BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Division of Marine Geosciences and Petroleum Geology

DEEP STRUCTURE OF THE SOUTHERN NORTH WEST SHELF: CRUISE PROPOSAL

Project 121.17

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EXECUTIVE SUMMARY

While the northern Carnarvon Basin at the southern end of the North West Shelf is one of Australia's most hydrocarbon-rich provinces, relatively little is known of its deep structure and the control this structure has on hydrocarbon occurrences. Consequently, it is proposed here to use the Bureau of Mineral Resources research vessel *Rig Seismic* in mid-1991 to acquire deep-crustal seismic data along a series of dip and strike traverses in the Exmouth, Barrow, Dampier, and Beagle Sub-basins of the northern Northern Carnarvon Basin, and parts of the Offshore Canning Basin. This work has the following aims:

* To determine the broad regional structural framework of the southern North West Shelf by examining the boundaries between the major structural elements

* To determine the deep crustal structure of the southern North West Shelf and its relationship to the development of the continental margin adjacent to the southeast Argo Abyssal Plain

* To assess the control of deep structure on the development of the major hydrocarbon fields and plays in the region, and in particular the structural and depositional effects resulting from reactivation of these structures.

Two cruises of seismic data acquisition are needed to meet these aims. The program proposed here covers the first of these cruises, with work being concentrated in the northern Carnarvon Basin. It is anticipated that a second cruise will concentrate in the Offshore Canning Basin, with some follow-up work being done in the Northern Carnarvon Basin.

The program for the first cruise consists of a total of 15 seismic lines, totalling 2931 km, in three distinct stages. All lines are tied to key exploration wells to provide regional ties of the principal geological horizons throughout the region. Stage I (1583 km) comprises four lines that constitute a major strike line tying together the Beagle, Dampier, Barrow, and Exmouth Sub-basins, while dip lines are to be run across the Exmouth Sub-basin (1 line), Barrow Sub-basin (2 lines), Barrow-Dampier junction (1 line), and Dampier Sub-basin. Stage II (471 km) comprises two lines in the Beagle Sub-basin. Stage III (877 km) comprises the remaining 3 lines that will form the first part of a study of the Offshore Canning Basin. Lines have been prioritised such that, in the event of serious equipment or weather problems, the most critical part of the data set (Stage I) should still be acquired. If no more than average equipment and weather problems prevail, then it should be possible to acquire all three stages.

The principal tool to be applied is deep seismic reflection (15 second records), using

dual airgun arrays (50 litres) as the source. The minimum seismic cable configuration that will be used (depending on equipment problems and the need to manoeuvre the vessel in restricted waters) will be 3600 m, with 144 x 25 m groups. Dependent on the delivery of new equipment, up to 192 chanels (4800 m) of seismic streamer will be deployed. Shots will be fired every 50 m, giving coverage of 3600% and 4800% for minimum and maximum cable configurations, respectively.

INTRODUCTION

The North West Shelf is a generalised term that refers to the suite of geologic provinces comprising the continental margin of northwest Australia, approximately from Northwest Cape to Darwin, a distance of some 2000 km and encompassing an area (including marginal plateaux) of approximately 800000 km^2 (Fig. 1). The principal sedimentary basins include, from south to north, the northern Carnarvon, offshore Canning, Browse, and Bonaparte Basins. While the majority of the sedimentary fill in most of these basins is of Mesozoic age, all of the basins probably began forming in the Palaeozoic.

As production of hydrocarbons from Bass Strait dwindles, the North West Shelf is certain to become the major source of hydrocarbon in Australia. To date, the principal discoveries are oil and gas in the Barrow Sub-basin, gas/condensate and more recently oil in the Dampier Sub-basin, gas/condensate in the Browse Basin, and oil and gas in the Bonaparte Basin. Current estimates suggest that the region contains undiscovered resources of 40-500 million kilolitres (280-3200 million barrels) of crude oil, 240-1300 billion cubic metres (8-45 tcf) of saleable gas, and 55-440 million kilolitres (350-2800 million barrels) of condensate, primarily in the Carnarvon, Browse, and Bonaparte Basins (BMR, 1989).

While portions of the North West Shelf have been quite intensively explored since the 1960's (particularly the Barrow-Dampier Sub-basins and parts of the Bonaparte Basin), there has been very little recent revision of its regional structural framework using modern extensional tectonic concepts, and large parts of the region, particularly the offshore Canning Basin, remain relatively under-explored. The Division of Marine Geosciences and Petroleum Geology of the Bureau of Mineral Resources, as part of its study program on the North West Shelf, will acquire regional deep seismic data across and between the major sedimentary basins, with the aim of improving understanding of the linkages between the major structural elements and allowing revision of the gross structure of the region. This information will be critical in developing new exploration strategies and will aid future basin framework and resource studies in the region.

To address the structural framework problems of the North West Shelf, a series of cruises by the BMR research vessel *Rig Seismic* have been allocated during a 2-year period. The program is as follows:

1) Bonaparte Basin - concentrating in the Vulcan Graben and adjacent areas - 1900 km of deep seismic data - completed November-December, 1990.

2) Bonaparte Basin and Timor Sea - 2000-3000 km of deep seismic data - scheduled

for April, 1991.

3) Northern Carnarvon Basin (Exmouth-Barrow-Dampier-Beagle Sub-basins) and first stage offshore Canning Basin - up to 2900 km of deep seismic data - scheduled for May, 1991.

4) Browse Basin - approximately 1000 km of deep seismic and 1500 km of regional conventional seismic - scheduled for 1992.

5) Offshore Canning stage II and follow-up work in the northern Carnarvon Basin - 2500 km of deep seismic data - tentatively scheduled for mid- to late-1992.

This Record contains background information on the northern Carnarvon Basin and the proposed cruise program for the third of the cruises listed above. Background geological information for the first stage of the Offshore Canning Basin work is contained in Leven (in prep.).

By the end of the cruise program outlined here, there will be available to industry a network of deep seismic data (recorded at up to 15 seconds TWT) for all of the major basins of the North West Shelf, from Northwest Cape to the Timor Sea.

EXPLORATION HISTORY

The initial oil exploration permits on the North West Shelf were granted to Ampol Petroleum Ltd in 1946. While these leases were primarily onshore, they did cover the offshore Carnarvon Basin out to a water depth of 100 fathoms (~183 m). In 1952, Ampol combined with Caltex to form West Australian Petroleum Pty Ltd (Wapet), and the new company drilled its first well (Cape Range-1) on a surface anticline in 1953. This well flowed oil from a small pool and provided a major impetus to exploration on the southern North West Shelf.

The first offshore seismic work was carried out by Wapet in 1961. In 1964, Wapet drilled a wildcat well on Barrow Island that discovered oil in Upper Jurassic sands. Subsequent appraissal drilling on Barrow Island showed the presence of a major oil field, principally reservoired in Cretaceous sands. In 1965, Wapet was granted acreage west of Barrow Island. At about the same time, Woodside (Lakes Entrance) Oil Co. (subsequently to become Woodside Petroleum) and associated companies were granted leases to the north and offshore from the Wapet leases. This general delineation of operations has persisted since the 1960's, with Wapet being considered the principal explorer in the Barrow Sub-basin, while Woodside is considered to be the prime explorer in the Dampier Sub-basin.

In 1968, Woodside made a non-commercial oil discovery at Legendre-1 on the landward flank of the Dampier Sub-basin. The major Woodside successes came in 1971, with major discoveries of gas/condensate at North Rankin-1, Goodwyn-1, and Angel-1 in fault blocks of the Rankin Platform (Fig. 3). Wapet continued the run of success on the Rankin Platform with the discovery of a major gas/condensate field in the Gorgon structure at the southwestern extremity of the platform in 1980.

