T_{max} has been carried out.

At Jerboa-1, TOC data show that most of the section penetrated is relatively organic-rich (Table 13). Shaly sequences throughout the well have moderately high TOC concentrations. TOC averages 0.94% in the Albian Ceduna Formation, 1.05% in the Barremian Neptune Formation, and 1.84% in the Neocomian Loongana Formation. The most organically-rich shales occur towards the base of the Loongana Formation (2435-2509 m), where TOC averages 2.88% (9 samples) and has a maximum of 5.46% (Burns, 1981). The kerogens in the shales are dominantly (> 50%) amorphous, and are rich in extractable hydrocarbons, suggesting that they have a high potential for liquid hydrocarbon generation (Burns, 1981). Unfortunately, the shales are fairly thin at Jerboa-1, though they may be both thicker and more thermally mature in locations away from basement highs.

Table 12: Hydrocarbon thresholds in Potoroo-1

Threshold	R_v(%)	Depth (m)	Formation
Top oil window	0.55	2392 ± 114	Base Platypus/ Ceduna
Top gas window	0.70	3273 ± 233	NP
Maximum oil generation	0.80	3761 ± 316	NP
Oil Floor	1.30	5335 ± 634	NP

Table 13: Total organic contents for formations in Potoroo-1 and Jerboa-1

Well	Formation	TOC % (range)	TOC % (av.)	No. samples
Jerboa-1	Ceduna	0.46 - 1.33	0.94	5
	Neptune	0.90 - 1.17	1.05	7
	Loongana*	0.78 - 5.46	1.84	29
	Loongana[1]	0.78 - 2.32	1.51	15
	Loongana[2]	1.29 - 2.22	1.70	5
	Loongana[3]	1.70 - 5.46	2.88	9
Potoroo-1	Platypus	1.4	1.4	
	Echidna	1.2 - 1.3	1.25	

* Includes all Loongana Formation samples
[1] samples from 2105-2361 m
[2] samples from 2375-2420 m
[3] samples from 2435-2509 m

iv) Thermal History

Potoroo-1

The geohistory plots for Potoroo-1 show an extremely irregular subsidence history (Fig. 70.1D), particularly between approximately 125 and 95 Ma. Subsidence during this period, which corresponds to the interval between western margin and southern margin breakup, appears to have been largely tectonically-driven, whereas subsidence between 95 and about 30 Ma was fairly smooth (thermally-driven). From 30 Ma to the present, subsidence rates increased significantly.

Potoroo-1 appears to have experienced a fairly 'gentle' thermal history (Fig. 70.1D), broadly similar to that of Jerboa-1, with the geohistory analysis (Fig. 70.1E) showing that the entire sedimentary section is thermally immature. The basal part of the Loongana Formation reached a maturity of R_v = 0.5% in the latest Cretaceous-earliest Paleocene (approximately 68-65 Ma) with the basal Ceduna Formation reaching R_v = 0.5% in the Eocene. The section immediately above basement in Potoroo-1 is now at a calculated maturity of about 0.58% (Fig. 70.1F), close to the onset of hydrocarbon generation. Extrapolating the maturity profile from Potoroo-1 to the main part of the Ceduna Sub-basin, suggests that hydrocarbon generation (R_v > 0.65%) probably commences at a depth of approximately 3050 m, with peak generation (R_v = 0.8-1.3%) occurring between approximately 3500 and 4600 m (Table 11). As with Jerboa-1, the charging of structural traps similar to Potoroo-1 would require significant lateral and vertical migration up-dip from more deeply buried source rocks on to the basin margins.

Jerboa-1

The tectonic subsidence plot for Jerboa-1 (Fig. 71.1A-D) indicates that subsidence was principally thermally-driven (at least to approximately 32 Ma), with a relatively small tectonic component. Subsidence was fairly regular from approximately 127 to 119 Ma. A period of non-deposition with slight uplift followed to approximately 95 Ma. Gradual thermal subsidence then continued to about 32 Ma, when subsidence rates increased dramatically. An increase in (non-thermal) subsidence rates at about 32 Ma is seen in all of the other Great Australian Bight wells modelled in this study, and may be related to the mechanical clearing of the Australian and Antarctic plates at that time.

The geothermal gradient is currently relatively low (at least in the vicinity of Jerboa-1) and it appears to have been low throughout the Cainozoic (Fig. 71.1D). Not unexpectedly, the thermal modelling and vitrinite data (Figs. 71.1E & F) show that the entire sedimentary section at Jerboa-1 is thermally immature (R_v < 0.65%). Only the basal unit in the well (Loongana Formation) has reached R_v = 0.5%, and this has occurred only within the last 35 Ma (Fig. 71.1E). The theoretical vitrinite reflectance at the base of Jerboa-1 is about 0.53%, which agrees well with measured data. Extrapolating the theoretical vitrinite reflectance profile indicates that the onset of hydrocarbon generation (R_v = 0.65%) can be expected at a depth of approximately 3050 m (Table 11), with peak maturity (R_v = 0.8-1.35%) at depths of about 3550-5700 m. Consequently, charging of structural traps similar to those at Jerboa-1 requires substantial vertical and lateral migration from (as yet undrilled) more deeply buried source rocks. On the basis of thermal maturity, it would appear that plays associated with the major basement fault on the southern flank of the Wombat Structure have more chance of tapping a suitable deep and mature hydrocarbon source.

v) Play Concepts

To date, the prospects drilled in the Bight Basin have consisted essentially of compaction drape of Cretaceous sediments over a tilted basement fault block (Jerboa-1) and a minor fault-dip closure adjacent to the northern boundary fault of the Southern Rift System (Potoroo-1); both wells were dry. Several large and complex leads can be mapped along the NW-SE axis of the Ceduna Sub-basin in water depths greater than 1000 m. Although dip-related closures are indicated by some seismic lines, gross structures appear to be largely fault-dependent. These structures have been recognised by industry as part of their analysis of exploration permits but, as yet, they remain undrilled.

In this report, and in previous work (Stagg & Willcox, 1989; Willcox & Stagg, 1990) it has been suggested that the Bight Basin is not just a simple rift basin, and that wrenching and strike-slip motion have played an important part in the tectonic development of the region. These wrench-related structures can be recognised as diffuse 'accommodation zones' (?reactivated transfer faults), 'positive flower' structures within the outer part of the Ceduna Sub-basin, and 'transpressional' anticlines and nappe-like structures at the junction of the Ceduna and Recherche Sub-basins. Amplitude anomalies (or 'fuzzy zones') which occur around some faults are probably caused by complex fracturing along fault planes or possibly, gas seepage.

The following play types can be recognised in the Bight Basin:

1) *Compaction drape* of Cretaceous sediments over tilted basement blocks. A typical structure of this type is Jerboa in the Eyre Sub-basin (Fig. 46.2) in which the target was Neocomian sandstone reservoirs sourced from Neocomian and ?Jurassic syn-rift fill in the adjacent half-grabens. Similar structures are present beneath the northern margins of the Ceduna and Recherche Sub-basins. The principal problem at Jerboa-1 was lack of source maturity. We believe that this will be less of a problem in the Ceduna and Recherche Sub-basins where the much higher degree of crustal thinning has probably resulted in higher heatflow.

2) *Clastic aprons* adjacent to the main northern basin-bounding fault, major fault scarps, and orthogonal transfer faults (*eg* Figs 37.4, 46.2, 46.3, & 49.4). These interpreted clastic aprons lie up-dip from potential ?Jurassic-Cretaceous lacustrine source rocks and should contain coarse sandy facies. However, the play type requires that reservoirs be sealed both vertically and against the fault plane. Figure 46.3 shows a possible 'flat spot' within Paleocene-Eocene sandy sediments directly above a major basement fault, that may have provided a conduit for leaking hydrocarbons.

3) *Lower to mid-Cretaceous fault blocks* in the central Ceduna Sub-basin (Figs 37.3 & 38.1). Fraser & Tilbury (1979) speculated that structural entrapment may exist in these fault blocks by a combination of dip closure and faulting. In the Central Ceduna Depositional Axis (Fig. 9.1) Lower Cretaceous sediments may be over-mature. However, we believe their is some potential where the overburden is thinner or where there is drape of the overlying Upper

Cretaceous section.

4) *Juxtaposition of a thick Upper Cretaceous deltaic sequence* (?interbedded sands and shales) directly above a probable fine-grained shallow marine sequence (Figs 37.5 & 38.1; Fraser & Tilbury, 1979). Either the fine-grained sediments in the pre-delta section or shales within the deltaic sequence are possible source beds. Mapping indicates that there may be a problem with closure at the top delta level, in which case higher-risk stratigraphic traps within the delta have greater potential.

5) *Reactivation of deep-seated basement faults* by post-breakup subsidence, perhaps with some wrenching, has produced both keystone and 'flower' faults within the Upper Cretaceous section above the Outer Margin High of the Ceduna Sub-basin. Fault throws are typically small (several 10s of metres) and the resulting structures can perhaps be considered as Jabiru 'look-alikes'. However, if the play type is valid, then potential field sizes will probably only be comparable to Jabiru and Challis.

6) *Stratigraphic traps against diapirs* in the southwest Ceduna Sub-basin (Fig. 37.5). Diapiric structures are seen to 'punch through' the foreset beds of the Upper Cretaceous delta at several places. We speculate that the cores of the diapirs are composed of similar material to that which has flowed in the nearby 'nappe' structures (Fig. 49.2). While we consider it unlikely that the diapirs are salt-cored, given their likely age (Early Cretaceous) and the high palaeo-latitudes prevailing at that time, it should be remembered that salt of a much older age (?Proterozoic) has been drilled in Mercury-1 in the Polda Trough to the northeast. It is possible (though unlikely) that the diapiric material was derived from much deeper in the section than appears obvious. Given the sparsity of data coverage in the outer Ceduna Sub-basin, it is not yet possible to determine if the diapirism has induced significant structuring in the adjacent sediments.

7) *Outer Margin High* beneath the southwest flank of the Ceduna Sub-basin. It has been speculated in this report and previously (Willcox & Stagg, 1990) that the southwest margin of the Ceduna Sub-basin has been at least partly formed by transpressional movement along a postulated 'Southwest Ceduna Accommodation Zone' (Fig. 9.1). This has resulted in a major zone of arching and uplift within Lower and Upper Cretaceous sediments within which many potential fault and dip-closed structural traps may exist (Fig. 38.1).

8) *Nappe-like structures* encompassing Barremian to ?Aptian continental-paralic and Albian shallow marine sediments beneath the continental rise at the boundary of the Recherche and Ceduna Sub-basins (Fig. 49.2). At present, there is insufficient geological knowledge to allow serious comment on source and reservoir possibilities. However, there can be no doubt of the structural possibilities with up to several hundred metres of relief at the top of individual structures. Although the zone of nappe structures encompasses an area of approximately 60000 km^2, this is a very long-term play by virtue of the water depths (>2500 m).

c) POLDA TROUGH

i) Introduction

Three hydrocarbon exploration wells have been drilled in the Polda Trough (Gemini-1, Mercury-1, and Columbia-1), and the results from all three have been uniformly disappointing. No traces of hydrocarbons were encountered, other than an insignificant 40 ppm of methane from a rafted black limestone within the mobilised halite beds in Mercury-1. Consequently, geochemical analysis of samples from the wells is very limited.

All of the wells were considered to test valid hydrocarbon plays, although Gemini-1 was inadvertently terminated before reaching the target sequences. Mercury-1 was sited on an anticlinal closure above an interpreted halite pillow in the 'salt belt' of the central Polda Trough. Areas of closure ranged from 44 km^2 at the base Jurassic level to 24 km^2 near the top of the salt, with vertical closures of 265 and 365 m, respectively (McClure, 1982a). Columbia-1 was designed to test for the presence of hydrocarbons within a large horst structure in the western half of the Polda Trough. At the level of interest (close to the intra-Kilroo reflector '1p' of this study) the area of closure was 18.5 km^2 and the vertical closure was 540 m (McClure, 1982b).

ii) Reservoir and Seal Potential

In all three wells, the fluviatile Upper Jurassic Polda Formation proved to be extremely porous and permeable. However, within the Polda Trough this formation is not considered to provide potential reservoirs due to their shallow sub-surface depth, probable lack of intra-formational seals, and to the uncertainty of suitable source rocks (McClure, 1982a). These sediments may provide a more useful reservoir in the undrilled western Polda Trough where the sedimentary section is interpreted to be of Mesozoic age, and the porous Upper Jurassic sediments may be deeper in the section. The potential reservoir properties of the Jurassic section reinforce the observation from other wells in the GAB that the Jurassic-Neocomian section constitutes a good hydrocarbon target.

Several intervals within the Proterozoic Kilroo Formation appeared to have some reservoir potential in both Columbia-1 and Mercury-1. In Columbia-1, some argillaceous and silty sandstones are present in the upper part of the Kilroo Formation, but they appear to have low porosities and little apparent permeability. However, log-derived porosities in the cleaner sands in this interval indicate values up to 19%. Thick quartzose sandstones are present in the basal sequence in the well; despite extensive silicification they still have porosities in the range 10-15%, and SP logs suggest there may be limited permeability. In Mercury-1, thin sandstone intervals in the top of the Proterozoic section had maximum log-derived porosities of 18%, while thick sandstone beds in the basal sequence provided the best potential for reservoir development with porosities of about 13%.

iii) Source Rocks and Maturity

Because of the low apparent source potential of sediments (much of the Proterozoic red bed section was heavily oxidised), only limited geochemical analyses have been carried out. No analyses of the Jurassic section were carried out at the time of drilling, presumably because of the rather unconsolidated nature of the sediments and the likely lack of maturity. Despite this, varying coal grades within the Upper Jurassic at all three wells are suggestive of some source potential elsewhere, if the section has been sufficiently deeply buried. Geochemical analysis of samples in the interval 310-810 m in Mercury-1 (McKirdy, 1984) indicate that the Jurassic Polda Formation has good source potential, with a mean TOC of 2.56%. Rock-Eval pyrolysis shows good genetic potential ($S_1 + S_2$), ranging from 2.97 to 22.42 kg/tonne.

In Mercury-1, a geochemical analysis was carried out on a sample from the rafted black limestone within the massive halite section. Headspace gas from this sample was particularly wet, suggesting that the sample came from a depth close to the maximum of the oil generation window. The total organic carbon (TOC) content of the sediment was only 0.06%, indicating that it constituted a very poor petroleum source rock.

In Columbia-1, five samples covering the interval 770-820 m at the top of the Proterozoic section were subjected to geochemical analysis. Headspace gases indicated that the sediments had not reached a maturity level equivalent to the onset of oil generation. TOC analysis of the sediments showed that the sediments had poor to moderate source potential, while Rock-Eval pyrolysis showed the sediments to be both immature and of poor source potential.

Geothermal gradients from Mercury-1 and Columbia-1 showed a gradient of 4.3-4.4 $^{o}C.km^{-1}$ for the Jurassic and younger section, and a gradient of 1.7-2.1 $^{o}C.km^{-1}$ for the pre-Jurassic section. These gradients suggest that the Polda Trough is a relatively 'cold' basin, and that hydrocarbon maturity will be reached only at considerable depth. Geohistory analysis has not been attempted for the Polda Trough wells because the biostratigraphic control is poor.

Overall the source potential of the central Polda Trough appears to be low, due to lack of maturity in the Jurassic section, and high degree of oxidisation of the Proterozoic section. However, two wells can hardly be considered a comprehensive test of the basin, and the western Polda Trough, where potential Mesozoic source and reservoir rocks may be present, remains totally untested.

iv) Play Concepts

The lack of good quality seismic data below the level of the Permo-Carboniferous (horizon 'lp') in the Polda Trough is a serious hindrance to the recognition of hydrocarbon plays. Bearing this problem in mind, it is suggested that the following play types may be worth considering.