Since the early 1970s, as the full potential of the North West Shelf has become apparent, exploration lease sizes have been steadily reduced and more players have become involved in exploration. During the 1980s, there has been a number of small- to medium-scale commercial and sub-commercial oil discoveries in both the Barrow and Dampier Sub-basins (eg Harriet, Talisman, Saladin, Wanaea, Cossack, Ramillies), and the former distinction between an "inner oil trend" and an "outer gas trend" has become blurred.

During the second half of the 1980s, emphasis has been shifting away from conventional 2-D seismic surveys to 3-D surveys, particularly over the major fields. One consequence of this shift in seismic techniques, in conjunction with the change to smaller permit sizes, is that there are very few regional seismic lines of post-1970s vintage. As most of the industry data are recorded to 5 or 6 seconds reflection time, it is also very difficult to construct good-quality regional seismic transects that show basin-forming structures, other than at the basin margins.

By 1990, in excess of 130000 km of 2-D reflection seismic data have been recorded, and over 250 wells have been drilled on the southern North West Shelf (Fig. 4). To our knowledge, only three deep seismic lines (recorded to below 10 seconds reflection time) are publically available in the Barrow and Dampier Sub-basins and adjacent areas (Fig. 5). These data comprise two lines (lines 3184 and 3185; total length 217 km) recorded in a non-exclusive survey by Geophysical Services International across the central Dampier Sub-basin in 1986, and a single wide-angle CDP line (line 55-21) recorded jointly by the Bureau of Mineral Resources and the Lamont-Doherty Geological Observatory across the Dampier Sub-basin and Exmouth Plateau, also in 1986.

STRUCTURE

The gross structure of the North West Shelf comprises a series of generally NE-SW trending rifted Mesozoic depocentres overlying Palaeozoic N-S trending basins that may have constituted failed arms of a previous rift valley (Veevers, 1988). Within the northern Carnarvon Basin, the four principal shelf and upper slope depocentres - the Exmouth, Barrow, Dampier, and Beagle Sub-basins (Fig. 6) - accumulated most of their sedimentary fill in the Triassic and Jurassic, before the rift system aborted with the separation of Australia from (?)Greater India along a parallel rift system along the northwest and northern margins of the Exmouth Plateau. Although the four sub-basins have frequently been treated as separate entities in the literature, this is largely due to the concentration of individual exploration companies in one or other of the sub-basins. In fact, the sub-basins are very closely related, particularly in the case of the Barrow and Dampier Sub-basins, and any analysis of the basin-forming mechanisms of the area should consider all of them together.

Of the sub-basins, the Barrow and Dampier are by far the best known, by virtue of the high level of exploration success in them. In this section, we will concentrate on those two sub-basins.

Boundaries Between Sub-basins

The boundaries between the sub-basins are complex and not, as yet, well-imaged or well-understood. In the southwest, the Exmouth Sub-basin is in *en echelon* arrangement with the Barrow Sub-basin (see, for example, Barber [1988], figure 2), with the boundary between the two usually being taken as the southern extension of the Rankin Trend (Alpha Arch) and the E-W trending Long Island Fault System. It is likely that the Long Island Fault System is a strike-slip or transfer fault zone. The junction between the Barrow and Dampier Sub-basins, northeast of Barrow Island, is defined largely on the basis of a change in strike of the main depocentres, from NNE-SSW in the Barrow Sub-basin to NE-SW in the Dampier Sub-basin. This junction, which is both complex and not imaged at depth, probably overlies a broad NW-SE trending transfer fault zone extending from the confluence of the Deepdale and Hauy Faults, northeast of the Monte Bello Islands, and through the bend in the Rankin Trend at the northeastern end of the Gorgon Structure. By virtue of the extremely thick Mesozoic sediment pile in the Barrow and Dampier Sub-basins, this boundary will probably be the most difficult to image with seismic techniques.

In the northeast, the boundary between the the Dampier and Beagle Sub-basins is taken at a feature that has been referred to as the 'De Grey Nose'. It is likely again that this feature is a transfer fault, or complex of transfer faults (C. Dempsey, Marathon Petroleum Australia, pers. comm.), 'closing off' the northeast end of the Dampier Sub-basin. In this report, we will continue to refer to the Dampier-Beagle

Sub-basin boundary as the De Grey Nose, while acknowledging that it is not a simple basement high. To the northeast, the Beagle Sub-basin, as with the Exmouth Sub-basin, is relatively poorly known, mainly because of the lack of exploration success and the commensurate lack of modern high-quality seismic data. It appears from published tectonic elements maps and papers that the Mesozoic trend of this basin is strongly influenced by underlying orthogonal trends of the Offshore Canning Basin, and in some reports it has been considered to be a Mesozoic sub-basin of the Canning Basin, as with the Rowley and Bedout Sub-basins. The easterly limit of the Beagle Sub-basin is taken at the N-S trending North Turtle Hinge.

Internal Sub-basin Structures (Figs 7 & 8)

The principal sub-basins of interest here, and the best mapped, are the Barrow and Dampier Sub-basins. To the southeast, the main depocentres of the rift are bound by the Flinders Fault System in the south and the *en echelon* Rosemary Fault System in the north. However, the main rift-bounding faults are more properly the Scholl Island Fault in the south and the Hauy Fault in the north. Between these two fault systems (Flinders-Rosemary and Scholl Island-Hauy), is a complex fault zone (Peedamullah Shelf and Enderby Trend) which principally includes Triassic and Permo-Carboniferous sediments. This area of the North West Shelf is one of the few areas where the Triassic-Jurassic section is thin enough that basin-forming structures can be distinguished with conventional seismic data.

Oceanwards of the Flinders and Rosemary Fault Systems and partially overlying them, is a complex zone where Cretaceous reactivation of pre-existing structures has caused extensive faulting and buckling of the Mesozoic section. This zone hosts the Saladin, Roller, and Yammaderry Fields in the Barrow Sub-basin and includes the oil-prone Legendre Trend in the Dampier Sub-basin.

The major Mesozoic depocentres include the sinuous and generally NNE-SSW trending Barrow Depocentre in the Barrow Sub-basin and the more linear NE-SW trending Lewis Trough in the Dampier Sub-basin. Both depocentres have expression as deep (~3 km Tertiary-Cretaceous and >5 km Jurassic, underlain by an unknown thickness of Triassic and Palaeozoics) essentially unfaulted downwarps, with the main axes of deposition offset slightly to the north.

The seaward boundary of the Barrow-Dampier rift is formed by the structurally high Rankin Trend and its associated structures, the Kendrew Trough (or Kendrew Terrace) and positive Madeleine Trend. The Rankin Trend itself is the southeastern border zone of the Exmouth Plateau/Rankin Platform megacrustal block (Woodside, 1988). The Rankin Trend has the strongest gravity signature on the southern North West Shelf (Fig. 9) and is obviously a fundamental structure of the rift system, as well as being host to the largest hydrocarbon reservoirs. For much of its length, the Rankin

Trend is strongly fault-segmented, consisting of a series of NNE-trending pivotal Triassic horsts and grabens, again in an *en echelon* arrangement, suggesting that the trend formed in response to strike-slip movements (Woodside, 1988). Woodside further suggest that the entire complex area lying between the Rankin Trend and the Madeleine Trend formed above a deep-seated wrench zone.

In the southwest, offshore from the Barrow Sub-basin, the Rankin Trend swings round to the south, where it becomes known as the Alpha Arch (which includes the large Gorgon gas field). While the deep structure of the Alpha Arch is probably less-known than that of the Rankin Trend, its gravity expression is as strong as that of the Rankin Trend, and it also appears to be the expression of a fundamental basin-forming structure.

The southeast boundary of the Exmouth Sub-basin is formed by the Rough Range Fault, while the northwest boundary is ill-defined, due to the scarcity of seismic data northwest of Northwest Cape. The deep structure of the Exmouth Sub-basin consists of a series of east-tilted fault blocks that are down-thrown to the west by as much as 3000 m in the pre-Cretaceous and show evidence of some reverse movement in the late Miocene (Parry & Smith, 1988).

As with the Exmouth Sub-basin, the Beagle Sub-basin is inadequately defined and mapped. The sub-basin is a transitional area between the northern Carnarvon Basin and the Offshore Canning Basin, and contains trends that are common to both of these basins (Crostella & Barter, 1980). In the west, the two principal identified elements are the NE-SW trending Cossigny Trough and Picard Trend, which are probably fairly straightforward extensions of the Lewis Trough and Rankin Trend, respectively. In the eastern half of the sub-basin, the dominant trend becomes N-S, as represented by the Thouin Graben and North Turtle Hinge.

Age and Style of Faulting

Etheridge & others (1991) consider that formation of the northern Carnarvon Basin has been influenced by four main stages of faulting. In descending age, these are as follows:

1) Crustal extension primarily in the (?Early) Permian (Yeates & others, 1987) along NE-trending normal faults separated by NW-trending transfer faults. These faults have probably determined the structural grain of the North West Shelf for the remainder of its history. The Scholl Island Fault is a relatively well-documented example of an extensional fault of this age (see, for example, Bentley [1988] figs 5 & 7).

2) Late Triassic to Early Jurassic faulting is widespread, particularly on the Rankin Trend and the Exmouth Plateau. This faulting has traditionally been interpreted as extensional and has been referred to frequently as 'rift onset'; however, the steep dips on these faults, the unsystemmatic fault block rotations on the Rankin Trend, and fault discontinity all point to strike-slip faulting, interpreted to be in a left-lateral sense. Faulting of this age has produced most of the large gas fields of the North West Shelf (North Rankin, Goodwyn, West Tryal Rocks, Gorgon).

3) Middle to Late Cretaceous faulting is again largely restricted to NE-trending high-angle zones that are complexly-structured. This phase of faulting has formed many of the structures on the oil-rich trend from Saladin to Talisman. Fault geometries again indicate dominantly left-lateral wrench motion.

4) In the Miocene, a final episode of wrench reactivation occurred, probably with right-lateral sense and in response to the collision of Australia with Timor. This activity is still evident today, particularly in the Timor Sea, where some faults reach seabed.

It is clear that these four episodes of faulting (one of normal extension, two of left-lateral wrenching, and one of right-lateral wrenching) have contributed heavily to the structural complexity of the North West Shelf today. Also, it is likely that much of the reactivation faulting seen in the upper part of the section is concentrated above the original basin-forming structures, themselves the loci of inherent crustal weakness. It seems logical that the ability to trace the basin-forming structures will enable a better definition of the most active areas of reactivation, and hence hydrocarbon reservoir development.

STRATIGRAPHY

While the work set out in this cruise proposal is primarily directed at solving structural problems on the southern North West Shelf, for completeness of background the following summary of general stratigraphy is given (Fig. 10). Given that the North West Shelf is well-explored by Australian standards, the stratigraphy is relatively well-documented. This section is based upon the studies of Parry & Smith (1988) and Woodside (1988).

Palaeozoic

Because of the great thickness of Mesozoic sediments beneath much of the northern Carnarvon Basin, Palaeozoic sediments have only been sampled infrequently. Carboniferous and Devonian rocks have been penetrated in Rough Range-1 and at shallower depth in wells on the Peedamullah Shelf, between the Flinders Fault System and the Scholl Island Fault. The Permian Byro Group has been documented in several wells on the Peedamullah Shelf and to the south, where it includes dark shale and siltstone with some sandstone. Parry & Smith (1988) believe that this sequence deserves more attention, given that there is a distinct possibility that shales in the group have generated hydrocarbons at some time and the fact that good-quality reservoir sandstones are present in the overlying Upper Permian Chinty Formation.

Mesozoic-Cainozoic

Mesozoic sedimentation commenced with the deposition of the Scythian to Ladinian Locker Shale. This sequence consists of a basal transgressive coarse paralic sandstone and a thin shelfal limestone overlain by sandy shales. The bulk of this sequence consists of a thick marine section of interbedded claystone and minor siltstone with a thin regressive sandy sequence at the top.

The Locker Shale grades upwards into the Mungaroo Formation, a dominantly fluvial sandstone sequence, with some coals. This sequence is the principal reservoir for the major gas accumulations of the Rankin Trend. The coarse clastics in the sequence were probably deposited in a braided channel or fluvio-estuarine environment, whereas the interbedded claystones and coals represent flood-plain deposits with minor marine influences. At the top of the Mungaroo Formation there appears to be a return to a more marine environment.

Overlying the Mungaroo Formation across most of the Dampier Sub-basin is a widespread Hettangian-Sinemurian sandstone sequence (North Rankin Beds; Woodside [1988]). These consist of marginal marine and fluvial sandstones interbedded with minor marginal marine and estuarine claystone, and was deposited in a nearshore/shoreline environment.

During most of the Jurassic, the thick Dingo Clastone was deposited across the southern North West Shelf. This formation is divided by Woodside (1988) into three sub-units - the lower, middle, and upper Dingo Claystone. Lateral equivalents include the more coarse-grained siliciclastic Biggada, Dupuy, Legendre, and Angel Formations. The base of the lower Dingo Claystone is marked by a transgression and an abrupt lithologic change from clastics to carbonates; this generated a basin-wide seismic marker. With deepening of the basin, the carbonates were succeeded by inner shelf calcareous claystones. In the Bajocian-Bathonian, a regional regression led to the deposition of westwards-prograding deltaic sediments across the northern Barrow-Dampier Sub-basins. This regression reached its maximum extent towards the end of the Middle Jurassic, coincident with a major phase of tectonic movement. This led to the formation of the ubiquitous 'Main Unconformity' ('MU'), separating the middle and upper Dingo Claystones, which has historically been interpreted as the expression of final continental breakup in the Argo Abyssal Plain. However, the generallyaccepted Callovian breakup age is seriously in dispute, as a result of ODP drilling (Gradstein, Ludden, & others, in press), and an alternative cause for this major tectonic spasm may have to be found. Much of the southern North West Shelf was emergent at this time; marine conditions persisted only in the rapidly-subsiding areas of the Lewis Trough and the Madeleine Trend.

The remainder of the Jurassic saw sedimentation in a true divergent margin setting with predominantly fine-grained mixed clastic sediments (upper Dingo Claystone) being rapidly deposited in the Lewis Trough. Within the uppermost part of the Dingo Claystone, a marine sandstone unit (Dupuy Sandstone Member) was deposited in moderate to deep water in the vicinity of Barrow Island and possibly also around the edges of the Rankin Platform.

The Dingo Claystone is disconformably overlain by the Barrow Group, a generally northwards-prograding regressive sequence of clastics of mainly Neocomian age. Three units have been named within the Barrow Group - the Malouet and Flacourt Formations, respectively comprising the bottomsets and foresets/topsets of the delta, and the Flag Sandstone (Kopsen & McGann, 1985), a massive submarine fan sandstone that is a facies equivalent of the Malouet Formation. The relationship between these three formations is shown diagramatically in Howell (1988, fig. 8) and Barber (1988, fig. 7).