1) *Halite-induced anticlinal closure* in the post-horizon pc interval and the upper part of the Kilroo Formation (as at Mercury-1). Individual closures appear to be substantial in area and vertical relief, but the lack of success in Mercury-1 is not encouraging.

2) *Sub-halite traps* caused by relief at the base of the halite, induced by the mobilisation. As any such traps are likely to be subtle and

will only be identified with very high-quality seismic data and velocity control. They will require the recording of new data, or new processing techniques to be applied to old data, if they are to be recognised.

3) *Basement-involved faulting of Proterozoic sediments* producing horst blocks, as identified at Columbia-1. The current level of data quality does not allow confident interpretation of this trap type, but it should be pursued further.

4) *Clastic aprons* adjacent to the steep southern boundary fault (as on the northern margin of the Ceduna and Eyre Sub-basins). As elsewhere, this play requires reservoirs to be sealed both vertically and against the fault plane.

5) *Unconformity traps* at the top Kilroo level (horizon 'pc'). Whilst there is a number of opportunities for reservoir development below this unconformity, there is likely to be a serious seal problem with the overlying Permo-Carboniferous glacigene sediments.

Most of the above play types are only applicable to the central Polda Trough and, with the likely source and maturity problems, they are probably of low potential. We believe that the acquisition of high-quality seismic data (possibly using innovative acquisition and processing techniques) is paramount if play types are to further developed in the central Polda Trough. Particular problems resulting from the current level of data quality are the difficulties in identifying the basin-forming structures and in following facies development and distribution within individual units. High-quality data are also required in the western Polda Trough (where existing data is, for the most part, of elderly vintage and very low quality) to develop play concepts in a part of the Polda Trough which we believe has a higher hydrocarbon potential.

d) DENMAN AND EUCLA BASINS

i) Introduction

In this study, only the offshore parts of the Permian Denman and Cretaceous/Tertiary Eucla Basins have been investigated. Only one well, Apollo-1 occurs in this area, whilst two wells, (Mallabie-1 and Nullarbor-8) intersect both basin sequences approximately 10 km onshore (Fig. 58.1). Data from these three wells have been used to assess the hydrocarbon potential of these platformal basins.

No geochemical analyses have been carried out on the condensed Cretaceous sequence in Apollo-1. The relative proximity of Potoroo-1 and the similar depositional environments during the Cretaceous (although more condensed), suggest that kerogen type, TOC, and theoretical hydrocarbon yields for Potoroo-1 may also be applicable to Apollo-1.

None of the wells tested a valid hydrocarbon play. Nullarbor-8 was drilled as a water bore in 1964 without the benefit of geophysical data. Mallabie-1 was drilled in 1969, essentially as a stratigraphic well to investigate a basement depression indicated by gravity and magnetic data (Scott & Spear, 1969). In contrast, Apollo-1 was sited on what was thought to be a Mesozoic dome on seismic data (Carter & Scott, 1976).

However, a much thinner stratigraphic section than expected was intersected, and the mapped reflector proved to be Archaean basement at a depth of only 858 m.

ii) Reservoir and Seal Potential

Significant reservoir units occur in Precambrian sandstones in Mallabie-1, with porosities up to 15% and permeability up to 280 millidarcys (Scott & Speer, 1969).

Sandstone units were intersected near the base of the Permian sequence in Apollo-1 and Mallabie-1 wells. In Apollo-1 three thin beds were intersected that showed evidence of moderate porosity and permeability (Carter and Scott, 1976). One sample from Mallabie-1 was analysed, showing 18% porosity, although the permeability of 0.1 millidarcy (Scott and Speer, 1969) seems abnormally low. A regional seal is provided by the overlying interbedded Permian claystone.

In Apollo-1 and Mallabie-1, thick sandstones occur in the upper part of the Permian, while in the overlying Eucla Basin, thicker Neocomian sandstones occur in the Loongana Formation, where they are interbedded with numerous thin shales. These sands 'appeared to be porous and permeable' in Apollo-1 (Carter and Scott, 1976) and 'very porous and permeable' in Mallabie-1 (Scott and Speer, 1969). The overlying Madura Formation shales could provide a regional seal for these sandstones. Thin sandstone stringers occur within these shales (with 35% porosity and 3.5 darcy permeability) which are overlain by an interbedded siltstone/sandstone unit. This unit is directly overlain by Tertiary sandstones and carbonates, which have good porosity and permeability but no obvious regional sealing potential.

iii) Hydrocarbon Generation and Maturation

There have been no significant oil or gas shows in cuttings, sidewall cores, or on a mud-logging unit in any of the three deep wells. A sharp kick on the mudstream gas detector occurred in Mallabie at 1459 m. However, the well was in Archaean basement at the time and no further testing was carried out on this methane anomaly (Scott & Speer, 1969). The only organic geochemistry undertaken on these wells was on one Upper Cretaceous Madura Formation core sample in the interval 194.5-194.6 m at Mallabie-1 (Saxby, 1977). The TOC value of 0.05% showed negligible source potential, and no vitrinite reflectance values were obtained.

Similarly low TOC values could be expected for the rest of the Cretaceous siltstones and shales in the Eucla Basin, based on lithological descriptions and the shallow condensed nature of the unit. Most of the Permian section comprises claystones and sandstones-siltstones also with a low visible organic carbon content.

The shallow, condensed nature of the sediments in the Eucla and Denman Basins, confirmed low TOC, and an anticipated low-moderate heat flow, indicate a low potential for hydrocarbon generation. However, there is still some potential for hydrocarbons sourced outside this region to migrate into Eucla and Denman Basin reservoirs. Two possible external sources are Cretaceous shales from the deeper, rifted Bight Basin to the south and Lower Palaeozoic-Upper Proterozoic sediments beneath the Denman and Eucla Basins. However, such a play requires long horizontal migration paths through a relatively thin and condensed section, and cannot be considered very likely.

Cambrian oil and bitumen shows have been reported by Laws (1966) in Hughes-2 and Denman-1 wells, 100 km and 80 km, respectively, onshore. The hydrocarbons were assumed to be sourced from within the Cambrian sequence. The occurrence of hydrocarbons within the Cretaceous sequence in Hughes-2 suggests that Cambrian hydrocarbons have migrated vertically into shallower sequences, and that the long period of erosion/non-deposition at the top of the Cambrian section has not led to the complete flushing of oil/source material from the Cambrian sediments. Vitrinite reflectance was calculated from the Methylpheanthrene Index for one sample in Hughes-2. This indicated that the Cambrian may still be within the oil window. TOC values, however, were only 0.21%.

Mallabie-1 and Nullarbor-8 wells did not intersect the same oil-prone Cambrian rocks intersected in Denman-1 and Hughes-2, although Mallabie-1 did intersect a thick Upper Proterozoic-Lower Palaeozoic sequence (Scott & Speer, 1969). The depth to basement map (Fig. 59.2) indicates that a basement depression which underlies the Denman Basin offshore, is well-developed to the east of Mallabie-1. It then bifurcates, with a northern limb passing west of Nullarbor-6, and a northwestern limb that includes Denman-1. Therefore, the absence of Cambrian oil-prone rocks in Mallabie-1 does not preclude their occurrence offshore.

iv) Play Concepts

Several hydrocarbon play types can be postulated for the Denman and Eucla Basins, although there is very little evidence of their existence to date. The minor tectonic deformation of most of the platform sediments means that both structural and stratigraphic traps are likely to be very subtle.

In the onshore and nearshore parts of the basins, migration of Cambrian oil vertically into Permian and Lower Cretaceous reservoirs appears to be the most attractive trapping mechanism. The occurrence of hydrocarbons within the Cretaceous sequence at Hughes-2 shows that such a mechanism may exist, even where wells are not sited on clearly-defined structures.

Trapping mechanisms for Permian and Cretaceous reservoirs are likely to be stratigraphic pinchout of thin sandstones, and low relief structural warping. However, evidence for such traps is beyond the resolution of currently available seismic data, and requires the acquisition of new high-resolution data.

In the south of the Eucla Basin, migration of Cretaceous hydrocarbons from the deeper, rifted Bight Basin is likely to be the only means of hydrocarbon accumulation. Prerequisites for this include sufficient hydrocarbon generation in the Bight Basin, excellent horizontal migration, and high-quality vertical seals along the entire migration path and at the final reservoir site. The coarse sandstones and conglomerates of the Loongana Formation (86 m thick at Apollo-1) are likely to have good lateral permeability whilst the thin shales within this formation could further enhance horizontal migration potential. The Madura Formation shale (153 m thick at Apollo-1) appears little deformed by faulting in the Eucla Basin. However, the equivalent section in the Bight Basin (Ceduna and Neptune Formations) is likely to be much more affected by rift faulting and thus be more prone to vertical leakage of hydrocarbons.

Potential trapping mechanisms in the southern part of the Eucla Basin are likely to include subtle warps and domes induced by westward sag of the Cretaceous section (Cockshell, 1990b), and Eocene-Oligocene warping, followed by southeastward tilting in the Miocene (Youngs, 1974).

Even though potential plays for the Denman and Eucla Basins are higher risk than adjacent basins, their potential should not be dismissed, particularly in light of the shallow water depths and proximity to land.

e) BREMER BASIN

i) Introduction

Since no stratigraphic, geochemical, or geothermal data exist for the offshore Bremer Basin, and the nearest basin from which such information is available (Eyre Sub-basin) is more than 500 km distant, the hydrocarbon potential of the basin can only be deduced by analogy, inference, and seismic structural and stratigraphic analysis.

Although there are obvious structural and stratigraphic differences between the Eyre Sub-basin and the Bremer Basin, there are some similarities that allow us to draw some conclusions about the potential of the Bremer Basin. In particular, the morphologic position of each basin high on the continental slope seawards of a major basement fault and the fact that the basins are probably contemporaneous, suggest that the thermal and sedimentary histories of both are similar. If this is the case, then it could be expected that the Bremer Basin has been relatively cool throughout its history (as indicated by Jerboa-1 in the Eyre Sub-basin) and hence that source maturity may be a problem. While this is a negative conclusion, there may be some positive evidence in the more intense structuring and possible inclusion of volcanics within the section in the Bremer Basin, both which may have caused an increase in the heatflow.

ii) Source, Reservoir, and Seal

The interpretation of the Bremer Basin seismic data in Chapter 3 concluded that the majority of the sedimentary section is composed of Upper Jurassic-Lower Neocomian (basement to horizon S) and Upper Neocomian (horizon S to horizon R) sediments, with a capping of Upper Cretaceous and Tertiary sediments of variable thickness. By analogy with the Bight Basin, the deeper part of the section could be inferred to contain good-quality lacustrine source beds, while the younger Neocomian section has been shown to be a good potential reservoir section elsewhere. The existence of a regional seal remains unknown.

iii) Play Concepts

Of the existence of potential structures for hydrocarbon entrapment, there can be no doubt. However, the regional nature of the seismic coverage in the basin makes it difficult to define structural closure. Bearing this in mind, the following hydrocarbon play types can be envisaged:

1) *Wrench anticlines* in the eastern half of the basin in water depths of 700 m and greater. Fault-independent closure on these structures is typically about 0.3 s TWT (*ca* 400 m), while fault-dependent closure is greater than 1 s TWT (*ca* 1400 m). However, in some cases, the anticline crests have been deeply eroded prior to the Late Cretaceous, increasing the possibility of hydrocarbons having been lost prior to deposition of a regional seal. If intraformational seals have developed within the Neocomian section, then there is a possibility of stacked reservoirs at a single location.

2) *Clastic aprons* adjacent to the northern boundary fault and orthogonal transfer faults. As with the corresponding play type in the Bight Basin, such clastic aprons may lie up-dip from potential Jurassic source rocks but they will also need to be sealed both vertically and against the fault plane.

3) *Stratigraphic traps* within dipping Neocomian sediments below the angular unconformity seen at horizon R (Figs 64.1 & 64.3). This play type requires sourcing from Jurassic or Lower Cretaceous sediments, migration up-dip into Neocomian reservoirs, and sealing by the ?post-breakup sequence Q-R. Although there is some doubt about a seal being deposited prior to hydrocarbon generation taking place, this play type does have the virtue of being at shallow depths, sub-seabed.

CHAPTER 5: TECTONIC DEVELOPMENT OF THE SOUTHERN RIFT SYSTEM

a) INTRODUCTION

The architecture of the southern continental margin of Australia is dominated by the Mesozoic 'Southern Rift System' (SRS) which was associated with fragmentation of Gondwanaland. The SRS extends for over 4000 km, from Broken Ridge in the west to the South Tasman Plateau in the southeast (Fig. 72.1). In most places, this system now underlies the continental slope, where it has physiographic expression in such marginal features as the Eyre, Ceduna, & Beachport Terraces, the South Tasman Plateau (or Rise), and a continental rise that is abnormally wide (*ca* 200 km) south of the Eyre Terrace and off the Otway/Sorell Basins.

In the Great Australian Bight, the northern bounding fault of the SRS generally lies approximately along the shelf-break. However, in the Duntroon Basin, the fault lies north of the shelf break, with the shelf being underlain by a complex of half-grabens, while in the Otway Basin area, the rift actually extends onshore (Fig. 72.1).

b) Lithospheric Extension

i) The Azimuth and Age of Extension in the Eyre and Recherche Sub-basins

The Eyre Terrace area is one of the few places on the southern margin where the azimuth of extension can be determined from mapping of the basin-forming tilt-blocks, and where the age of this extension can be estimated from the sedimentary section penetrated at Jerboa-1.

In this folio we confirm that the basement of the Eyre Sub-basin (Fig. 40.1) is structured by ENE-trending normal faults and SE-trending transfer faults (Chapter 3c, this report). In addition, the major fault scarp oceanwards of the south-bounding basement block of the Eyre Sub-basin and the crest of the first major rotated block beneath the continental rise also have prominent ENE trends, as mapped in the seismic data.

In the Recherche Sub-basin, south of the Eyre Terrace, the rotation of faulted basement blocks apparently increases southwards, and beneath the lower rise these blocks are lying almost side-on or have been stripped-off during continental extension, leaving sedimentary section lying directly on lower crust. Etheridge & others (in press) have computed an average attenuation of the upper crust of 20% for the Eyre Sub-basin (based on normal fault geometries) and 200% for the lower crust underlying the continental rise (based on a balanced section across the conjugate Australian-Antarctic margins; Fig. 72.3). This difference in attenuation accounts for the major difference in subsidence of these two areas. The sedimentary section beneath the continental rise is thick (>3 s TWT; >5 km) and largely undisturbed by faulting, except at the base of the continental slope (Fig. 72.2, profile 6), where south-dipping syn-sedimentary listric faulting of the upper section soles out on a major decollement ('ND' in Fig. 72.2; horizon 'n' in Chapter 4 of this report). The section between the basement blocks and the decollement appears to be flat-lying and relatively undisturbed: it becomes progressively more featureless seismically to the south, and is characterised by a high (5.0 km.s^{-1}) seismic refraction velocity (Station 37 of Talwani & others, 1979).

The BMR Survey 65 seismic transects shown in Figure 72.2 can be tied directly to Esso Jerboa-1 well in the Eyre Sub-basin and, via Shell lines, to Shell Potoroo-1 on the northern margin of the Ceduna Sub-basin. The tying of seismic sequences from continental slope to rise is based, in part, on character correlations, which can be done with some confidence with the data available.