A major transgression beginning in the late Valanginian initiated the deposition of the units of the Winning Group (successively, the Birdrong Sandstone, Muderong Shale, Windalia Sandstone Member, Windalia Radiolarite, Gearle Siltstone and Haycock Marl). It is likely that this transgression was in response to margin breakup adjacent to the Perth Basin. The basal transgressive unit consists of the Birdrong Sandstone along much of the Peedamullah Shelf, and the mid- and outer-shelf Mardie Greensand to the south of Barrow island. Both units consist of quartzose sandstone; the Birdrong also contains minor interbedded siltstone, while the Mardie Greensand is heavily glauconitic. The basal sands were succeeded by the Muderong Shale, a widespread unit of marine claystones which provides a regional seal for most of the hydrocarbon accumulations in the Barrow and Dampier Sub-basins. A minor regressive phase is indicated by the deposition of the Windalia sandstone Member, a storm-winnowed shelf sand, at the top of the Muderong Shale.

In the Aptian, a marked environmental change and a rise in sea level led to the deposition of the widespread Windalia radiolarite, composed of radiolarite grading basinwards to radiolarian claystone, siltstone, and chert. The Windalia Radiolarite was succeeded by the Gearle Siltstone in the Barrow area and the Haycock Marl in the Dampier Sub-basin, with these units being deposited in open ocean settings.

Extensive carbonate sedimentation commenced in the Turonian with the deposition of the Toolonga Calcilutite. During the remainder of the Cretaceous, sedimentation was fairly evenly split between open marine carbonates and claystones (Korojon Calcarenite, Withnell Formation, and Miria Marl). Most of the Tertiary sequences on the North West Shelf are the result of out- and up-building of the continental shelf during a series of transgressive/regressive sea-level pulses, with the dominant sediment type being carbonate.

HYDROCARBON ACCUMULATIONS

The hydrocarbon fields of the southern North West Shelf fall into two categories (Vincent & Tilbury, 1988) - those reservoired in the pre-'Main Unconformity' (pre-MU) section, and those reservoired in the post-MU section.

The pre-MU fields are characterised by the fault blocks of the Rankin Trend, which host several giant gas/condensate fields - most notably North Rankin, Goodwyn, and Gorgon. These fields are sub-unconformity traps and have in common reservoirs of the fluviatile Mungaroo Formation and are sealed by the Cretaceous Muderong Shale (much of the intervening Jurassic-Cretaceous section is absent through non-deposition or erosion). Sourcing is interpreted to be from the immense thickness of lower Dingo Claystone in the Lewis Trough, and possibly also from the Triassic (Pre-Mungaroo Formation) Locker Shale. The fault blocks are frequently tilted or triangular in outline, with varying degrees of rotation and, as discussed previously, appear to be wrench reactivations of older structures.

The post-MU hydrocarbon fields are generally much more subtle than the Rankin Trend fault blocks and they tend to be oil-prone. With some exceptions (Barrow Island and, more recently, Wanaea-Cossack) the field sizes have tended to be quite small. There is a greater variety of traps than with the pre-MU fields, with trap types including drape, anticlines (some faulted), rollover into faults, and fault-controlled (Appendix 6). As with the pre-MU fields, most, if not all of these fields are the result of reactivation of older structures. Hydrocarbons are primarily reservoired in three sections - Jurassic Angel Formation, Cretaceous Barrow Group (including Flag Sandstone), and Cretaceous Winning Group (particularly Windalia Sandstone Member and Mardie Greensand). In general, the Jurassic reservoirs are gas-rich and found on the Rankin Trend and in adjacent structures, while the Cretaceous reservoirs are oil-rich and found within the basins (eg Barrow Island) or along the southeast basin flank. As with the pre-MU fields, sourcing is probably from the Dingo Claystone.

In the literature, until recently, there has typically been reference to an 'inner oil trend' and an 'outer gas trend'. Until the late 1980's this was generally true, with hydrocarbon discoveries on the outer flank of the rift (Rankin Trend) being predominantly gas/condensate, while oil was the principal discovery within the rift or on the inner flank. However, with the successes at Chinook/Griffin/Ramillies and Wanaea/Cossack, on the Alpha Arch and the Madeleine Trend, the distinction between oil and gas trends is breaking down.

GENERAL OBJECTIVES & SPECIFIC PROBLEMS

The broad objectives of the program proposed here are as follows:

* To determine the regional structural framework of the northern Carnarvon Basin by examining the boundaries between major structural elements along key transects of the shelf.

* To determine the deep crustal structure of the sub-basins of the northern Carnarvon Basin and their relationship to the development of the continental margin adjacent to the southeastern Argo Abyssal Plain.

* To assess the effect of deep structure on the development of the major fields and petroleum plays in the region, and in particular the structural and depositional effects resulting from Tertiary reactivation of these deep structures.

A valuable by-product of such a regional deep-seismic program is the acquisition of a regional grid of seismic data that ties together the Mesozoic-Cainozoic sedimentary section across the southern North West Shelf. In the past 10-15 years, while high-quality seismic data have been collected by industry, these data have tended to be concentrated at a prospect level in isolated fashion, resulting in a dearth of consistent high-quality regional well- and basin-tie data.

At a more specific level, we believe that the following geoscientific problems evident in the northern Carnarvon Basin and offshore Canning Basin can be addressed to varying degrees by the acquisition of deep seismic data:

1) Detachment Models: Recent models of the formation of passive continental margins propose that the formation of sedimentary basins takes place by extension above and below sub-horizontal detachment faults in the crust (Lister & others, 1986). Assuming such detachment models provide a plausible explanation for basin formation, where are the major detachment faults beneath the northern Carnarvon Basin and how can detachment models be applied to the area?

2) Original Extension: What is the age, amount, and azimuth of the original extension that formed the nascent northern Carnarvon and Offshore Canning Basins? Published and unpublished seismic data show that, while there was a major faulting episode in the Late Triassic (which has been typically interpreted as rift onset), there is very little extension on these faults, and it appears to these authors (and to others) that the major extension episode took place much earlier (perhaps in the Permian).

3) Strike-Slip Movements: The *en echelon* character of the major faults systems and the Rankin Trend fault blocks, and the existence of major anticlines (Barrow Island Anticline) and sedimentary deeps (eg Lewis Trough), has led to the obvious conclusion that strike-slip movement has been a major factor in the genesis of the northern Carnarvon Basin. What was the age, extent, and azimuth of these ?multiple phases of movement, and what is their relationship to any phases of simple basin-forming extension?

4) Transfer Faults: Major transfer faults in the Barrow-Dampier Sub-basins can be broadly identified or inferred, but have not been delineated seismically. These transfer zones probably have significant effects on the distribution of reservoir and source rocks, migration paths, and as trapping mechanisms. Is it possible to image these transfer zones in deep seismic data, such that, at a later stage of study, they can be mapped more accurately and related to the known hydrocarbon fields?

5) Late Reactivation: A number of hydrocarbon discoveries in the 1980s on the North West Shelf have been in traps that have been subjected to Cretaceous Tertiary reactivation. How are these reactivation traps related to deep structures and can an understanding of such deep structures lead to a prediction of likely locations for late hydrocarbon trapping?

6) Inter-relationship of Sub-basins: There is a lack of a regional understanding of the relationships between the Exmouth, Barrow, Dampier, and Beagle Sub-basins. Can a good-quality, deep strike line allow the pre-Callovian histories of these four sub-basins to be better related?

7) Rankin Platform Gravity: The most prominent gravity feature of the southern North West Shelf is the positive anomaly associated with the Rankin Platform, and it is obvious that the Rankin Platform is a structure that is fundamental to the genesis of the area. Why is the peak of the anomaly offset from the shallowest part of the Rankin Platform and what bearing does this have on extensional basin models?