A re-interpretation of the biostratigraphy in Potoroo-1 and Jerboa-1, presented in earlier chapters, shows that both wells penetrated extensive Mesozoic-Cainozoic sections as old as Valanginian. The previous dating for Jerboa-1 (Bein & Taylor, 1981) interpreted the deepest sediments at the well as Oxfordian (Upper Jurassic). In Jerboa-1 (Fig. 46.2), the major sedimentary sequences penetrated are now considered to comprise:

- Valanginian sands and overlying shale-prone lacustrine sediments;
- Hauterivian sand-prone non-marine sediments with excellent reservoir properties;
- Barremian non-marine claystones and shales;
- thin Albian marine shale-prone sediments;
- thick Cenomanian, marine, interbedded shales, claystones, and sandstones; and
- Middle Eocene and younger open-marine carbonates with a thin underlying sandstone.

Dating of the syn-rift section (and the thin underlying sequence above basement which has uncertain association) is critical to determining the timing of onset and termination of extension. Bein and Taylor (1981) interpret the sediments immediately overlying basement in the half-grabens to be of the same age as the basal sediments in Jerboa-1 (that is, Valanginian); if this identification is correct, and these sediments are infra-rift, then extension probably commenced in the early Valanginian. However, we believe that the resolution of the seismic data does not permit this correlation, and that the basal sequence in the half-grabens may be considerably older than Valanginian, and hence absent at Jerboa-1. Consequently, we can only say definitely that extension had begun by the early Valanginian. Dating of the end of this first extensional phase is more straightforward. Interpretation of company and BMR seismic data indicates that the top of the syn-rift section is probably of Neocomian age (*ca* 122 Ma). This implies that, if extension commenced in the early Valanginian, then extension and concomitant sedimentation were very rapid (*ca* 5 Ma); these unusually high rates are further support for a pre-Valanginian (?Jurassic) onset for extension.

ii) Other Evidence of Extension

Examination of key seismic lines in the central GAB reveals that the generally-held view of the central southern margin of Australia as having formed by N-S extension and spreading, or NNE-SSW extension (Veevers & Eittreim, 1988), may need substantial revision. Willcox & others (1987) outlined a number of different lines of evidence which have a bearing on the nature of extension along the southern margin:

Gravity Field: Examination of the gravity field of the southern margin shows that a number of gravity provinces can be enclosed by parallelograms with approximately ENE- and SE-trending sides that presumably reflect crustal discontinuities, particularly the trend of extensional elements bounded by transfer faults (Willcox, 1990).

Polda Trough: Nelson & others (1986) presented a map of magnetic basement in the Polda Trough which indicated ENE-trending *en-echelon* basement depressions progressively offset to the SE along interpreted NE-SW and NW-SE synthetic and antithetic fault systems that may be related to wrenching. While the initiation of these fault systems appears to have taken place in the Proterozoic-Palaeozoic, there are indications in the seismic data that they may have been re-activated in the Mesozoic.

Ceduna Sub-basin: Fraser & Tilbury (1979) and Stagg & others (1989) presented maps of the seismic and magnetic basement surfaces beneath the eastern half of the GAB. These maps are consistent with an ENE- and SE-trending configuration of basin-forming faults beneath the northern flank of the depocentre underlying the Ceduna Terrace (Fig. 11.2).

Duntroon Basin: This basin appears to exhibit similar ESE and SE trends as the Bight Basin (Figs 9.1 & 11.2). Willcox & others (1987) suggested that the 'Central High' of Whyte (1978; referred to in Chapter 3 of this report as the 'central basement high') may have been the result of NW-SE wrenching, or accommodation of independently-initiated but offset rift centres.

Seafloor Spreading Anomalies: The magnetic anomalies south of the Magnetic Quiet Zone (MQZ), originally identified as 19-22 were re-modeled by Cande and Mutter (1982) as anomalies 20-34, which were formed during a phase of slow spreading. Veevers (1986) refined this interpretation and concluded that Australia-Antarctic breakup occurred in the Cenomanian-Turonian (95 +/-5 Ma). Detailed examination of the poorly-defined slow-spreading anomalies by Veevers & others (1990) strongly indicates that the earliest phase of seafloor spreading was along an azimuth of 155^{o} (SSE).

Structure of the Bremer Basin area: Our mapping of the Bremer Basin (Fig. 63.1) shows that its northern margin is also composed of alternate ENE-WSW normal fault segments, and NW-SE trending transfer faults. The interpretation of the transfer faults is further supported by the presence of large wrench-related anticlines which are related to major offsets of the basin margin.

Gippsland Basin - Bass Strait area: In the Gippsland and Bass Basins, the interpreted normal and transfer fault trends indicate that basin formation was initiated by north-northeast to south-southwest lithospheric extension, almost orthogonal to that in the Eyre Sub-basin area. Etheridge & others (1985) believe this to have taken place largely during the Early Cretaceous. The Otway Basin is generally assumed to form part of this same extensional system, although there is evidence to suggest that strike-slip movements played a significant role in the basin's evolution (Hinz & others, 1986).

Tasmania - South Tasman Plateau: Basins on the western margin of Tasmania and on the South Tasman Plateau (Rise) appear to have been formed by a complex association of extensional and wrench-related phases of movement (Willcox, 1986). For example, the Strahan Sub-basin of the Sorell Basin is bounded on its eastern side by a steep, linear, north-northwesterly-trending fault, and is floored by one or two half-grabens with low-angle normal faults which have an easterly trend. The sub-basin is considered to be of largely strike-slip origin (Willcox & others, 1989, fig. 16) and the basin-forming faults are of Cretaceous, or more likely, pre-Cretaceous age. Basins of similar character and age also appear to be present on the South Tasman Plateau.

Thus, the the available evidence leads us to conclude that lithospheric extension in the area of the Eyre Sub-basin occurred on an approximately northwest-southeast azimuth, commenced in or before the Late Jurassic, and was largely complete by the Hauterivian. The stress field was responsible for rifting from the Bremer Basin (or more probably Broken Ridge) in the west, to at least the Kangaroo Island area in the east. However, further east, in the Bass Strait area and along the western margin of Tasmania, extension appears to have had a NNE-SSW azimuth and probably occurred in the Early Cretaceous.

iii) A Detachment Model for the Central GAB

Etheridge & others (in press) have used the gross architecture of the Eyre Terrace area to create a detachment model for the central southern margin (Fig. 72.3). The main implication is that the Australian margin is a 'lower plate margin' which has been pulled out from beneath the 'upper plate' Antarctic margin. The most highly-extended part of the lower crust (200-400% extension) occurs beneath the continental rise south of the Eyre Terrace (Recherche Sub-basin), and probably beneath the Ceduna Terrace (Ceduna Sub-basin). In the Recherche Sub-basin, highly-extended remnants of the upper plate, comprising low-angle tilt-blocks on the detachment, are visible below the upper continental rise. Under most of the lower continental rise, the tilt-blocks appear to be absent, with rift-stage sediments directly overlying the lower crust. Near the foot of the continental rise, a basement high, interpreted by Veevers (1986) as the continent-ocean boundary (COB), may be an area in which the sub-horizontal detachment surface forms a 'dome' or 'arch', close to, or above seabed. High-quality, migrated BMR seismic data from south of the Ceduna Terrace show that this 'basement high' has a complex faulted structure with apparent adjacent syn-rift sediments. By analogy with the 'Basin and Range Province' of the western USA, this could be a 'metamorphic core complex', topped by a mylonite zone. Areas of lesser extension (about 20%), which have consequently undergone less subsidence, now correspond with features such as the Eyre Sub-basin and Bremer Basin.

The area of maximum extension corresponds approximately with the 'magnetic quiet zone' (MQZ). Its northern boundary (itself a detachment branch fault) lies in the vicinity of, or somewhat north of the magnetic trough which is so prominent along the southern margin. Thus the MQZ appears to be a signature of highly-thinned lower continental crust, in places overlain by a few remnant upper-crust tilt-blocks. It is presumed that the MQZ in the Otway Basin-Tasmania margin will have a similar origin, though, as yet, this is not clear from the available seismic data. Low-intensity magnetic lineations, which in some areas are observed within the MQZ, may be generated by a variety of sources: these sources might include the upturned edges of basement tilt-blocks, magmas intruded into fault-planes, dikes of oceanic basalt intruded laterally from a central breakup location, and cooling of the lower plate below the Curie Point during gradual unloading of the upper plate.

The detachment model has important implications for heat-flow and source rock maturity on the southern margin of Australia. In general, such a model predicts a horizontal transfer of lithospheric extension across the detachment: the degree of extension within the deep-seated ductile zone defining the area of maximum uplift and the location of the thermal anomaly associated with rifting. Thus, an area of maximum extension in the upper crust, created by normal faulting, may be far removed from the zone of maximum heatflow, associated with maximum thinning and ductile flow in the lower crust. This leads to the conclusions that, intuitively, may be unexpected: for instance, that within any one rift system, a highly structured rift basin containing thick syn-rift sediments on a lower plate margin, could have been subjected to much lower heatflow than a simply structured upper plate basin with thin syn-rift sediments. Thus, the position of a basin in the overall structure of the rift system needs to be understood, and will have a profound effect on the degree of maturation of its source rocks. If, for example, heat-flow was too high, source rocks within the syn-rift/ rift section would rapidly be brought to maturity and could migrate to surface before seals were laid down. In the optimum situation, source rocks would be brought to maturity during more recent geological time, when there would be a high chance that seals were in place and that late-stage structures had developed to entrap migrating fluids.

The detachment model appears to be applicable to the GAB as a whole. However, in the area of Kangaroo Island, where the continental slope is particularly steep and where there are no sedimentary basins on the margin, the polarity of the model may be reversed; that is, the Australian margin may be the upper plate, with the main basin development taking place on a conjugate Antarctic lower plate. If one assumes that the Otway Basin is located on a lower plate, then major transfer faults must occur to the west and east of Kangaroo Island. The sparse seismic data in the area do not allow this situation to be resolved.

iv) Central Bight Basin: 'Nappe Zone' and Outer High

Subsequent to the basin formation that produced the foundered basement blocks, the major structuring phase appears to have taken place in the period following the formation of the Neocomian decollement ('ND' in Fig. 72.2). Two styles of structuring are prominent - listric faulting beneath the Ceduna Terrace and thrust faulting that has produced a NW-SE trending zone of spectacular overthrust and nappe-like structures beneath the upper continental rise (Fig. 49.2, 72.2). The listric faults appear to sole out on the decollement, which itself is interpreted to extend from the Ceduna Terrace to the rise, with a maximum gradient of 1^{o} beneath the lower slope. The mode of formation of the nappe structures is at present unclear; however, there appear to be three main possibilities:

- The apparently unfaulted nature of the decollement beneath the nappes suggests that they may have formed by the slippage or mobility of incompetent sediments - these being squeezed out from beneath the terrace during the thermal sag phase of margin formation, owing to the gradient and differential weight of the overburdens on the terrace and the rise. This interpretation is consistent with our observation that the 'nappe layer' thins north-eastwards beneath the terrace. The nappes may in fact be 'toe-thrusts' of the type described by Boeuf and Doust (1975), with the head of the thrust system being expressed as listric faulting beneath the terrace.

- The nappes may be salt-cored: the seismic character of some beds within the nappes bears a strong similarity to halite structures in the Polda Trough to the northeast. However, the Polda Trough halite is interpreted to be of Proterozoic age (Chapter 3, this report), and it is very difficult to interpret sediments within the nappe zone as being older than Barremian. The possibility of Cretaceous salt remains, although this is considered extremely unlikely, given the prevailing palaeo-latitudes in the Early Cretaceous (50s to 60s) and the absence of any salt of this age elsewhere around Australia.

- An alternative mechanism for triggering these structures, which finds support in the marked NNW-SSE linearity of the nappe system (Fig. 9.1), is that there has been transpressional movement along the zone between the listric faults and the nappes. The nappes would then effectively be the expression of a giant 'positive flower structure', in which the sediment pile had been squeezed upwards and outwards, during left-lateral adjustment along a deep-seated transfer fault or accomodation structure which underlies and gives rise to the southwest margin of the Ceduna Sub-basin ('Southwest Ceduna Accommodation Zone' in Fig. 9.1). This gains some support from the presence on some Shell 'Petrel' seismic lines of a deep-seated basement high or change in basement elevation at the location of the postulated transfer fault (southwest end of line 69-289, Fig. 38.1).

This third mechanism suggests that the azimuth of extension may have undergone adjustment at about the time of Cenomanian breakup. The width of this nappe zone (about 80-100 km) is, intuitively, difficult to reconcile with transfer fault adjustment. However, in recent discussions on this matter with Dr. James Lowell, he pointed out that accomodation structures of similar scale were present within the Svalbard (Spitzbergen) Gypsum Basin and in the Maracaibo region of Venezuela. Both were associated with with less-competent sediments undergoing folding adjacent to major strike-slip faults, and over distances of up to 100 km.

v) Consequences of Two-phase Extension

The data now available and summarised in this paper point very strongly to a generally NW-SE direction of initial extension for the southern margin of Australia. It is likely that the ESE-trending Cenomanian faults within the Ceduna Sub-basin, which have been used by some authors (*eg* Veevers & Eittreim, 1988) to infer NNE-SSW directed extension in the GAB, are primarily in response to:

- thermal uplift and subsidence of the incipient margin sub-parallel to the rift axis; or
- a structural 'overprint' created by a younger episode of extension which is believed to have created the offshore basins of southeastern Australia (Etheridge & others, 1985).

In either case, this pre-Cenomanian tectonism would have occurred sometime after formation of the GAB Basins - that is, these faults are <u>not</u> basin-forming structures. The extension in the GAB region commenced no later than the early Valanginian (and perhaps as early as the Middle to Late Jurassic) and was complete by the end of the Hauterivian (*ca* 120 Ma), as evidenced by the age of the syn-rift sequence in the Eyre Sub-basin (Jerboa-1). It is possible that basin formation actually began much earlier: much of the GAB may even be underlain by a Palaeozoic intracratonic basin, as indicated by Permian sediments in the Denman Basin and Polda Trough.

Figure 72.4 presents a general scheme for the formation of Australia's southern margin which is based on all data available to us. It comprises at least three periods of continental extension during which the Australian and Antarctic Plates were joined or in partial contact, and two periods of drifting. Figure 72.4c shows the position of the incipient suture following continental extension, whereas Figures 72.4b & 72.4a show the situation prior to each phase of extension.

The location of the continent-ocean boundary (COB) suture within the extended 'Australia-Antarctic Superplate' has been determined by Veevers & Eittreim (1988) from seismic and magnetic profiles. Its position (Fig. 72.4c) is generally well-constrained, except in the area east of about 144^{o} (on the Australian Plate) where data are sparse.

We consider that the position occupied by the South Tasman Rise (STR) in these plate reconstructions is uncertain. In the post-rift/pre-drift extension situation, Veevers & Eittreim (1988) assume that the incipient suture passed between the Antarctic Plate and the STR, which they postulate lay about 100 km eastwards of its present position (STR/B; Fig. 72.4c). However, we consider it more likely that the STR was then part of the Antarctic Plate, and was juxtaposed against the Otway/Sorell Basin area until drifting commenced (STR/A). This is consistent with the similar seismic stratigraphy of the Otway Basin and STR, and the linear strike-slip character of the northeastern margin of the STR. The suture would thus have passed between the STR and Tasmania.

In the GAB, pre-Valanginian extension (Phase E1, Table 14) is computed to have been approximately 300 km in a NW-SE sense (Fig. 72.4a & b). This extension resulted in the formation of the extensional Eyre Sub-basin, the largely 'transtensional' Bight and Duntroon Basins, and possibly the (?)extensional Robe Trough: it also led to modification of structures within the much older Polda Trough. During this period, a major left-lateral strike-slip fault, or fault-zone, is postulated to have extended through the nascent Otway Basin: it probably passed between Tasmania and the STR (see alternative positions STR/A and STR/B) and led to formation of the strike-slip Sorell Basin and northeast margin of the STR. A branch of this strike-slip zone may have passed through the Bass Basin and Tamar Graben areas of northern Tasmania, acting as a conduit for the extrusion of Jurassic dolerite.

During the Early Cretaceous (probably post-Neocomian) a major change in the stress field took place: this was probably related to global changes in plate boundary configurations in the Aptian. At about this time, an extensional regime, with a NNE-SSW sense, led to the formation of the Gippsland and Bass Basins, and enhanced development of the Otway and Sorell Basins of southeastern Australia (Fig. 72.4c). This extension was about 120 km (Phase E2, Table 14) in the region between the Australian mainland and Tasmania, but may have decreased northwestwards.

The almost orthogonal sense of the pre-Valanginian (E1) and later

Table 14: Phases of Extension and Drifting South of Australia

Extension/drift phase	Age Onset	 Termination	Sense	Extent (km)	Comment
E1 (Fig. 72.4b)	early Valanginian, ?or older (?>126 Ma)	late Hauterivian (~120 Ma)	NW-SE	~300	Extension in GAB; strike-slip Otway/west Tasmania; Jurassic volcanics
E2 (Fig. 72.4c)	Early Cretaceous	(~100 Ma)	NNE-SSW	120	Southeast Australian basins; structural overprint in GAB; (?) plate boundary problems
E3/D1 (Fig. 72.4d)	Cenomanian (~96 Ma)	?Middle Eocene (~42 Ma)	165°	500	Wrenching on Tasmanian margin
D2 (Fig. 72.4d)	Middle Eocene (~42 Ma)	Present	N-S	2600	Plate clearance in Oligocene (35 Ma); west margin of South Tasman Rise forms

Early Cretaceous (E2) phases of extension is probably responsible for the structural complexity of the region, in that:

- Early Cretaceous extensional faults might be expected to overprint older structures in the GAB, and/or
- a temporary plate dislocation (plate boundary) may have developed within either/or both the Australian and Antarctic Plates in the region of Kangaroo Island (Fig. 72.4c).

The orientation and extent of seafloor spreading since the Cenomanian (~95 Ma) is shown in Figure 72.4d. This consists of 500 km of slow spreading (D1) on an azimuth of 155^{o}, until the mid-Eocene (~44 Ma), followed by about 2600 km of fast spreading (D2) on a N-S azimuth. We envisage that the STR (STR/A) was part of the Antarctic Plate through the Late Cretaceous and Early Tertiary, moving from juxtaposition with the Sorell Basin to its present location. This led to continued structuring of the Tasmanian margin (Phase E3), concomitant with drift (Phase D1). The western margin of the STR formed as a left-lateral strike-slip fault (eventually the Tasman Fracture Zone) when the Australian and Antarctic Plates cleared in the mid-Oligocene (~32 Ma): from then on, the STR was essentially a micro-plate. At this time we see no simple explanation for the change in extension/spreading azimuths from SE (Valanginian and older), to SSW (later in the Early Cretaceous), and back to SSE at the onset of spreading in the Cenomanian: however, they are probably related to the geometry of plate fragmentation and drifting on a global scale.

c) SOUTHERN MARGIN BREAKUP AND SEAFLOOR SPREADING

Breakup of the southern margin (that is, the onset of seafloor spreading) has in most cases been determined from identification of seafloor spreading magnetic anomalies adjacent to the margin (Weissel & Hayes, 1972; Cande & Mutter, 1982), or by extrapolation of the spreading-rate/time-span, between the oldest anomaly and the interpreted COB (Veevers, 1986). Using these methods, breakup for the southern margin has been computed as Cenomanian (95 +/-5 Ma). However, we consider that this may not be valid for the area west of the Ceduna Sub-basin. Two lines of evidence in this area - the oldest magnetic anomalies and the stratigraphy of the continental rise - lead us to conclude that both rifting and breakup were probably older than Cenomanian, or that there may have been two distinct episodes of rifting and seafloor spreading.

The oldest magnetic anomalies (approximately A24 to A34, as determined by Cande & Mutter, 1982; Fig. 72.1) occur sporadically between the Diamantina Zone and the continental slope, from the Naturaliste Plateau in the west, to the Eyre Sub-basin in the east. They appear to be truncated by the southwest margin of the Ceduna Sub-basin. In the Naturaliste Plateau area, Markl (1974) showed these anomalies to have a ENE-trend and implied that they may form part of the 'M-Series' which he had identified in the Perth Abyssal Plain area. South of the Eyre Sub-basin, the anomalies are usually shown to have an east-west trend, but the evidence for this trend is scant. We speculate that, in this area too, the anomalies may form part of the M-Series period of spreading (that is, Oxfordian to Aptian) and that breakup was in the Hauterivian (ca 120 Ma), as on the western margin. Dating of these anomalies by the usual method remains inconclusive, because they are compressed by the very slow spreading rate. If this speculation is correct, then an arm of the western margin rift system, which began development in the Permian, must have extended eastwards at least as far as southwest margin of the Ceduna Sub-basin. From this, it follows that there is a good possibility of shallow marine incursions in the axis of the rift valley a long time prior to their appearance in the Albian at Jerboa-1 and Potoroo-1.

An alternative approach used to establish the age of breakup, has been to determine the relationship of the margin stratigraphy and the oceanic crust, using seismic data. Using this technique, Willcox (1978) demonstrated that Upper Cretaceous sediments overlie oceanic crust south of the Ceduna Sub-basin - an observation at variance with the breakup age, which at that time was dated as Paleocene (Weissel & Hayes, 1972). This method can now be applied to the area south of the Eyre Sub-basin using high-quality BMR seismic profiles.

On lines extending southwards from the Eyre Sub-basin we observe a Neocomian (approximately late Hauterivian) unconformity, which has been dated by a tie to Jerboa-1 (Fig. 72.2). A tentative tie to Potoroo-1 in the Ceduna Sub-basin also establishes this unconformity as pre-Cenomanian. Beneath the continental rise, where the sediments are abnormally thick (*ca* 6000 m), this unconformity (horizon 'n' in this report, and 'ND' in Willcox & Stagg, 1990, and in Fig. 72.2) becomes the most significant in the section: it is almost flat-lying, terminates an older period of deposition shown by a seismically characterless (?indurated) sequence overlying ill-defined tilt-blocks, and forms a decollement upon which slump- and nappe-like structures (>2000 metres thick) have formed. A similar surface, interpreted to be of similar age, has also been recognised in the Duntroon Sub-basin (this report). The surface ND has some of the characteristics of a 'breakup unconformity', showing substantial erosion of the underlying sequence and with the overlying sediments onlapping it. Furthermore, when traced oceanwards to the magnetically-defined COB of Veevers (1986), it is seen to overlie both an outermost tilt-block and the igneous basement which is juxtaposed on its southern side. On some lines which have been migrated, the igneous basement itself appears to be rifted and/ or gives way to another zone of tilt-blocks to its south. These observations lend support to some new conclusions and point to several unresolved problems:

- the 'ND' unconformity overlies Neocomian and older syn-rift and rift sediments and is probably a 'breakup unconformity' related to western margin spreading: it extends eastwards into the Duntroon Basin, implying that in this area too the initial breakup event was Neocomian and rifting was considerably older than Neocomian.

- if the 'ND' unconformity extends across true oceanic basement beyond the magnetically-defined COB, then the age identification of the magnetic seafloor spreading anomalies is incorrect.

- if the igneous basement on the outer continental rise, beyond the magnetically-determined COB, is Neocomian or older: is it a product of intrusion into the rift, lateral injection of an oceanic melt along fault conduits, or possibly part of a zone of a 'mixed crust' composed of alternate slivers of continental and oceanic material?

- if it were oceanic crust, is its faulted character created by cooling during very slow spreading, followed by re-rifting?

- could this zone of relatively shallow-seated igneous basement be a 'metamorphic core complex' under the master detachment fault: it would then be composed of mylonite and brought to near surface during the unloading of the 'upper' Antarctic Plate?

These observations may explain the conclusions of Talwani & others (1979) that the 'quiet zone crust can best be treated as something unique, being neither continental nor oceanic'. However, we interpret this crust to be composed of mainly a thinned lower plate, probably injected by ribbons of oceanic basalt towards its southern edge.

The tectonic subsidence curves for Potoroo-1 and Jerboa-1 (Figs 70.1 & 71.1) show periods of rapid subsidence in the Valanginian and Cenomanian. These events could be interpreted as the rift-onset and thermal-sag (breakup) phases of margin formation or, alternatively, as an expression of western margin and southern margin breakup, respectively.

d) SUMMARY OF TECTONIC HISTORY

The above discussion allows us to deduce a speculative tectonic history for the Great Australian Bight region, and for the Southern Rift System, in general:

1) Lithospheric extension in the 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 SRS. Movement would have been predominantly strike-slip or transtensional in the nascent Otway Basin, and in Bass Strait/ west Tasmania area.

2) Permian to Jurassic sedimentary basins developed along the embryonic SRS (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 floored by crust which ranged from highly-extended continental, through mixed slivers of oceanic and continental material, to purely oceanic. Crust with the more 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 that which has already taken place in the west.

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

5) Cenomanian breakup and the onset of thermal sag. This 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 caused by 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 formed in the Duntroon Basin. Several thousand metres of sediment were probably eroded from the tops of these structures. We have 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.

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APPENDIX I
EXPLORATION TENEMENTS - SOUTH AUSTRALIA

LICENCE/ PERMIT	HOLDER	PERIOD
OEL 7	R.F. Bristowe/Santos Ltd	1/3/54-27/2/89
OEL 20/21	Delhi Australian Petroleum Ltd/Santos Ltd	28/2/59-27/2/69
OEL 26	Haematite Exploration Pty. Ltd	1/8/61-30/9/68
OEL 27	H.F. Blacker, P.L. Brady & T. Turner	1/10/61-30/9/62
OEL 32	H.F. Blacker, P.L. Brady & T. Turner	1/6/63-31/5/65 Part relinquishment 13/5/64
OEL 33	Outback Oil Co. N.L., Union Texas (Aust) Co, Rock Island Oil & Refining Co. Inc., Tenneco Australia Inc., Coastal Petroleum N.L.	20/1/64-8/6/66
OEL 38	Shell Development (Australia) Pty. Ltd.	1/6/66-31/12/88 Part relinquishment 6/12/67
EPP 1	Hematite Petroleum Pty. Ltd.	4/7/68-20/10/70
EPP 3	Hematite Petroleum Pty. Ltd.	14/11/68-16/2/71
EPP 4	Outback Oil Co. N.L.	12/12/68-21/6/77 Part relinquishment 12/12/74
EPP 5	Shell Development (Australia) Pty. Ltd.	12/12/68-11/12/75 Part Relinquishment 12/12/74
EPP 6	Shell Development (Australia) Pty. Ltd.	12/12/68-11/12/75 Part relinquishment 12/12/74
EPP 7	Shell Development (Australia) Pty. Ltd.	9/1/69-8/1/76 Part relinquishment 9/1/75
EPP 10	Shell Development (Australia) Pty. Ltd.	8/5/69-7/5/77 Part relinquishment 8//5/73 Part relinquishment 8/5/75
EPP 11	Shell Development (Australia) Pty. Ltd.	8/5/69-7/5/77 Part relinquishment 8/5/73 Part relinquishment 8/5/75
EPP 12	Outback Oil Co. N.L.	24/6/69-15/2/74
EPP 13	Bridge Oil N.L., Aurora Minerals N.L., Target Exploration Pty. Ltd., Continental Oil Co. of Australia Ltd.	3/7/69-27/11/74
EPP 15	Outback Oil Co. N.L., Australian Occidental Petroleum Inc., Charter Resources Aust. Co., OKC Petroleum International Inc., Marion Corporation, Jeltie Oil Co. Ltd.	16/10/75-7/1/83 Part relinquishment 16/10/81
EPP 16	BP Petroleum Development Pty. Ltd. Hematite Petroleum Pty. Ltd.	30/6/80-29/6/82
EPP 17	Stirling Petroleum N.L., Magnet Metals Ltd. Monarch Petroleum N.L., Lennard Oil N.L.	21/10/80-26/5/83
EPP 19	Outback Oil Co. N.L.	3/7/81-14/9/84
EPP 21	Getty Oil Development Ltd, Ampol Exploration Ltd, Natomas Petroleum International Inc., Sovereign Oil Australia Ltd, South Australian Oil & Gas Corp. Pty. Ltd., Diamond Shamrock Oil Co. (Aust.) Pty. Ltd, BP Petroleum Development Ltd.	29/6/82-28/6/86

APPENDIX II

SEISMIC SURVEY SUMMARY - GREAT AUSTRALIAN BIGHT/DUNTROON BASINS STUDY

YEAR	SURVEY NAME	OPERATOR	CONTRACTOR	SEISMIC ENERGY SOURCE	TRAVERSE LENGTH(km) ( ) for REFRACTION	CDP COVERAGE (REFRACTION)	REFERENCE OR FILE NUMBER	STATE
1960	'Vema' Cruise 16, Marine Seismic Refraction Studies - Continental Margins	BMR, ANU and Lamont Geological Observatory	Lamont Geological Observatory	Explosives	(185)	(R)	Hawkins & others (1965)	SA & WA
1966	South Australian Shelf R-1 Marine Seismic Survey	Shell Development	Western Geophysical	Explosives	687 +(56)	100 & 300 (R)	PSSA 66/11135	SA
1967	Marine Seismic Survey Offshore Eucla Basin	Tenneco	Western Geophysical	Explosives	582 +(160)	300 & 600 (R)	PSSA 66/11139	SA & WA
1967	Marine Seismic Survey Offshore Eucla Basin (R-2)	Tenneco	Western Geophysical	Explosives	1197	300	PSSA 67/11195	SA & WA
1967	1967 Global Expedition of ESSA R.V. 'Oceanographer'	Atlantic Oceanic Laboratories	USC & GS	Airgun	188	100	Conolly & others, 1970	SA & WA
1968	South Australian Shelf Marine Seismograph Survey (R-2)	Shell Development	Namco Geophysical	Airgun and Explosives	745 +(99)	600, 1800 2400 (R)	PSSA 67/11205	SA
1968-1969	South Australian Shelf R-3 Marine Seismic Survey	Shell Development	Shell BIPM.	Airgun and Explosives	1298	600 & 2400	PSSA 68/3048	SA
1969	South Australian Shelf R-4 Marine Seismic Survey	Shell Development	GSI	Airgun	4162 +(13)	2400 (R)	P(SL)A 69/2	SA
1970	South Australian Offshore 1970 GSI Marine Seismic Survey	Shell Development	GSI	Airgun	3899	2400	P(SL)A 70/1	SA
1970	First Offshore Polda Basin Marine Seismic Survey	Bridge Oil	Teledyne Exploration	Airgun and Sparker	974	100 & 2400	PSSA 70/163	SA

APPENDIX II (CONT.)