8) Alpha Arch: At the southwest end of the Rankin Platform, the trend of the gravity high changes to south-southwest (overlying the Gorgon structure and the Alpha

Arch). In addition to hosting the the Gorgon gas field, the southern Rankin Platform/Alpha Arch is proving to be a fruitful exploration area for oil (Griffin, Chinook, Ramillies).What is the deep structure of this part of the Barrow Sub-basin and how does it control the distribution of hydrocarbon fields?

9) Beagle Sub-basin: While the Barrow and Dampier Sub-basins are both well-explored and hydrocarbon-rich, the same cannot be said for the next basin to the northeast, the Beagle Sub-basin. This complexly-structured basin has been little explored in the 1980s and has been penetrated by a limited number of wells. What is the deep structure of this basin and what influence has this had on the lack of exploration success to date?

10) Offshore Canning Basin: As with the Beagle Sub-basin, the Offshore Canning Basin (including the Mesozoic Bedout and Rowley Sub-basins) is poorly explored by seismic and drilling. In addition, this area has the added complication of lying at the intersection of the major northwest-trending Palaeozoic Canning Basin and the northeast-trending Mesozoic Westralian 'Superbasin'. What is the nature of the boundary between the Palaeozoic and Mesozoic basins offshore, and what is the relationship of the major faults/detachments to the development of the Argo Abyssal Plain? Recent BMR deep seismic data from the onshore Canning Basin have produced a major revision of the understanding of the tectonics of the Fitzroy Trough. If this model also applies to the offshore Fitzroy Trough then it has ramifications for the direction of exploration effort in that area.

PROPOSED PROGRAM

It is proposed that a regional grid of deep seismic lines be shot to address the problems outlined above. It is likely that it will not be possible to acquire more than about 2900 km of data in a one-month cruise. Because of this, it is envisaged that two cruises will ultimately be required to adequately cover the northern Carnarvon and Offshore Canning Basins. Our intention is that the first cruise (mid-1991) will concentrate in the northern Carnarvon Basin and initiate work in the Offshore Canning, while the second cruise (mid- to late-1992) will concentrate in the offshore Canning but also provide for follow-up work in the northern Carnarvon Basin.

The proposed lines for the first cruise are shown in Plate 1. (Note that the lines shown as 3184, 3184A, 3185, and 3185A are deep crustal lines recorded by Geopysical Services International in 1986, while the line S55-21 is a wide-angle CDP line recorded jointly by the Bureau of Mineral Resources and Lamont-Doherty Geological Observatory.) The program proposed here is divided into three stages. Stage I is primarily directed at the Exmouth-Barrow-Dampier Sub-basins, and is considered to be the highest priority. It is anticipated that, even in the event of serious operational problems, this stage should be achievable. The short Stage II, concentrated in the Beagle Sub-basin, should also be achieved even with moderate operating problems. Stage III, as proposed here, comprises the first phase of a deep seismic program in the Offshore Canning Basin. This stage may not be fully achievable on this first cruise, in which case any remaining lines will be picked up during a cruise in 1992. A brief summary of the function of each line is as follows (number in parentheses refer to number of the specific problems referred to previously):

STAGE I (1583 km)

Lines 1-4 (606 km; 4, 6, 9): Major strike line linking the depocentres of the Beagle,Dampier, Barrow, and Exmouth Sub-basins. Ties to Phoenix-1, Angel-3, Bowers-1, and Jurabi-1.

Line 5 (106 km; 1, 2): Dip line across the Exmouth Sub-basin from the vicinity of the Muiron Islands to the southwest Exmouth Plateau. Ties to West Muiron-2 and Zeewulf-1.

Line 6 (132 km; 1, 2, 3, 5, 8): Dip line across the southern Barrow Sub-basin from the vicinity of the Saladin oil field, across the Alpha Arch, to the inner edge of the Exmouth Plateau. Ties to Rosaliy-1A and Zeepard-1.

Line 7 (249 km; 1, 2, 3, 5): Dip line across the central Barrow Sub-basin from the vicinity of the South Pepper oil discovery, across the major Gorgon structure, to the crest of the Exmouth Plateau. Ties to Robot-1A, Gorgon-1, and Jupiter-1.

Line 8 (135 km; 1, 2, 3, 7): Dip line near the junction of the Barrow and Dampier Sub-basins from the junction of he Deepdale and Hauy Fault Systems, across the Rankin Platform, to the inner edge of the Exmouth Plateau. Ties to Arabella-1 and Parker-1.

Line 9 (208 km; 1, 2, 7): Dip line from the Lambert Shelf, across the central Dampier Sub-basin, to the inner edge of the Exmouth Plateau. Ties to Strickland-1, Hampton-1, Rosemary-1, and Goodwyn-7.

Line 10 (147 km; 1, 2, 3, 7): Dip line from the Lambert Shelf, across the northern end of the Dampier Sub-basin and Rankin Platform, to the inner edge of the Exmouth Plateau. Ties to Lawley-1, Legendre-1, Lambert-1, and Brigadier-1.

STAGE II (471 km)

Line 11 (229 km; 1, 2, 9): Dip line from the Lambert Shelf, across the western Beagle Sub-basin (Cossigny Trough and Picard Trend), to the northern Exmouth Plateau. Ties to Hauy-1 and Cossigny-1.

Line 12 (242 km; 1, 2, 9): Obliquely-oriented line from the Lambert Shelf, across the eastern Beagle Sub-basin, to the northern Exmouth Plateau. Ties to Depuch-1 and Poissonier-1.

STAGE III (877 km)

Line 13 (264 km; 2, 10): Line from the Lambert Shelf, across the western Bedout Sub-basin and Bedout High, to the margin of the Rowley Sub-basin. Ties to Phoenix-1.

Line 14 (206 km; 2, 10): Mesozoic dip line from the the Samphire Depression, across the Bedout Sub-basin and Bedout High, to the margin of the Rowley Sub-basin. Ties to Lagrange-1.

Line 15 (407 km; 2, 10): Palaeozoic dip line across the near-shore Offshore Canning Basin, including the Fitzroy Trough. Ties to Lacepede-1A.

The total distance represented by these lines is 2931 km and data recording parameters are set out in Appendix 3.

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APPENDIX 1
WELLS TIED BY SEISMIC LINES

(Locations of wells are noted in Appendix 2.)

Well	Operator	Date	TD	Oldest Sequence	Status
Angel-3	Woodside/Burmah	1973	3780	U. Ju	Susp.; cond., gas
Arabella-1	Aust. Occidental	1983	2209	Lw. Perm	Dry
Bowers-1	Wapet	1982	4300	U. Tr	Dry
Brigadier-1	Woodside	1978	4292	Tr	Dry
Cossigny-1	Woodside/Burmah	1972	3203	M. Tr	Dry
Depuch-1	Woodside/Burmah	1974	4300	Lw. Ju	Dry
Goodwyn-7	Woodside	1985	3446	U. Tr	Cond., gas
Gorgon-1	Wapet	1980	4401	U. Tr	Susp.; cond., gas
Hampton-1	Woodside/Burmah	1974	2584	Lw. Tr	Dry
Hauy-1	Woodside/Burmah	1972	825	Lw. Tr	Dry
Jupiter-1	Phillips	1979	4946	U. Tr	Dry
Jurabi-1	Esso	1982	3712	U. Tr	Dry
Lacepede-1A	Burmah	1970	2286	U. Perm	Dry
Lagrange-1	BP	1982	3260	U. Perm	Dry
Lambert-1	Woodside/Burmah	1973	3700	Lw. Ju	Dry; o/g shows
Lawley-1	Hudbay Oil	1981	1120	M. Tr	Dry
Legendre-1	Burmah	1968	3473	M. Ju	Dry
N Turtle-1	BP	1982	4420	Lw. Ju	Dry
Parker-1	Woodside	1979	4737	Lw. Ju	Dry
Phoenix-1	BP	1980	4880	M. Tr	Dry
Poissonnier-1	Woodside/Burmah	1973	1962	Tr	Dry
Robot-1A	BP	1988	3459	Lw. Cret	Dry
Rosaliy-1A	Wapet	1982	3066	Lw. Cret	Dry
Rosemary-1	Woodside/Burmah	1972	3909	Ju	Dry
Strickland-1	Hudbay Oil	1982	1050	Tr	Dry
West Muiron-2	Wapet	1975	3220	U. Tr	Dry
Zeepard-1	Esso	1980	4215	U. Tr	Dry; show gas
Zeewulf-1	Esso	1979	3500	U. Tr	Dry; cond., gas