YEAR	SURVEY NAME	OPERATOR	CONTRACTOR	SEISMIC ENERGY SOURCE	TRAVERSE LENGTH(km) ( ) for REFRACTION	CDP COVERAGE (REFRACTION)	REFERENCE OR FILE NUMBER	STATE
1969-1970	USNS Eltanin Cruises 39-45	Lamont-Doherty Geological Observatory	U.S.N.S.	Airgun and Sparker	114720	100	Talwani (ed.) 1976	WA,SA, VIC,TAS
1970-1971	South Australian Deepwater Seismic Survey 1970	Shell Development	Western	Aquapulse	3900	2400	P(SL)A 70/1	SA
1970	Teledyne Reconnaissance Seismic Survey	Teledyne Exploration	Teledyne Exploration	Sparker	1600	1200	P(SL)A 70/19	WA
1970	Offshore Twilight Cove Seismic and Magnetic Survey	Hartogen Exploration	GSI	Airgun	1640	1200	PSSA 70/440	WA
1970	Baudin Marine Seismic and Magnetic Survey (Young Rocks)	Hematite Petroleum	Western Geophysical	Aquapulse	487	2400	PSSA 70/178	SA
1970-1973	Geophysical Surveys of the Continental Margins of Australia	BMR	Compagnie Generale De Geophysique	Sparker	186548	600	BMR REC. 74/110, 74/111, 75/151, 104 & 152	WA,SA,VIC TAS,NSW, QLD,NT
1971	Polda Basin Second Marine Seismic Survey	Target Exploration	Teledyne Exploration	Airgun and Sparker	1159 +(29)	100, 2400 (R)	PSSA 71/355	SA
1971	Offshore Eyre Seismic Survey	Hartogen Exploration	GSI	Airgun	56	2400	P(SL)A 71/34	WA
1971-1972	South Australian Offshore Program 1971, Shallow Water Marine Seismic Survey	Shell Development	GSI	Airgun	1556	2400	P(SL)A 71/2	SA
1971-1972	South Australian Offshore Program, 1971, Deepwater Marine Seismic Survey	Shell Development	GSI	Airgun	2881	2400		SA

YEAR	SURVEY NAME	OPERATOR	CONTRACTOR	SEISMIC ENERGY SOURCE	TRAVERSE LENGTH(km) ( ) for REFRACTION	CDP COVERAGE (REFRACTION)	REFERENCE OR FILE NUMBER	STATE
1972	Offshore Esperance Seismic Survey	Continental Oil	GSI	Airgun	957	2400	P(SL)A 72/7	WA
1972	Denman Basin Seismic Survey	Outback Oil	GSI	Airgun	1350	2400	P(SL)A 72/17	SA
1972	Denman Basin Seismic Survey Extension	Outback Oil	GSI	Airgun	1844	2400	P(SL)A 72/17	SA
1972	USNS Eltanin Cruises 51-55A	Lamont-Doherty Geological Observatory	U.S.N.S.	Airgun	74191	100	Talwani (ed.) 1978	WA,SA,VIC TAS,NSW
1972-1973	Marine Geophysical Survey Offshore Australia (Petrel)	Shell Development	Shell BIPM	Airgun	10904	2400	P(SL)A 72/30	WA,SA,VIC, TAS,NSW
1973	Scorpion Bight Seismic and Gravity Survey	Coastal Petroleum	Geosurveys	Explosives	(18)	(R)	PSSA 72/3276	WA
1973	South Australia 1973, SA5 & SA6/7 Marine Seismic Survey (R-7)	Shell Development	GSI	Airgun	1895	2400	P(SL)A 73/6	SA
1974	Offshore Marine Seismic Survey (R8)	Shell Development	GSI	Airgun	1767	2400, 4800	P(SL)A 74/2	SA
1974	Great Australian Bight R-9 Marine Seismic Survey	Shell Development	GSI	Airgun	981	2400	P(SL)A 74/21	SA
1974	Bremer (R74A) Marine Seismic Survey	Esso	GSI	Airgun	2224	2400, 4800	P(SL)A 74/3	WA
1976	R-10 Marine Seismic Survey	Shell Development	Prakla-Seismos GMBH	Airgun	833	2400	P(SL)A 76/7	SA
1981	SA EPP 16 S81 Marine Seismic Survey	BP Petroleum	GSI	Airgun	986	4800		SA

APPENDIX II (CONT.)

YEAR	SURVEY NAME	OPERATOR	CONTRACTOR	SEISMIC ENERGY SOURCE	TRAVERSE LENGTH(km) ( ) for REFRACTION	CDP COVERAGE (REFRACTION)	REFERENCE OR FILE NUMBER	STATE
1980-1981	1981 Polda Seismic Survey	Australian Occidental	Western Geophysical	Airgun	3214	300, 4800		SA
1982	GSI-82-SPEC Marine Seismic Survey	GSI	GSI	Airgun	827	4800		SA
1982	GSI-82-EPP19 Marine Seismic Survey	Outback Oil	GSI	Airgun	539	4800		SA
1981-1982	SA EPP 16 S82 Marine Seismic Survey	BP Petroleum	Western Geophysical	Airgun	1202	5000		SA
1983	Duntroon Basin EPP-21 Marine Seismic Survey 1983	Getty Oil	GSI	Airgun	2035	6000		SA
1984	1984 Duntroon Seismic Survey	Getty Oil	Western Geophysical	Airgun	1017	6000		SA
1986	Rig Seismic Survey 65	BMR	BMR	Airgun	3574	1200, 2400	BMR REPORT 286	SA, WA

APPENDIX III

MAGNETIC SURVEY SUMMARY - GREAT AUSTRALIAN BIGHT/DUNTROON BASINS STUDY

YEAR	SURVEY NAME	OPERATOR	CONTRACTOR	SURVEY ALTITUDE (m)	LINE SPACING	TRAVERSE LENGTH (KMS)	REFERENCE
1954	Reconnaissance Aeromagnetic Survey of the Eucla Basin	BMR	BMR	450	Reconnaissance	5600	BMR Record 1958/87
1953	Eyre Peninsula Aeromagnetic Survey	SADME	BMR	460 bar	Arcuate lines 1.6 km apart	-	1:250 000 sheets
1955	Southern Eyre Peninsula Aeromagnetic Survey	SADME	Adastra	460 bar	1.6 km	-	1:250 000 sheets
1955	Southern Yorke Peninsula Aeromagnetic Survey	SADME	Adastra	300	1.6 km	-	1:250 000 sheets
1956	Kangaroo Island Aeromagnetic Survey	SADME	Adastra	150	1.6 km	-	1:250 000 sheets
1959	Streaky Bay-Yardea Aeromagnetic Survey	SADME	BMR	150	1.6 km	-	1:250 000 sheets
1960	"Vema" Cruise 16, Seismic Refraction Studies-Continental Margins	BMR, ANU & Lamont-Doherty Geological Observatory	Lamont-Doherty Geological Observatory	Shipborne magnetic profiles along seismic traverses	Reconnaissance	-	Hawkins & others (1965)
1961	Childara-Gairdner Aeromagnetic Survey	SADME	BMR	150	1.6 km	-	1:250 000 sheets
1961	Bass Strait - Encounter Bay Aeromagnetic Survey	Haematite Exploration	Aeroservice Ltd	610 m a.s.l.	3.2/6.4/9.6	28700	PSSA 60 PSSA 62/1710-11

YEAR	SURVEY NAME	OPERATOR	CONTRACTOR	SURVEY ALTITUDE (m)	LINE SPACING	TRAVERSE LENGTH (KMS)	REFERENCE
1964	Airborne magnetometer Survey over St Vincent Gulf and Investigator Strait	Beach Petroleum	Aeroservice Ltd	610	2.4/14.4 kms to 2.4/9.6 kms	4400	PSSA 64/4609
1966	Aeromagnetic Survey O.E.L. 33/38	Outback/ Shell	Aeroservice Ltd	450	11	16000	PSSA 66/4620-21
1967	1967 Global Expedition of ESSA R.V. "Oceanographer"	Atlantic Oceanic Laboratories	USC & G.S.	Shipborne profiles along reconnaissance seismic lines	Reconnaissance	-	Conolly & others (1970)
1968	Young Rocks Aeromagnetic Survey	Hematite Petroleum	C.G.G.	450	3/6 kms	28660	PSSA 68/3055
1969-1974	Shell Deepwater Seismic Surveys 'R4' to "R9"	Shell Dev.	G.S.I. Western Geophysical	Shipborne profiles	Variable	-	P(SL)A 69/2, 70/1, 71/2 73/6, 74/2, 74/21
1969-72	USNS Eltanin Cruises 39-45 and 51-55A	Lamont-Doherty Geol. Obs.	U.S.N.S.	Shipborne profiles	Lines spaced approx. every 5^{o} of longitude	-	
1970-73	Geophysical Surveys of the Continental Margins of Australia	BMR	C.G.G.	Shipborne traverses	N-S lines spaced 30-50 kms apart	-	BMR REC. 74/15, 74/147
1972-73	Airborne Magnetic and Radiometric Survey of Coompana, Nullarbor, Fowler and Nuyts 1:250 000 areas	SADME	BMR	150	1.6	3200	BMR REC. 1977/52
1972-73	Marine Geophysical Survey Offshore Australia (Petrel)	Shell Development	Shell BIPM	Shipborne traverses along seismic traverses	Reconnaissance	-	P(SL)A 72/17

APPENDIX III (CONT.)

YEAR	SURVEY NAME	OPERATOR	CONTRACTOR	SURVEY ALTITUDE (m)	LINE SPACING	TRAVERSE LENGTH (KMS)	REFERENCE
1975	Spencer Gulf Aeromagnetic Survey	SADME	BMR	150	1.6	-	1:250 000 sheets
1978	Polda Basin Aeromagnetic Survey	Outback Oil	Aero Exploration	150	1.0	5000	SADME ENV 3419
1981	Polda Basin Marine Seismic, gravity & magnetic survey	Australian Occidental	Western Geophysica	Shipborne traverses	Seismic traverses	3200	SADME ENV 3419
1982	Stansbury Basin Aeromagnetic Survey	SADME	Geoex	150	1.0 E/W 5.0 N/S	-	1:100 000 sheets
1986	Rig Seismic Survey 65 Southern Margin Project	BMR	BMR	Shipborne traverses	Reconnaissance	3574	BMR Report 286
1988	Eyre Peninsula Aeromagnetic/Radio-metric	SADME	Geoterrex	100	1.0 E/W	60000	1:100 000 sheets (in prep.)

APPENDIX IV

GRAVITY SURVEYS SUMMARY - GREAT AUSTRALIAN BIGHT/DUNTROON BASINS STUDY

YEAR	SURVEY NAME	OPERATOR	CONTRACTOR	STATION SPACING (KM)	NO. OF STATIONS	REFERENCE
1954-55	Regional gravity traverses across the Eucla Basin.	BMR	BMR	8	395	BMR RECORD 1956/145
1964	St Vincent Gulf Submarine gravity	Beach Petroleum	Geosurveys of Australia Pty Ltd	2	374	PSSA 63/1914
1965	Investigator Strait gravity	Beach Petroleum	Geosurveys of Australia Pty Ltd	3	64	PSSA 70/975
1965-66	Eucla Basin gravity survey OEL 33	Outback Oil Co N.L.	Geosurveys of Australia Pty Ltd	5	1103	PSSA 65/4819
1967	1967 Global Expedition of ESSA R.V. "Oceanographer"	Atlantic Oceanic Laboratories	USC + GS	Shipborne Profiles along seismic lines.	-	Conolly & others (1970)
1967	Regional gravity Survey - Kimba and Elliston 1:250 000 sheet areas.	SADME	SADME	7	-	SADME Quart. Geol. Notes 25
1969-72	USNS "Eltanin" Cruises 39-45 and 51-55A	Lamont-Doherty Geol. Obs.	USNS	Shipborne profiles along seismic lines.	-	
1970	Reconnaissance helicopter gravity survey of S. Aust.	BMR	Wongela Geophysical	7	7800	BMR Record 1974/88
1970-73	Geophysical surveys of Continental Margins of Australia.	BMR	CGG	Shipborne profiles along seismic lines.	-	BMR Record 1974/147

APPENDIX IV (CONT.)

YEAR	SURVEY NAME	OPERATOR	CONTRACTOR	STATION SPACING (KM)	NO. OF STATIONS	REFERENCE
1972-73	Marine Geophysical Survey offshore Aust. (Petrel)	Shell Development	Shell BIPM	Shipborne profiles along seismic lines	-	P(SL)A 1972/17
1980-81	Polda Basin marine seismic survey EPP 15	Australian Occidental Pty Ltd	Western Geophysical Co	Shipborne profiles along seismic lines	-	SADME Env 3988
1986	Rig Seismic Survey 65 Southern Margins Project	BMR	BMR	Shipborne traverses along seismic lines	-	BMR Report 286

APPENDIX V

DRILLING ACTIVITY 1969-1986

WELL	YEAR	OPERATOR	TENEMENT	DRILL RIG	SPUDDED	RIG RELEASE	LATITUDE	LONGITUDE	TD	STATUS
Apollo-1	1975	Outback Oil	EPP 4	Regional Endeavour	07/10/75	16/10/75	32°32'16"	130°51'13"	892	P&A
Columbia-1	1982	Occidental	EPP 15	Danwood Ice	07/02/82	10/04/82	33°29'38.9"	133°53'04.49"	2168	P&A
Duntroon-1	1986	BP Aust	EPP 21	Zapata Arctic	11/01/86	05/03/86	35°35'27"	135°20'59.8"	3515.6	P&A
Echidna-1	1972	Shell	EPP 7	Ocean Digger	16/01/72	17/03/72	35°36'15"	135°37'12"	3823	P&A
Gemini-1	1975	Outback Oil	EPP 15	Regional Endeavour	18/10/75	07/11/75	33°28'44"	134°12'04"	893.7	P&A
Jerboa-1	1980	Esso Aust	WA-126P	Sedco 472	03/04/80	26/04/80	33°30'14.83"	127°36'02.75"	2537.5	P&A
Mallabie-1	1969	Outback Oil	PEL 5	Drilcon	21/06/89	06/08/69	31°32'14"	130°36'06"	1496	P&A
Mercury-1	1981	Occidental	EPP 15	Danwood Ice	27/11/81	01/02/82	33°33'47.3"	134°14'14"	3178.8	P&A
Platypus-1	1972	Shell	EPP 6	Ocean Digger	21/03/72	30/04/72	35°25'10"	134°49'27.699"	3881	P&A
Potoroo-1	1975	Shell	EPP 5	Regional Endeavour	17/03/75	26/04/75	33°23'13.5"	130°46'06.9"	2923	P&A

APPENDIX VI

BIGHT/DUNTROON BASINS: FORMATION TOPS: DATUM KB (m)

WELL	APOLLO-1	DUNTROON-1	ECHIDNA-1	JERBOA-1	MALLABIE-1	PLATYPUS-1	POTOROO-1
YEAR	1975	1986	1972	1980	1969	1972	1975
SEA LEVEL DATUM	9	27	30	10	60	30	9
SEABED		171	169	761	-	188	261
FORMATION							
QUATERNARY							
EUCLA GROUP							
NULLARBOR LST.							
WILSON BLUFF		1424	1002	1075	33	1421	
PIDINGA/HAMPTON*	380*	1631	1209	1103*	141	1628	940*
BIGHT GROUP							
POTOROO FM.	ABS	1833	ABS	ABS	ABS	1691	990
WIGUNDA FM.	ABS	2155	ABS	ABS	ABS	2206	1570
WOMBAT SANDSTONE MEMBER	ABS	2468	ABS	ABS	ABS	2871	ABS
PLATYPUS FM.	ABS	2541	ABS	[1148]	ABS	2974	[1776]
DUNTROON GROUP							
CEDUNA FM.	ABS	2590		[1224]	ABS	3376	[2420]
BORDA FM.	ABS	2983	1304	ABS		NP	ABS
NEPTUNE FM.	ABS	NP	3016	[1635]		NP	[2690]
ECHIDNA FM.	ABS	NP	3595	ABS		NP	
MADURA FM	394				169		
LOONGANA FM.	547			2099	260		2734
UNNAMED PERMIAN	633	NP	NP	ABS	335	NP	ABS
PRECAMBRIAN-ARCHAEAN	858	NP	NP	2509	437	NP	2812
TD	892	3515.6	3823	2537.5	1496	3881	2923

[ ] denotes 'equivalent': NP not penetrated: * Hampton Sandstone: ABS absent

APPENDIX VII

BIGHT/DUNTROON BASINS: FORMATION THICKNESSES (METRES)

WELL	APOLLO-1	DUNTROON-1	ECHIDNA-1	JERBOA-1	MALLABIE-1	PLATYPUS-1	POTOROO-1
EUCLA GROUP							
NULLARBOR LST*		1253	833	314	-	1233	-
WILSON BLUFF LST		207	207	28	-	207	-
HAMPTON SST	14	-	-	45	-	-	50
PIDINGA FM	-	202	95	-	28	63	-
BIGHT GROUP							
POTOROO FM	-	322	-	-	-	515	580
WIGUNDA FM	-	313	-	-	-	665	206
WOMBAT SST MBR	-	73	-	-	-	103	-
PLATYPUS FM	-	49	-	[76]	-	402	[644]
DUNTROON GROUP							
CEDUNA FM	-	393	-	[411]	-	505+	[270]
BORDA FM	-	532.6+	1712	-	-	-	-
NEPTUNE FM	-	-	579	[464]	-	-	[44]
ECHIDNA FM	-	-	228+	-	-	-	-
MADURA FM	153	-	-		91	-	-
LOONGANA FM	86	-	-	410	75	-	78
UNNAMED PERMIAN	225	-	-	-	102	-	-
BASEMENT	34+	-	-	28.5+	1059+	-	111+

* Can include unspecified Quaternary sediments

[ ] Denotes equivalent

APPENDIX VIII

BIGHT/DUNTROON BASINS: FORMATION TOPS: DATUM MSL - TWO-WAY TIME (milliseconds)

WELL	APOLLO-1	DUNTROON-1	ECHIDNA-1	JERBOA-1	MALLABIE-1	PLATYPUS-1	POTOROO-1
YEAR	1975	1986	1972	1980	1969	1972	1975
SEA LEVEL DATUM	-	-	-	-	43	-	-
SEABED		88	186	1005	-	210	336
FORMATION							
QUATERNARY							
EUCLA GROUP							
NULLARBOR LST.							
WILSON BLUFF		1082	825	1307	-27	1065	
PIDINGA/HAMPTON*	391	1197	955	1331	87	1165	940*
BIGHT GROUP							
POTOROO FM.	ABS	1306	ABS	ABS	ABS	1204	973
WIGUNDA FM.	ABS	1513	ABS	ABS	ABS	1555	1432
WOMBAT SANDSTONE MEMBER	ABS	1694	ABS	ABS	ABS	1987	ABS
PLATYPUS FM.	ABS	1738	ABS	[1374]	ABS	2044	[1602]
DUNTROON GROUP							
CEDUNA FM.	ABS	1760		[1447]	ABS	2271	[2050]
BORDA FM.	ABS	1988	1017	ABS		NP	ABS
NEPTUNE FM.	ABS	NP	1996	[1832]		NP	[2226]
ECHIDNA FM.	ABS	NP	2316	ABS		NP	
MADURA FM	402				115		
LOONGANA FM.	530			2231	212		2250
UNNAMED PERMIAN	610	NP	NP	ABS	293	NP	ABS
PRECAMBRIAN-ARCHAEAN	795	NP	NP	2523	352	NP	2288
TD	812	2255	2425	2546	827	2510	2335

[ ] denotes 'equivalent': NP not penetrated: * Hampton Sandstone: + Approximate (No Well Velocity Survey)

APPENDIX IX
GEOCHEMICAL DATA SUMMARY

Vitrinite Reflectance data - Platypus-1 (after McKirdy, 1984)

DEPTH (ft)	(m)	FORMATION	R_V(%)
1650.00	502.93	WILSON BLUFF	
3020.00	920.51	WILSON BLUFF	
3590.00	1094.25	WILSON BLUFF	0.27
3960.00	1207.02	WILSON BLUFF	0.30
4410.00	1344.18	WILSON BLUFF	
5020.00	1530.11	WILSON BLUFF	0.36
5310.00	1618.51	WILSON BLUFF	
5530.00	1685.56	PIDINGA	0.35
6000.00	1828.82	POTOROO	0.35
6500.00	1981.22	POTOROO	0.35
7000.00	2133.63	POTOROO	0.38
7500.00	2286.03	WIGUNDA	0.36
8100.00	2468.91	WIGUNDA	0.41
8510.00	2593.88	WIGUNDA	0.42
8930.00	2721.90	WIGUNDA	0.40
9420.00	2871.25	WOMBAT	0.49
9510.00	2898.68	WOMBAT	0.46
9540.00	2907.83	WOMBAT	0.49
9760.00	2974.88	PLATYPUS	0.50
9900.00	3017.56	PLATYPUS	0.50
10000.00	3048.04	PLATYPUS	0.49
10180.00	3102.90	PLATYPUS	0.49
10340.00	3151.67	PLATYPUS	0.54
10490.00	3197.39	PLATYPUS	0.54
10760.00	3279.69	PLATYPUS	0.57
11090.00	3380.27	CEDUNA	0.59
11310.00	3447.33	CEDUNA	0.57
11470.00	3496.10	CEDUNA	0.59
11790.00	3593.64	CEDUNA	0.55
12220.00	3724.70	CEDUNA	0.68
12270.00	3739.94	CEDUNA	0.72
12540.00	3822.24	CEDUNA	0.71
12720.00	3877.10	CEDUNA	0.73

APPENDIX IX (Cont.)

Vitrinite Reflectance Data - Echidna-1 (after McKirdy, 1984)

DEPTH (ft)	(m)	FORMATION	R_{V}(%)
1490.00	454.16	NULLARBOR	0.19
1920.00	585.22	NULLARBOR	
2110.00	643.14	NULLARBOR	
2600.00	792.49	NULLARBOR	
2950.00	899.17	NULLARBOR	
3220.00	981.47	NULLARBOR	0.35
3290.00	1002.80	WILSON BLUFF	
3350.00	1021.09	WILSON BLUFF	
3490.00	1063.76	WILSON BLUFF	0.39
3860.00	1176.54	WILSON BLUFF	
3980.00	1213.12	PIDINGA	0.39
4230.00	1289.32	PIDINGA	
4360.00	1328.94	BORDA	0.42
4430.00	1350.28	BORDA	0.42
4750.00	1447.82	BORDA	0.41
4780.00	1456.96	BORDA	0.45
4800.00	1463.06	BORDA	0.45
4820.00	1469.15	BORDA	0.45
4830.00	1472.20	BORDA	0.44
5150.00	1569.74	BORDA	0.44
5570.00	1697.76	BORDA	0.44
6390.00	1947.70	BORDA	0.70
6860.00	2090.95	BORDA	0.70
7400.00	2255.55	BORDA	0.82
7880.00	2401.85	BORDA	0.82
8180.00	2493.29	BORDA	0.95
8590.00	2618.26	BORDA	1.02
9050.00	2758.47	BORDA	1.03
9440.00	2877.35	BORDA	1.22
9790.00	2984.03	BORDA	1.59
10190.00	3105.95	NEPTUNE	1.68
10610.00	3233.97	NEPTUNE	1.76
10990.00	3349.79	NEPTUNE	1.76
11430.00	3483.91	NEPTUNE	2.04
11820.00	3602.78	ECHIDNA	2.33
12190.00	3715.56	ECHIDNA	2.74
12570.00	3831.38	ECHIDNA	2.77

APPENDIX IX (Cont.)

Vitrinite Reflectance Data - Potoroo-1

Depth (m)	Formation	R_v(%)	No of samples
1160	Potoroo	0.42	21
1280	Potoroo	0.39	20
1410	Potoroo	0.37	20
1520	Potoroo	0.43	22
1610	Wigunda	0.42	20
1700	Wigunda	0.36, 0.49	15, 6
1880	Platypus	0.41	22
1970	Platypus	0.43	20
2060	Platypus	0.49	22
2126	Platypus	0.39	27
2150	Platypus	0.61	20
2240	Platypus	0.49	21
2330	Platypus	0.56	20
2362	Platypus	0.43	19
2420	Ceduna	0.56	2
2450	Ceduna	0.45	5
2510	Ceduna	0.45	23
2548	Ceduna	0.45	19
2600	Ceduna	0.57	22
2660	Ceduna	0.53	20
2690	Loongana	0.57	20
2788	Loongana	0.64	17
2810	Loongana	0.57	23

Vitrinite Reflectance Data - Jerboa-1 (after Burns, 1981)

Depth (m)	Formation	R_v(%)
1328	Ceduna equivalent	0.23
2105	Loongana	0.46
2165	Loongana	0.37
2197	Loongana	0.41
2242	Loongana	0.46
2249	Loongana	0.44
2255	Loongana	0.44
2291	Loongana	0.41
2392	Loongana	0.43
2442	Loongana	0.38
2490	Loongana	0.51
2509	Loongana	0.50

APPENDIX IX (Cont.)

TOC & Rock-Eval Pyrolysis - Platypus-1 Coals (after McKirdy, 1984)

FORMATION	DEPTH (ft)	DEPTH (m)	T MAX	S1	S2	S3	S1+S2	PI	S2/S3	PC	TOC	HI	OI
WOMBAT	9510	2898.7	427	4.21	56.00	23.47	60.21	0.0	2.39	5.01	54.80	102	43
WOMBAT	9540	2907.8	424	7.40	97.90	16.60	105.30	0.07	5.90	8.77	51.20	91	32
WOMBAT	9720	2962.7	428	3.80	26.00	17.00	29.80	0.13	1.53	2.48	32.80	79	52
PLATYPUS	9770	2977.9	424	3.42	25.04	14.19	28.46	0.12	1.76	2.37	36.50	69	39
PLATYPUS	9850	3002.3	432	6.96	42.84	24.80	49.80	0.14	1.73	4.15	57.60	74	43
PLATYPUS	9890	3014.5	431	4.86	54.22	12.47	59.08	0.08	4.35	4.92	35.60	152	35
PLATYPUS	9910	3020.6	432	4.24	75.28	10.66	79.52	0.05	7.06	6.62	38.70	195	28
PLATYPUS	9960	3035.8	430	9.32	134.95	11.84	144.27	0.06	11.40	12.02	53.30	253	22
PLATYPUS	10000	3048.0	430	7.47	124.66	13.49	132.13	0.06	9.24	11.01	59.60	209	23
PLATYPUS	10020	3054.1	430	4.18	76.93	9.79	81.11	0.05	7.86	6.75	37.20	207	26
PLATYPUS	10040	3060.2	430	4.77	69.44	11.74	74.21	0.06	5.91	6.18	38.70	179	30
PLATYPUS	10090	3075.5	428	5.18	55.18	11.94	60.36	0.09	4.62	5.03	35.10	157	34
PLATYPUS	10120	3084.6	431	6.60	92.33	14.36	98.93	0.07	6.43	8.24	49.60	186	29
PLATYPUS	10150	3093.8	428	6.57	94.09	12.09	100.66	0.07	7.78	8.38	48.00	196	25
PLATYPUS	10180	3102.9	430	6.60	102.56	11.46	109.16	0.06	8.95	9.09	54.00	190	21
PLATYPUS	10210	3112.0	432	5.58	82.94	11.17	88.52	0.06	7.43	7.37	46.80	177	24
PLATYPUS	10250	3124.2	429	6.49	76.28	11.85	82.77	0.08	6.44	6.89	40.30	189	29
PLATYPUS	10340	3151.7	433	5.32	66.82	11.21	72:14	0.07	5.96	6.01	42.30	158	27
PLATYPUS	10390	3166.9	429	5.14	64.27	11.65	69.41	0.07	5.52	5.78	41.10	156	28
PLATYPUS	10430	3179.1	433	3.39	48.67	11.13	52.06	0.07	4.37	4.33	32.30	151	34
PLATYPUS	10470	3191.3	431	3.68	47.57	11.05	51.25	0.07	4.30	4.27	35.90	133	31
PLATYPUS	10490	3197.4	435	3.70	50.30	10.80	54.00	0.07	4.66	4.50	43.80	115	25
PLATYPUS	10510	3203.5	431	5.19	59.80	11.25	64.99	0.08	5.32	5.41	42.00	142	27
PLATYPUS	10550	3215.7	431	3.39	42.29	12.01	45.68	0.07	3.52	3.80	34.70	122	35
PLATYPUS	10590	3227.9	431	4.53	54.44	13.88	58.97	0.08	3.92	4.91	47.10	116	29
PLATYPUS	10610	3234.0	432	6.83	75.84	11.88	82.67	0.08	6.38	6.88	47.80	159	25
PLATYPUS	10680	3255.3	427	3.97	52.14	11.12	56.11	0.07	4.69	4.67	37.20	140	30
PLATYPUS	10770	3282.7	420	5.92	64.60	19.55	70.52	0.08	3.30	5.87	51.10	126	38
PLATYPUS	10810	3294.9	429	5.22	84.68	11.08	89.90	0.06	7.64	7.49	44.00	192	25
PLATYPUS	10840	3304.1	435	4.54	43.23	17.47	47.77	0.10	2.47	3.98	47.20	92	37
PLATYPUS	10960	3340.6	430	8.05	89.22	12.33	97.27	0.08	7.24	83.10	52.90	169	23
PLATYPUS	11030	3362.0	424	3.42	46.84	9.00	50.26	0.07	5.20	4.18	30.30	155	30

APPENDIX IX (Cont.)

TOC & Rock-Eval Pyrolysis - Platypus-1 Coals (cont.)