APPENDIX 2
SEISMIC LINE WAY POINTS

Line	SP	Latitude	Longitude	Comments
BMR-1	100	18 37 07.8	118 49 13.2	SOL
BMR-1	200	18 38 07.1	118 47 07.4	Phoenix-1
BMR-1	1720	18 54 35.3	118 05 16.0	North Turtle-1
BMR-1	4580	19 23 34.3	116 50 56.6	EOL
BMR-2	100	19 23 34.3	116 50 56.6	SOL
BMR-2	660	19 32 30.5	116 37 32.9	Angel-3
BMR-2	4320	20 26 47.1	115 11 25.7	EOL
BMR-3	100	20 26 47.1	115 11 25.7	SOL
BMR-3	760	20 45 32.1	115 03 25.7	EOL
BMR-4	100	20 45 32.1	115 03 25.7	SOL
BMR-4	1160	21 06 13.9	114 42 54.0	Bowers-1
BMR-4	2740	21 37 12.1	114 11 55.6	Jurabi-1
BMR-4	2840	21 39 00.8	114 10 02.9	EOL
BMR-5	100	21 37 30.0	114 16 00.0	SOL
BMR-5	190	21 35 38.7	114 13 31.2	West Muiron-2
BMR-5	1890	21 06 32.5	113 37 13.2	Zeewulf-1
BMR-5	2240	21 00 00.0	113 29 25.7	EOL
BMR-6	100	20 24 54.6	114 07 57.7	SOL
BMR-6	1060	20 44 13.9	114 25 22.0	Zeepard-1
BMR-6	2460	21 12 08.0	114 52 01.0	Rosaliy-1A
BMR-6	2740	21 18 12.9	114 58 17.1	EOL
BMR-7	100	20 56 15.0	115 10 17.1	SOL
BMR-7	540	20 48 13.8	115 01 06.1	Robot-1A
BMR-7	1260	20 34 43.2	114 46 21.9	Gorgon-1
BMR-7	4660	19 34 53.0	113 31 58.0	Jupiter-1
BMR-7	5020	19 27 03.2	113 22 58.1	EOL
BMR-8	100	19 31 36.4	115 17 51.8	SOL
BMR-8	1380	20 00 07.9	115 40 07.9	Parker-1
BMR-8	2700	20 28 12.0	116 01 52.0	Arabella-1

BMR-8	2800	20 30 19.3	116 03 42.9	EOL
Line	SP	Latitude	Longitude	Comments
BMR-9	100	20 14 13.3	116 43 18.3	SOL
BMR-9	200	20 12 31.4	116 41 02.2	Strickland-1
BMR-9	570	20 07 04.5	116 32 47.4	Hampton-1
BMR-9	1140	19 57 16.3	116 20 41.1	Rosemary-1
BMR-9	2200	19 37 41.7	115 57 36.8	Goodwyn-7
BMR-9	4300	19 00 00.0	115 14 00.0	EOL
BMR-10	100	19 00 00.0	116 02 49.0	SOL
BMR-10	380	19 05 48.8	116 08 09.5	Brigadier-1
BMR-10	1500	19 27 23.2	116 29 23.0	Lambert-1
BMR-10	2210	19 40 19.0	116 43 55.5	Legendre-1
BMR-10	3000	19 54 20.8	117 00 32.1	Lawley-1
BMR-10	3100	19 56 06.9	117 02 33.8	EOL
BMR-11	100	19 50 22.1	117 15 04.3	SOL
BMR-11	200	19 47 39.2	117 15 15.5	Hauy-1
BMR-11	1260	19 19 53.3	117 17 26.0	Cossigny-1
BMR-11	4890	17 46 25.3	117 26 21.3	EOL
BMR-12	100	17 46 25.3	117 24 40.4	SOL
BMR-12	2710	18 50 06.6	117 55 18.9	Depuch-1
BMR-12	3870	19 18 33.6	118 09 19.1	Poissonnier-1
BMR-12	4940	19 45 12.1	118 23 02.0	EOL
BMR-13	100	19 45 12.1	118 20 28.4	SOL
BMR-13	2780	18 38 07.1	118 47 07.4	Phoenix-1
BMR-13	5385	17 31 12.6	119 13 27.5	EOL
BMR-14	100	17 55 00.0	118 55 00.0	SOL
BMR-14	1270	18 16 27.7	119 19 08.1	Lagrange-1
BMR-14	4218	19 10 40.0	120 20 56.6	EOL
BMR-15	100	19 20 05.4	120 05 05.7	SOL
BMR-15	5900	17 05 18.4	121 26 41.4	Lacepede-1A
BMR-15	8310	16 09 38.6	122 00 00.0	EOL

APPENDIX 3
SEISMIC ACQUISITION PARAMETERS

Seismic Cable Configuration

Minimum	length -	3600 m
	group length -	25 m
	no. channels -	144
Desirable	length -	4800 m
	group length -	25 m
	no. channels -	192

Seismic Source

Airgun capacity	50 litres (3000 cu in)
Airgun pressure	1800 psi
Shot interval	50 m
Shot rate	19.4 s @ 5 kn
	21.6 s @ 4.5 kn

Fold

Minimum -	3600%
Desirable -	4800%

Recording Parameters

Record length -	15 s
Sample interval -	4 ms

APPENDIX 4
EQUIPMENT TO BE UTILISED

FJORD Instruments seismic receiving array: 6.25 m, 12.5 m, 18.75 m, or 25 m group lengths; up to 288 channels; up to 6000 m active streamer length.

Syntron RCL-3 cable levellers; individual remote control and depth readout

Haliburton Geophysical Service 32 x 150 cubic inch airguns in two 16-gun arrays; normal operating array is two x 10 guns, giving a total of 3000 cubic inches normal operating volume

Air compressor system: 4 x A-300 Price compressors, each providing 300 scfm at 2000 psi (62 litres/min at 14 MPa)

Digital seismic acquisition system designed and built by BMR: 16-bit floating point, SEG-Y output at 6250 bpi

Reftek sonobuoy receiver and sonobuoys

Yaesu sonobuoy receiver and Spartan SSQ-57A sonobuoys

Raytheon echo-sounders: 3.5KHz (2 KW) 16-transducer sub-bottom profiler, and 12 KHz (2 KW) precisson echo-sounder

Geometrics G801/803 magnetometer/gradometer

Bodenseewerk Geosystem KSS-31 marine gravity meter

Differential GPS capability

Magnavox T-Set stand-alone GPS receiver

Magnavox MX 1107RS and MX 1142 transit satellite receivers

Magnavox MX 610D and Raytheon DSN 450 dual axis sonar dopplers; Ben paddle log

Sperry, Arma-Brown, and Robertson gyro-compasses

APPENDIX 5
COMPANIES CONSULTED DURING PROPOSAL PREPARATION

During preparation of this cruise proposal, the following exploration companies were contacted to provide input. We are grateful to staff of these companies for this input.