FORMATION	DEPTH (ft)	DEPTH (m)	T MAX	S1	S2	S3	S1+S2	PI	S2/S3	PC	TOC	HI	OI
CEDUNA	11070	3374.2	428	6.23	89.17	7.88	95.40	0.07	11.32	7.95	43.80	204	18
CEDUNA	11090	3380.3	432	9.81	151.12	6.44	160.93	0.06	23.47	13.41	61.10	247	11
CEDUNA	11140	3395.5	433	3.96	58.81	9.50	62.77	0.06	6.19	5.23	35.60	165	27
CEDUNA	11190	3410.8	417	4.54	53.23	9.49	57.77	0.08	5.61	4.81	34.30	155	28
CEDUNA	11230	3422.9	437	8.50	71.10	12.30	79.60	0.11	5.78	6.63	54.80	130	22
CEDUNA	11280	3438.2	428	3.30	42.40	13.30	45.70	0.07	3.19	3.80	36.80	115	36
CEDUNA	11310	3447.3	433	4.63	61.05	9.89	65.68	0.07	6.17	5.47	39.40	155	25
CEDUNA	11350	3459.5	433	3.98	49.57	11.10	53.55	0.07	4.47	4.46	39.20	126	28
CEDUNA	11390	3471.7	437	3.57	49.08	9.17	52.65	0.07	5.35	4.38	36.30	135	25
CEDUNA	11430	3483.9	434	4.45	66.13	10.39	70.58	0.06	6.36	5.88	45.20	146	23
CEDUNA	11470	3496.1	438	5.10	69.06	12.50	74.16	0.07	5.52	6.18	51.90	133	24
CEDUNA	11510	3508.3	439	8.24	91.20	8.98	99.44	0.08	10.16	8.28	54.90	166	16
CEDUNA	11550	3520.5	434	6.20	70.70	7.70	76.90	0.08	9.18	6.40	43.60	162	18
CEDUNA	11590	3532.7	439	9.09	87.27	6.46	96.36	0.09	13.51	8.03	49.40	177	13
CEDUNA	11630	3544.9	436	6.88	62.20	7.15	69.08	0.10	8.70	5.75	37.40	166	19
CEDUNA	11670	3557.1	443	6.66	43.71	4.57	50.37	0.13	9.56	4.19	30.40	144	15
CEDUNA	11720	3572.3	433	7.18	71.81	8.54	78.99	0.09	8.41	6.58	42.70	168	20
CEDUNA	11790	3593.6	439	5.09	48.84	4.80	53.93	0.09	10.18	4.49	31.30	156	15
CEDUNA	11830	3605.8	434	5.56	60.72	7.01	66.28	0.08	8.66	5.52	37.30	163	19
CEDUNA	11870	3618.0	430	6.02	74.59	6.63	80.61	0.07	11.25	6.71	33.60	222	20
CEDUNA	11910	3630.2	434	3.03	35.55	7.47	38.58	0.08	4.76	3.21	30.20	118	25
CEDUNA	11950	3642.4	436	4.57	43.82	10.21	48.39	0.09	4.29	4.03	37.40	117	27
CEDUNA	11990	3654.6	437	6.79	62.71	7.37	69.50	0.10	8.51	5.79	39.50	159	19
CEDUNA	12030	3666.8	430	6.05	54.03	14.03	60.08	0.10	3.85	5.00	41.60	130	34
CEDUNA	12060	3675.9	438	7.31	83.11	8.06	90.42	0.08	10.31	7.53	50.50	165	16
CEDUNA	12100	3688.1	435	2.93	29.85	8.35	32.78	0.09	3.57	2.73	25.60	117	33
CEDUNA	12140	3700.3	433	3.87	38.62	6.51	42.49	0.09	5.93	3.54	24.60	157	26
CEDUNA	12180	3712.5	435	5.40	48.36	6.68	53.76	0.10	7.24	4.48	29.40	164	23
CEDUNA	12220	3724.7	438	9.09	119.81	5.09	128.90	0.07	23.54	10.74	49.00	245	10
CEDUNA	12250	3733.8	439	0.74	133.24	4.62	143.98	0.07	28.84	11.99	49.80	268	9
CEDUNA	12280	3743.0	437	0.83	136.94	6.01	147.77	0.07	22.79	12.31	53.50	256	11
CEDUNA	12330	3758.2	436	3.05	165.36	7.47	178.41	0.07	22.14	14.86	57.70	287	13
CEDUNA	12370	3770.4	437	4.94	49.04	5.50	53.98	0.09	8.92	4.49	24.30	202	23
CEDUNA	12440	3791.8	439	2.66	28.47	10.66	31.13	0.09	2.67	2.59	29.80	96	36

APPENDIX IX (Cont.)

TOC & Rock-Eval Pyrolysis - Platypus-1 Coals (cont.)

FORMATION	DEPTH (ft)	DEPTH (m)	T MAX	S1	S2	S3	S1+S2	PI	S2/S3	PC	TOC	HI	OI
CEDUNA	12510	3813.1	443	0.19	128.46	4.80	138.65	0.07	26.76	11.55	49.80	258	10
CEDUNA	12520	3816.1	440	2.22	38.33	5.37	40.55	0.05	7.14	3.37	24.40	157	22
CEDUNA	12540	3822.2	441	1.52	140.93	6.35	152.45	0.08	22.19	12.70	58.60	240	11
CEDUNA	12560	3828.3	441	1.91	134.84	4.24	146.75	0.08	31.80	12.22	39.10	345	11
CEDUNA	12600	3840.5	441	5.09	63.30	5.18	68.39	0.07	12.22	5.69	30.10	210	17
CEDUNA	12650	3855.8	445	0.00	0.00	7.96	0.00	0.00	0.00	0.00	48.90	0	16
CEDUNA	12680	3864.9	443	1.33	116.09	5.90	127.42	0.09	19.68	10.61	61.60	188	10
CEDUNA	12710	3874.1	443	2.82	127.97	5.95	140.79	0.09	21.51	11.73	57.30	223	10
CEDUNA	12740	3883.2	440	3.59	33.49	4.66	37.08	0.10	7.19	3.09	18.10	185	26

APPENDIX IX (Cont.)

TOC & Rock-Eval Pyrolysis - Echidna-1 Coals (after McKirdy, 1984)

FORMATION	DEPTH (ft)	DEPTH (m)	T MAX	S1	S2	S3	S1+S2	PI	S2/S3	PC	TOC	HI	OI
BORDA	4730	1441.7	430	18.63	71.62	6.54	90.25	0.21	10.95	7.52	26.00	275	25
BORDA	4740	1444.8	430	10.24	52.58	6.92	62.82	0.16	7.60	5.23	19.90	264	35
BORDA	4750	1447.8	427	12.22	49.76	10.37	61.98	0.20	4.80	5.16	26.90	185	39
BORDA	4760	1450.9	427	9.74	54.22	15.17	63.96	0.15	3.57	5.33	33.60	161	45
BORDA	4770	1453.9	430	10.79	89.11	11.06	99.90	0.11	8.06	8.32	34.60	258	32
BORDA	4780	1457.0	429	13.24	76.29	10.83	89.53	0.15	7.04	7.46	31.60	241	34
BORDA	4790	1460.0	429	10.92	38.69	14.00	49.61	0.22	2.76	4.13	31.20	124	45
BORDA	4800	1463.1	429	27.07	89.71	16.69	116.78	0.23	5.38	9.73	47.20	190	35
BORDA	4810	1466.1	430	20.60	77.82	12.00	98.42	0.21	6.49	8.20	36.20	215	33
BORDA	4820	1469.2	431	16.91	59.60	7.96	76.51	0.22	7.49	6.37	24.80	240	32

APPENDIX IX (Cont.)

TOC & Rock-Eval Pyrolysis - Platypus-1 Shales (after McKirdy, 1984)

FORMATION	DEPTH (ft)	DEPTH (m)	T MAX	S1	S2	S3	S1+S2	PI	S2/S3	PC	TOC	HI	OI
WOMBAT	9510	2898.7	424	0.20	0.47	1.24	0.67	0.30	0.38	0.05	1.31	35	94
WOMBAT	9540	2907.8	424	0.44	7.51	2.56	7.95	0.06	2.93	0.66	5.35	140	47
WOMBAT	9720	2962.7	432	0.09	0.59	1.35	0.68	0.13	0.44	0.05	1.29	45	104
PLATYPUS	9770	2977.9	418	0.12	0.25	1.32	0.37	0.33	0.19	0.03	1.12	22	117
PLATYPUS	9850	3002.3	432	0.10	0.81	1.74	0.91	0.11	0.47	0.07	1.76	46	98
PLATYPUS	9890	3014.5	430	0.84	9.27	3.68	10.11	0.08	2.52	0.84	8.25	112	44
PLATYPUS	9910	3020.6	433	0.90	26.10	5.65	27.00	0.03	4.62	2.25	16.90	154	33
PLATYPUS	9960	3035.8	423	0.63	11.72	2.43	12.35	0.05	4.82	1.02	5.70	205	42
PLATYPUS	10000	3048.0	427	0.19	2.28	1.74	2.47	0.08	1.31	0.20	2.04	111	85
PLATYPUS	10020	3054.1	433	0.65	10.30	2.71	10.95	0.06	3.80	0.91	7.70	133	35
PLATYPUS	10040	3060.2	432	0.20	1.41	2.25	1.61	0.12	0.63	0.13	1.89	74	119
PLATYPUS	10090	3075.5	431	0.41	4.92	2.70	5.33	0.08	1.82	0.44	4.80	102	56
PLATYPUS	10120	3084.6	430	0.43	9.90	2.93	10.33	0.04	3.38	0.86	6.75	146	43
PLATYPUS	10150	3093.8	432	0.24	3.96	1.53	4.20	0.06	2.59	0.35	3.04	130	50
PLATYPUS	10180	3102.9	433	1.25	21.70	3.25	22.95	0.05	6.68	1.91	12.80	169	25
PLATYPUS	10210	3112.0	434	0.19	1.56	1.32	1.75	0.11	1.18	0.14	1.92	81	68
PLATYPUS	10250	3124.2	436	0.61	8.64	2.05	9.25	0.07	4.21	0.77	5.95	145	34
PLATYPUS	10340	3151.7	433	0.53	4.63	1.87	5.16	0.10	2.48	0.43	4.15	111	45
PLATYPUS	10390	3166.9	432	0.28	2.98	2.02	3.26	0.09	1.48	0.27	3.08	96	65
PLATYPUS	10430	3179.1	432	0.38	4.69	2.26	5.07	0.08	2.08	0.42	4.90	95	46
PLATYPUS	10470	3191.3	432	1.20	19.46	5.22	20.66	0.06	3.73	1.72	14.80	131	35
PLATYPUS	10490	3197.4	432	0.18	1.51	1.96	1.69	0.11	0.77	0.14	2.32	65	84
PLATYPUS	10510	3203.5	431	2.63	29.12	5.80	31.75	0.08	5.02	2.64	19.30	150	30
PLATYPUS	10550	3215.7	431	0.25	1.87	1.89	2.12	0.12	0.99	0.17	1.86	100	101
PLATYPUS	10590	3227.9	432	0.85	7.11	2.79	7.96	0.11	2.55	0.66	6.35	111	43
PLATYPUS	10610	3234.0	424	0.87	7.30	2.02	8.17	0.11	3.61	0.68	4.75	153	42
PLATYPUS	10680	3255.3	431	0.27	2.02	1.56	2.29	0.12	1.29	0.19	1.43	141	109
PLATYPUS	10770	3282.7	433	0.81	8.61	3.98	9.42	0.09	2.16	0.78	8.05	106	49
PLATYPUS	10810	3294.9	428	0.28	4.30	1.59	4.58	0.06	2.70	0.38	3.18	135	50
PLATYPUS	10840	3304.1	429	0.21	2.10	1.78	2.31	0.09	1.18	0.19	1.94	108	91
PLATYPUS	10960	3340.6	433	0.69	9.48	2.22	10.17	0.07	4.27	0.84	6.85	138	32
PLATYPUS	11030	3362.0	431	0.21	1.80	1.33	2.01	0.10	1.35	0.16	1.75	102	76

APPENDIX IX (Cont.)

TOC & Rock-Eval Pyrolysis - Platypus-1 Shales (cont.)

FORMATION	DEPTH (ft)	DEPTH (m)	T MAX	S1	S2	S3	S1+S2	PI	S2/S3	PC	TOC	HI	OI
CEDUNA	11070	3374.2	430	0.33	3.89	1.16	4.22	0.08	3.35	0.35	2.76	140	42
CEDUNA	11090	3380.3	433	0.31	4.34	1.31	4.65	0.07	3.31	0.38	3.44	126	38
CEDUNA	11140	3395.5	434	0.26	2.53	1.44	2.79	0.09	1.76	0.23	2.32	109	62
CEDUNA	11190	3410.8	432	0.37	4.09	1.21	4.46	0.08	3.38	0.37	3.52	116	34
CEDUNA	11230	3422.9	434	0.26	2.22	1.26	2.48	0.10	1.76	0.20	2.00	111	63
CEDUNA	11280	3438.2	431	0.32	2.61	2.14	2.93	0.11	1.22	0.24	3.74	69	57
CEDUNA	11310	3447.3	432	0.13	1.31	1.35	1.44	0.09	0.97	0.12	2.02	64	66
CEDUNA	11350	3459.5	432	0.08	1.01	1.59	1.09	0.07	0.64	0.09	1.78	56	89
CEDUNA	11390	3471.7	434	0.12	1.68	1.42	1.80	0.07	1.18	0.15	2.24	75	63
CEDUNA	11430	3483.9	431	0.12	1.28	1.29	1.40	0.09	0.99	0.11	1.86	68	69
CEDUNA	11470	3496.1	430	0.23	3.49	1.59	3.72	0.06	2.19	0.31	3.74	93	42
CEDUNA	11510	3508.3	433	0.16	1.41	1.16	1.57	0.10	1.22	0.13	1.63	86	71
CEDUNA	11550	3520.5	433	0.15	1.27	0.91	1.42	0.11	1.40	0.11	1.68	75	54
CEDUNA	11590	3532.7	426	0.11	1.13	1.02	1.24	0.09	1.11	0.10	1.50	75	68
CEDUNA	11630	3544.9	430	0.36	2.28	1.31	2.64	0.14	1.74	0.22	2.48	91	52
CEDUNA	11670	3557.1	427	0.38	2.54	1.38	2.92	0.13	1.84	0.24	2.82	90	48
CEDUNA	11720	3572.3	431	0.28	1.84	2.69	2.12	0.13	0.68	0.17	2.72	67	98
CEDUNA	11790	3593.6	431	0.15	1.37	1.19	1.52	0.10	1.15	0.12	1.78	76	66
CEDUNA	11830	3605.8	432	0.23	1.59	1.11	1.82	0.13	1.43	0.15	2.00	79	55
CEDUNA	11870	3618.0	430	0.33	3.04	1.29	3.37	0.10	2.36	0.28	2.52	120	51
CEDUNA	11910	3630.2	430	0.18	1.29	1.76	1.47	0.12	0.73	0.12	1.54	83	114
CEDUNA	11950	3642.4	430	0.14	0.95	1.27	1.09	0.13	0.75	0.09	1.56	60	81
CEDUNA	11990	3654.6	432	0.26	1.79	1.05	2.05	0.13	1.70	0.17	1.68	106	62
CEDUNA	12030	3666.8	430	0.11	0.81	1.12	0.92	0.12	0.72	0.07	1.44	56	77
CEDUNA	12060	3675.9	429	0.18	1.16	1.06	1.34	0.13	1.09	0.11	1.54	75	68
CEDUNA	12100	3688.1	431	0.17	0.88	1.56	1.05	0.16	0.56	0.08	1.68	52	92
CEDUNA	12140	3700.3	436	0.84	8.22	1.26	9.06	0.09	6.52	0.75	4.80	171	26
CEDUNA	12180	3712.5	434	0.29	1.05	1.26	1.34	0.22	0.83	0.11	1.28	82	98
CEDUNA	12220	3724.7	436	1.23	12.84	1.25	14.07	0.09	10.27	1.17	7.95	161	15
CEDUNA	12250	3733.8	439	3.62	27.87	1.19	31.49	0.11	23.42	2.62	12.10	230	9
CEDUNA	12280	3743.0	414	0.23	2.28	1.32	2.51	0.09	1.73	0.20	1.39	164	94
CEDUNA	12330	3758.2	436	1.47	16.27	0.94	17.74	0.08	17.31	1.47	7.25	224	12

APPENDIX IX (Cont.)

TOC & Rock-Eval Pyrolysis - Platypus-1 Shales (cont.)