Ampol Exploration Ltd

Bridge Oil Ltd

BHP Petroleum Pty Ltd

British Petroleum

Conoco Australia Ltd

Esso Australia Ltd

Hadson Energy Ltd

Lasmo Oil (Australia) Ltd

Marathon Petroleum Australia Ltd

Norcen International Ltd

Petroz NL

Phillips Australian Oil Co

Shell Development (Australia) Pty Ltd

West Australia Petroleum Pty Ltd

Western Mining Corporation Py Ltd

Woodside Offshore Petroleum Pty Ltd

APPENDIX 6
NORTHERN CARNARVON BASIN - OIL & GAS FIELDS
(Summarised from Cockbain, 1989)

Basin	Year	Company	Age	Trap[1]	Orig. Reserves[2] Gas	Cond	Oil
		PRE-BREAKUP FIELDS					
Barrow Deep	1973	Wapet	Ju	A	8	-	-
Dockrell	1979	Woodside	Tr	TiFB	-	-	0.8
Eaglehawk	1972	Woodside	Tr	HB	-	-	0.2
Goodwyn	1971	Woodside	Tr, Ju	TiFB	131	40	2
Goodwyn South	1973	Woodside	Tr	TrFB	-	-	3
Gorgon	1981	Wapet	Tr	HB	234	2	-
North Rankin	1971	Woodside	Tr, Ju	HB	225	1	-
N Rankin West	1972	Woodside	Ju	FB	7	1	-
Rankin	1971	Woodside	Tr	TiFB	6	-	-
Tidepole	1975	Woodside	Tr	TiFB	15	2	1
West Tryal Rocks	1973	Wapet	Tr	HB	81	4	-
Wilcox	1983	Woodside	Tr	FB	10	3	-
		POST-BREAKUP FIELDS					
Angel	1972	Woodside	Ju	D	36	11	-
Bambra	1982	Bond	Cret	A	1	-	-
Barrow Island	1964	Wapet	Ju, Cret	A	5	0.4	42
Campbell	1986	Bond	Cret	A	2	-	-
Chervil	1983	WMC	Cret	FA	-	-	0.7
Dixon	1984	Woodside	Ju	D			
Egret	1973	Woodside	Ju	F-C	-	-	1
Harriet	1983	Bond	Cret	F-C	1	-	6
Lambert	1974	Woodside	Ju	R			
Legendre	1968	Wodside	Cret	FA			
North Herald	1983	WMC	Cret	FA	-	-	0.3
Rosette	1987	Bond	Cret	A	1	-	0.3
Saladin	1985	Wapet	Cret	F-C	0.6	-	8
Scarborough	1979	Esso	Cret	Dome	350	-	-
South Chervil	1983	WMC	Cret	FA			
South Pepper	1983	WMC	Cret	FA	-	-	0.5
Spar	1976	Wapet	Cret	R	7	1	-
Talisman	1984	Marathon	Cret	F-C			
Tubridgi	1981	Otter	Cret	A	2	-	-

Notes

1 Trap types as follows -

A	Anticline
TiFB	Tilted fault block
HB	Horst block
TrFB	Triangular fault block
FB	Fault block
D	Drape
FA	Faulted anticline
F-C	Fault-controlled
R	Rollover

2 Units for reserves

Gas	x 10^9 m^3
Condensate	x 10^6 kL
Oil	x 10^6 kL

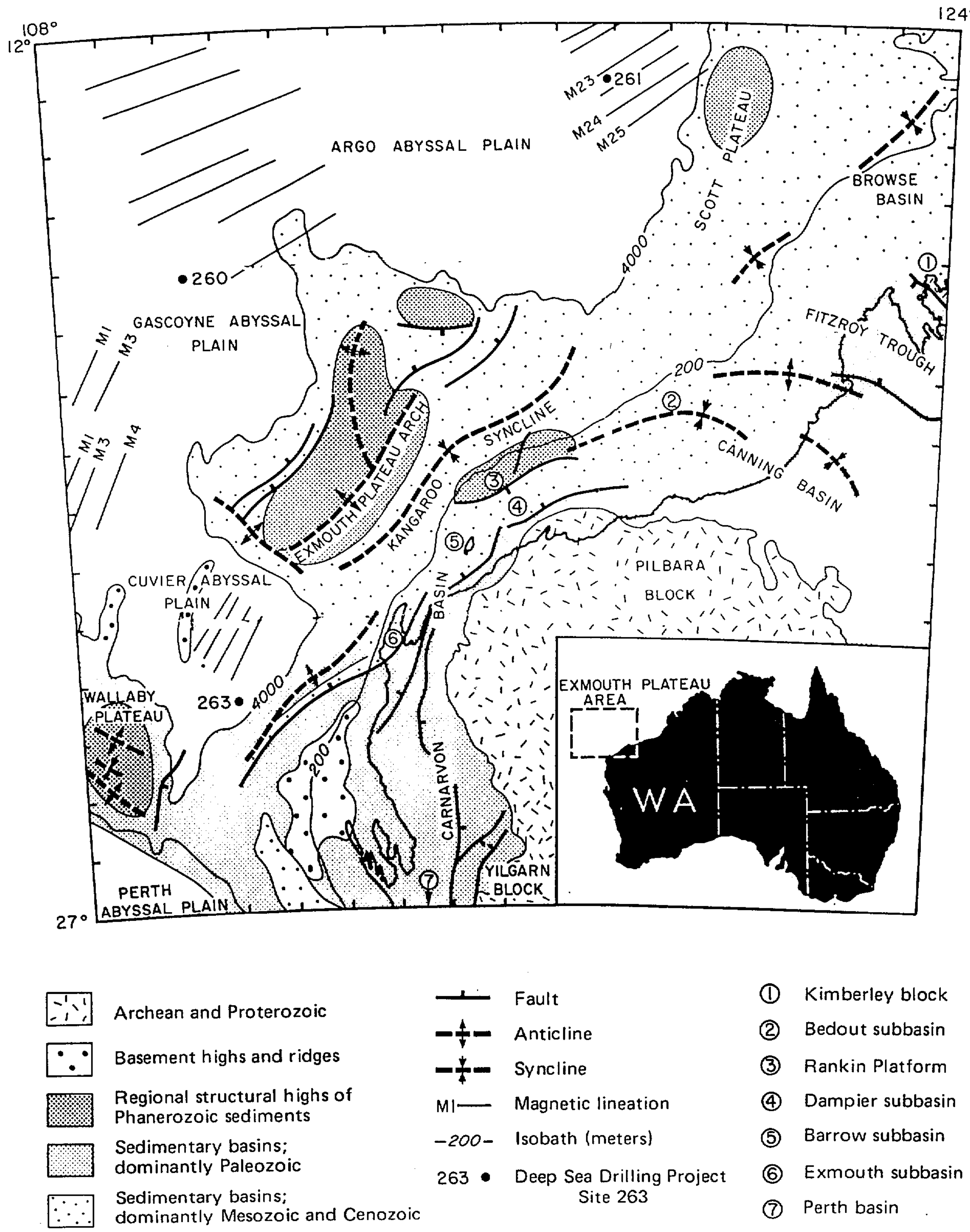


Figure 1: Regional setting of North West Shelf (after Exon & Wilcox, 1980).