FORMATION	DEPTH (ft)	DEPTH (m)	T MAX	S1	S2	S3	S1+S2	PI	S2/S3	PC	TOC	HI	OI
CEDUNA	12370	3770.4	430	0.22	1.09	0.97	1.31	0.17	1.12	0.10	1.15	94	84
CEDUNA	12440	3791.8	396	0.11	0.51	1.05	0.62	0.18	0.49	0.05	0.84	60	125
CEDUNA	12510	3813.1	437	0.65	5.89	1.16	6.54	0.10	5.08	0.54	4.00	147	29
CEDUNA	12520	3816.1	435	0.24	1.31	1.42	1.55	0.16	0.92	0.12	2.26	57	62
CEDUNA	12540	3822.2	433	0.16	1.23	1.01	1.39	0.12	1.22	0.11	1.66	74	60
CEDUNA	12560	3828.3	436	0.74	8.04	1.11	8.78	0.08	7.24	0.73	4.85	165	22
CEDUNA	12600	3840.5	435	0.24	1.82	1.12	2.06	0.12	1.63	0.17	2.06	88	54
CEDUNA	12650	3855.8	434	0.44	3.28	1.10	3.72	0.12	2.98	0.31	2.66	123	41
CEDUNA	12680	3864.9	438	0.52	2.94	1.03	3.46	0.15	2.85	0.28	2.94	100	35
CEDUNA	12710	3874.1	442	4.44	48.68	2.58	53.12	0.08	18.87	4.42	21.50	226	12
CEDUNA	12740	3883.2	433	0.22	1.49	1.15	1.71	0.13	1.30	0.14	1.80	82	63

APPENDIX IX (Cont.)

TOC & Rock-Eval Pyrolysis - Echidna-1 Shales (after McKirdy, 1984)

FORMATION	DEPTH (ft)	DEPTH (m)	TMAX	S1	S2	S3	S1+S2	PI	S2/S3	PC	TOC	HI	OI
BORDA	4680	1426.5	429	2.20	1.42	1.42	3.62	0.61	1.00	0.30	1.16	122	122
BORDA	4730	1441.7	425	2.15	8.03	1.13	10.18	0.21	7.11	0.84	3.88	207	29
BORDA	4740	1444.8	430	0.86	3.48	0.37	4.34	0.20	9.41	0.36	2.38	146	16
BORDA	4750	1447.8	430	4.04	18.33	0.00	22.37	0.18	ERR	1.86	12.60	145	0
BORDA	4760	1450.9	429	3.06	24.10	0.00	27.16	0.11	ERR	2.26	17.90	135	0
BORDA	4770	1453.9	431	2.23	20.87	0.00	23.10	0.10	ERR	1.92	11.30	185	0
BORDA	7950	2423.2	433	0.83	0.93	1.41	1.76	0.47	0.66	0.14	0.79	118	178
BORDA	8010	2441.5	441	0.54	0.78	1.41	1.32	0.41	0.55	0.11	0.73	107	193
BORDA	8070	2459.8	448	0.40	0.64	1.18	1.04	0.38	0.54	0.08	0.62	103	190
BORDA	8130	2478.1	450	0.36	0.79	1.40	1.15	0.32	0.56	0.09	0.81	98	173
BORDA	8190	2496.3	450	0.33	0.68	0.95	1.01	0.33	0.72	0.08	0.75	91	127

APPENDIX X

SURVEY 66 DREDGE LOCATIONS AND SAMPLE DESCRIPTIONS

Dredge No.	Location On/Off	Depth (m)	Mass (kg)	Description of Sample
1	33°56.0'/128°38.3' 33°53.5'/128°37.0'	3280 2950	750	Equal proportions of Tertiary fine limestone & Maastrichtian siltstone, sandstone, etc. Also Paleocene phosphatic sediment and undated alkali basalt.
2	34°01.5'/126°43.9' 33°59.8'/128°43.8'	2500 2070	50	Precambrian granodiorite, part cataclastic; minor Eocene mudstone.
3	33°58.4'/128°36.6' 33°57.5'/128°34.7'	3535 3390	20	U. Cretaceous mudstone, sandstone, conglomerate and Tertiary siliceous carbonate. Minor alkali basalt lava.
4	34°09.5'/129°06.7' 34°09.2'/129°07.6'	3332 3095	0.2	Small piece of soft friable siliceous wackestone, probably Early Tetiary.
5	35°14.0'/130°45.0' 35°12.0'/130°43.0'	3800 3200	0	Unsuccessful
6	35°34.0'/132°54.5' 35°33.5'/132°52.4'	2620 2015	50	L. to U. Oligocene fine pelagic wackestone.
7	35°42.0'/133°19.0' 35°42.1'/133°17.4'	2720 2200	20	U. Cretaceous & U. Paleocene to L. Eocene mudstone/siltstone and Miocene intebedded wackestone and siltstone.
8	35°40.7'/134°26.0' 35°38.1'/134°24.7'	2826 2244	30	Mostly U. Paleocene to L. or M. Eocene gravelly siltstone and mudstone and some L. and M. Eocene wackestone.

Dredge No.	Location On/Off	Depth (m)	Mass (kg)	Description of Sample
9	$36^{\circ}00.1'/134^{\circ}49.8'$ $36^{\circ}00.5'/134^{\circ}53.2'$	3680 2982	2	Mostly Pliocene brown mudstone and white wackestone.
10	$35^{\circ}59.8'/134^{\circ}50.8'$ $35^{\circ}55.6'/134^{\circ}47.6'$	3614 2925	15	M. Eocene and L. Miocene wackestone.
11	$35^{\circ}49.7'/135^{\circ}09.6'$ $35^{\circ}50.1'/135^{\circ}14.1'$	3200 2141	40	Mostly M.-U. Oligocene wackestone, some L. Eocene pyritic calcareous sandstone and U. Cretaceous organic-rich muddy siltstone. Minor undated phosphatic muddy quartz arenite.
12	$35^{\circ}54.8'/135^{\circ}05.4'$ $35^{\circ}56.0'/135^{\circ}08.9'$	3670 2720	120	Mostly U Eocene & L Oligocene wackestone. Minor U. Paleocene and M. Eocene organic rich mudstone.
13	Near DR 14			unsuccessful.
14	$35^{\circ}58.3'/135^{\circ}11.8'$ $35^{\circ}58.0'/135^{\circ}12.2'$	3064 2627	35	M. and U. Eocene and L. Oligocene wackestone. Minor L. Eocene organic-rich mudstone.
15	$36^{\circ}20.1'/135^{\circ}40.1'$ $36^{\circ}19.1'/135^{\circ}36.3'$	3394 2494	80	M Oligocene & L Miocene lime mudstone.
16	$36^{\circ}24.1'/135^{\circ}51.3'$ $36^{\circ}24.2'/135^{\circ}50.9'$	3302 3432	5	?Oligocene dolomitic packstone and siliceous wackestone; some shows faulting.

APPENDIX XI

SURVEY 66 HEATFLOW DATA

Only successful stations are listed.

Stn	Lat.	Long.	WD	N	Temp	Core	Rec.	K	G	Q
HF02	33 55.820	132 02.441	701	3	6.87	GC04	2.15	0.80	448	358*
HF03	34 01.774	131 58.218	879	3	4.83	GC04	2.15	0.80	152	122
HF10	34 15.932	130 12.405	1676	3	2.56	GC05	2.47	0.83	55	46
HF13	35 16.668	131 10.897	2643	2	1.93	PC01	2.34	0.96	65	62
HF14	35 12.156	131 13.597	2326	3	2.12	GC11	1.0	0.89	68	61
HF15	35 09.216	131 16.225	2010	4	2.33	GC12	1.67	0.87	68	59
HF16	34 59.643	131 21.541	1734	3	2.54	GC13	1.6	0.95	101	96
HF17	34 50.137	131 25.983	1498	4	2.67	GC14	2.18	0.87	75	65
HF18	34 41.721	131 33.056	1376	4	2.86	GC15	2.07	0.94	47	44
HF19	34 32.528	131 39.272	1253	3	2.97	GC16	0.91	0.90	126	113
HF20	34 24.251	131 44.095	1186	3	3.13	GC17	2.13	0.93	84	78

Column headings as follows:

Stn	- Heatflow station number
Lat, Long	- Station position in degrees and minutes
WD	- Water depth in metres
N	- Number of thermistors in sediment
Temp	- Bottom water temperature in ^{o}C
Core	- Core number used for thermal conductivity
Rec.	- Core recovery in metres
K	- Thermal conductivity in $W.(m.K)^{-1}$
G	- Thermal gradient in $^{o}C.km^{-1}$
Q	- Heatflow in $mW.m^{-2}$

* This heatflow value highly suspect.

APPENDIX XII

INTERPRETATION OF MAGNETIC PROFILES USING THE WERNER TECHNIQUE

i) Background

The magnetic data interpretation technique of Werner deconvolution applied here is that described by Hsu and Tilbury (1977) and Aero Service Corporation (1974). The model used in the interpretation assumes that the observed magnetic field arises from two discrete magnetic sources and a quadratic magnetic background 'noise'; these sources are either thin sheets (dykes) or interfaces. The equations defining the model are solved analytically using a 'window' of observed data values (11 samples in the case of the model used here); the window is stepped along the profile, usually one sample at a time.

The interpretation is repeated for a number of passes of the sampling window, with the interpretation window opening wider at each pass (or 'level'), scanning progressively lower frequency events; in effect, this means that the technique searches for successively deeper sources. For deeper passes, the magnetic field is upward-continued to remove the high frequency components and, hence, the effects of shallow sources.

Each interpretation window produces a set of solutions based on either the interface model or the thin sheet model, but not both; the interpreter will normally require solutions from both models to produce a meaningful interpretation. While these models are simple geometrically and realistic geologically, magnetic anomalies may frequently arise from a variety of sources that have little correspondence to the models used in the Werner deconvolution program. In these cases, spurious estimates will be produced as the interpretation window scans over the 'bad' magnetic source.

ii) Magnetic Interpretation

The magnetic data set used here consists of north-south profiles at an average spacing of 45 km (CGG, 1975) and NW-SE and NE-SW profiles over the western Ceduna Terrace/Eyre Terrace region. The location of these profiles, an interpreted magnetic basement map, and selected interpreted profiles are shown in Plate 11.

The principal features observed in the profiles include -

Shallow magnetic basement, comprising the eroded surface of the Gawler Block in the east and the Albany-Fraser Block in the west, is well-defined in both interface and thin sheet models by intense and numerous estimates (Fig. 11.5, line 16/128). Basement edges (eg the Polda Trough boundaries and the northern margin of the GAB Basin) are particularly sharp, and the depth extent of the Polda Trough (~3 km) is quite well-defined.

The corners of tilt-blocks of magnetic basement, created during continental extension, are clearly evident from the concentrations of estimates in both models, with the thin sheet model giving a good indication of the throw on major faults. Line 16/160 from the Eyre Terrace area (Fig. 11.4) shows the Yilgarn Block at about

0.5 km depth at the right of the section, and two major basement tilt-blocks downthrown towards the continental margin. These two faults, which have a combined throw of about 6 km, are the main basin-forming structures within the Eyre Sub-basin.

Basement escarpments, such as the GAB Basin boundary fault, create well-defined estimates in both models, and the depth (throw) is clearly indicated, provided that dips are not too steep (Fig. 11.5, line 16/128).

Line 16/164 (Fig. 11.3) shows the location of Precambrian basement blocks underlying the Eyre Sub-basin and the landward edge of the continental rise. These blocks are considered to have rotated on a mid-crustal detachment surface which lies at about 15 km depth. The head of this detachment is located at A on line 16/164, with a sub-branch probably occurring at B. A general absence of clustered solutions south of C, off the frame of the figure, corresponds to the Magnetic Quiet Zone: an area where highly extended lower crust has been largely stripped of upper crustal blocks (Etheridge & others, 1990). Etheridge & others also interpret the top of the synrift sequence (broken line between B and C in line 16/164) as a shallow decollement for accommodation faults within the Upper Cretaceous.

Isolated deep estimates, occur in places beneath the Ceduna Terrace and the continental rise at depths of up to 12 km (Fig. 11.4, line 16/160; Stagg & others, 1989, fig. 10). These probably represent the tops of basin-forming basement blocks.

The map of magnetic basement (Fig. 11.2) has been compiled primarily from the Werner deconvolution profiles. In localised areas. particularly the Eyre Sub-basin and the Polda Trough, the mapped structures have been constrained by previous interpretations (Bein & Taylor, 1981; Nelson & others, 1986); elsewhere, the seismic data do not enhance the information available in the magnetic profiles. The map illustrates two aspects of the interpretation - namely, the principal basement escarpments (bold lines), and generalised contours of depth to magnetic basement. The map scale and the line separation of the profiles interpreted preclude the detailed mapping of small-scale structures (notably the Eyre Sub-basin) and contours in such areas are necessarily generalised.

The magnetic basement depth contours indicate four major depressions ranging from 8 to 12 km below sea level. From west to east, these correspond to seismically-defined depocentres - beneath the continental rise south of the Eyre Terrace, and beneath the western Ceduna Terrace, eastern Ceduna Terrace, and Duntroon Embayment area. The depth to basement cannot be interpreted from the available seismic data except in the area of the Eyre Terrace. The Ceduna Terrace depressions are probably connected, and outline the major Mesozoic depocentre in the Great Australian Bight region, containing at least 10 km of section. The depth map also shows the Eyre Sub-basin and Polda Trough in which sediments are at least 3 km thick.

The most prominent feature of the basement map is the scarp that delineates the northern edge of the continental margin basins. In the centre of the GAB, this scarp is oriented E-W and it is clear that it is collinear with the northern margin of the Polda Trough. To the west, the trend dies out with the Eyre Sub-basin. Detailed seismic mapping of this structure in the Eyre Sub-basin (Bein & Taylor, 1981) shows that it consists of a series of ENE-trending normal faults and SE to ESE-trending probable transfer faults. Similarly, in the Polda Trough, Nelson & others (1986) interpreted a series of *en echelon* depocentres that appear to be offset by NW-SE trending transfer faults. In the central GAB, although control is coarse (~40 km line spacing), minor sinuosity and changes in the dip of the magnetic basement escarpment are consistent with its being formed by a similar association of faults.

The gross alignment of the Eyre-Polda escarpment is an interesting phenomenon, since while the Eyre Sub-basin appears to have been initiated as an extensional feature in the Mesozoic during or prior to the Middle Jurassic, the Polda Trough is a Palaeozoic and perhaps older (?Precambrian) structure, possibly reactivated during rifting. It appears that continental extension in the Mesozoic was bounded northward by this old line of weakness and that Polda Trough sediments may extend westward in the fault blocks which underlie the northern edge of the GAB Basin and the eastern end of the Eyre Sub-basin.

The magnetic interpretation indicates that, with the exception of the Polda Trough and the northern edge of the Eyre Sub-basin, the continental shelf beneath the central and western GAB is underlain by basement at a depth of only a few hundred metres, although there are indications of isolated pockets of non-magnetic rocks (sediments or acid igneous) up to 1.5-2 km deep. These pockets are not obviously reflected in the low quality Continental Margin Survey seismic data and cannot be reliably correlated from line to line.

Beneath the eastern half of the GAB, the basement scarp is complex. While the scarp is basically oriented WNW-ESE, there are two significant embayments - the Duntroon basin and the Gambier Embayment southeast of Kangaroo Island - which cut back into it. Long segments of the scarp are parallel to the extension direction in the Eyre Sub-basin (as shown by the strike of the Eyre Sub-basin structures), to the interpreted wrench structures in the Polda Trough (Nelson & others, 1986), and to offsets in the COB as defined by Veevers (1987). Willcox & others (1987) used these observations to support their hypothesis of an early phase of NW-SE extension.