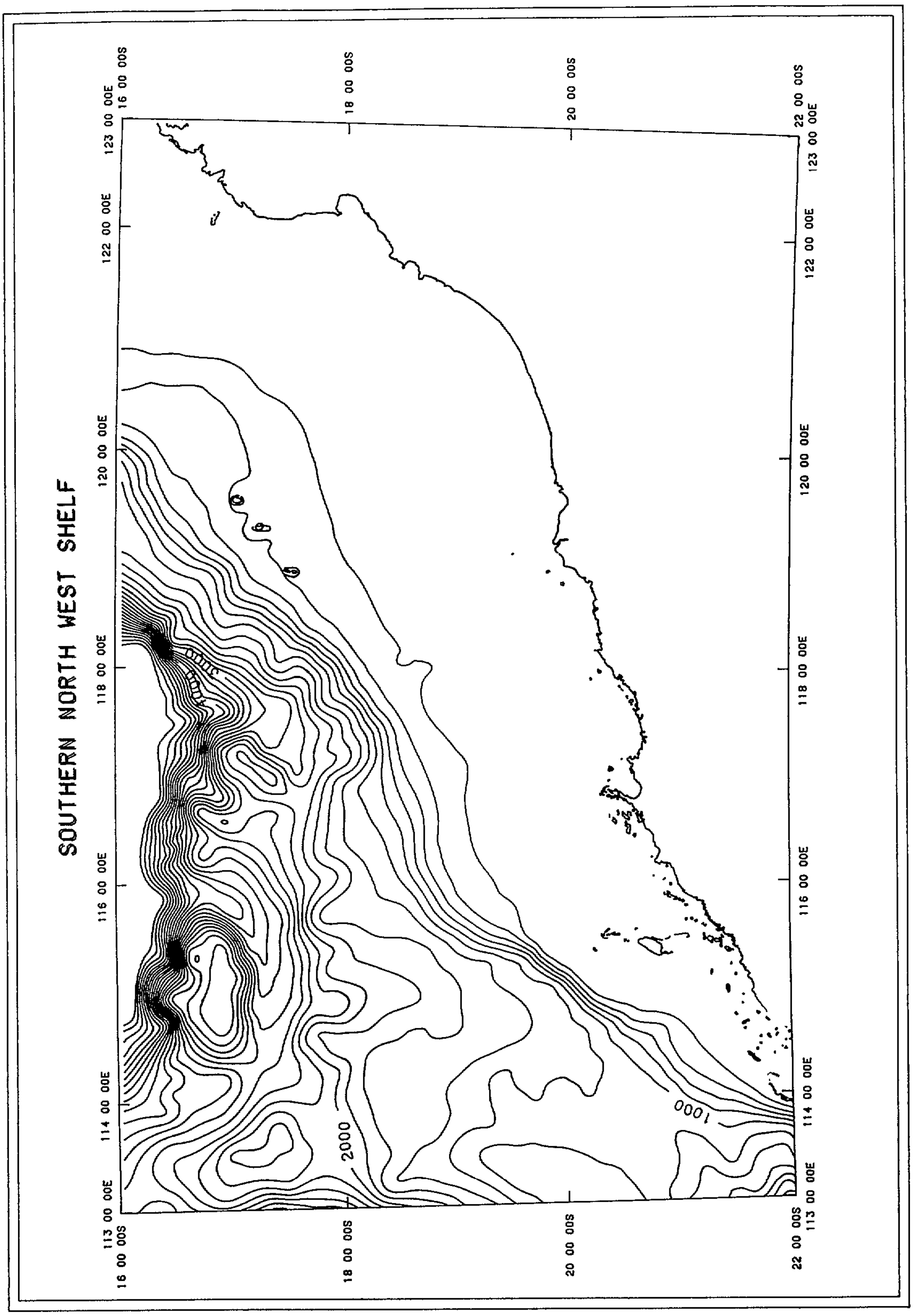


Figure 2: Bathymetry of the southern North West Shelf. Contour interval 200 metres

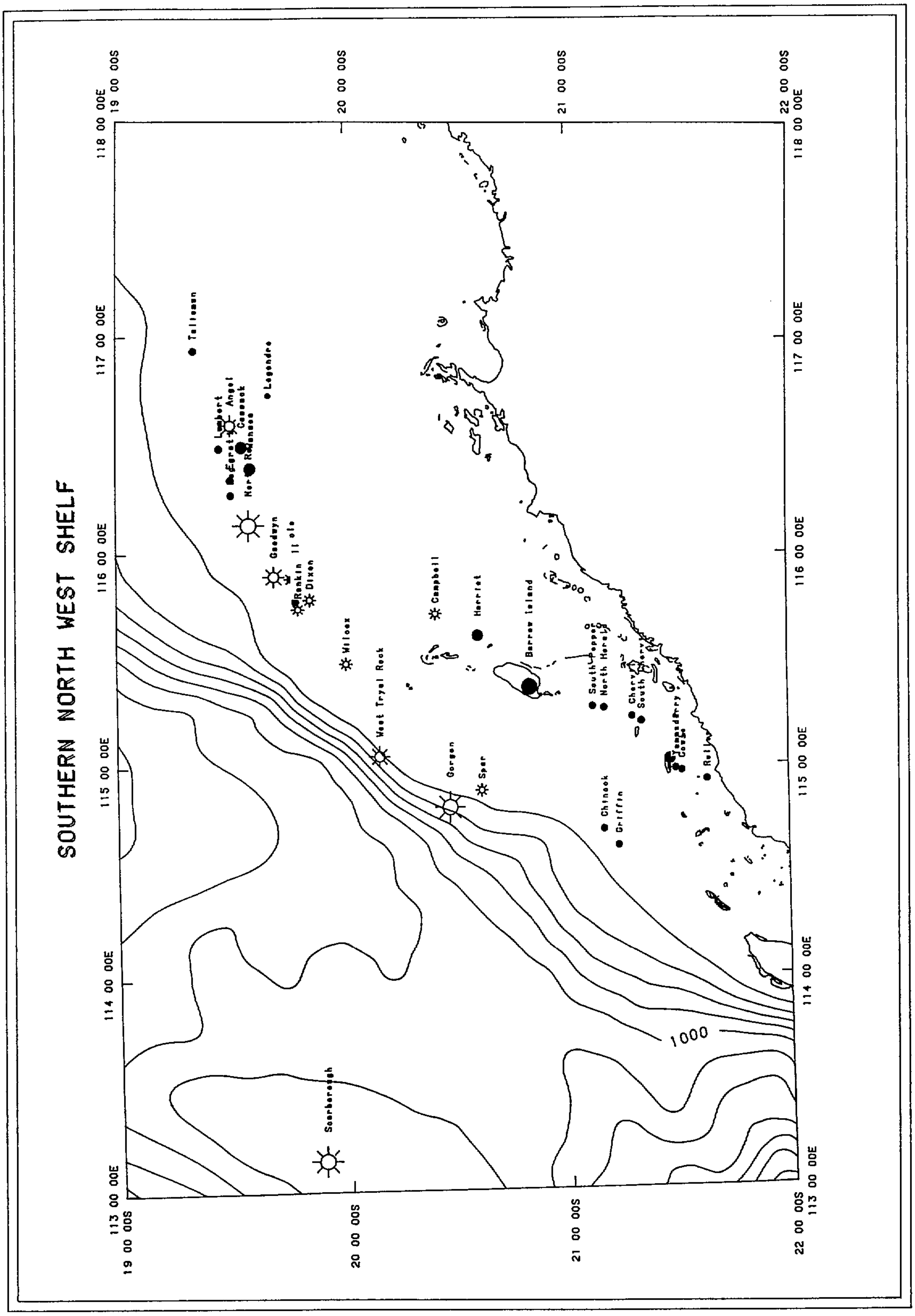


Figure 3: Location of oil and gas fields on the southern North West Shelf. Bathymetry contour interval 500 metres.

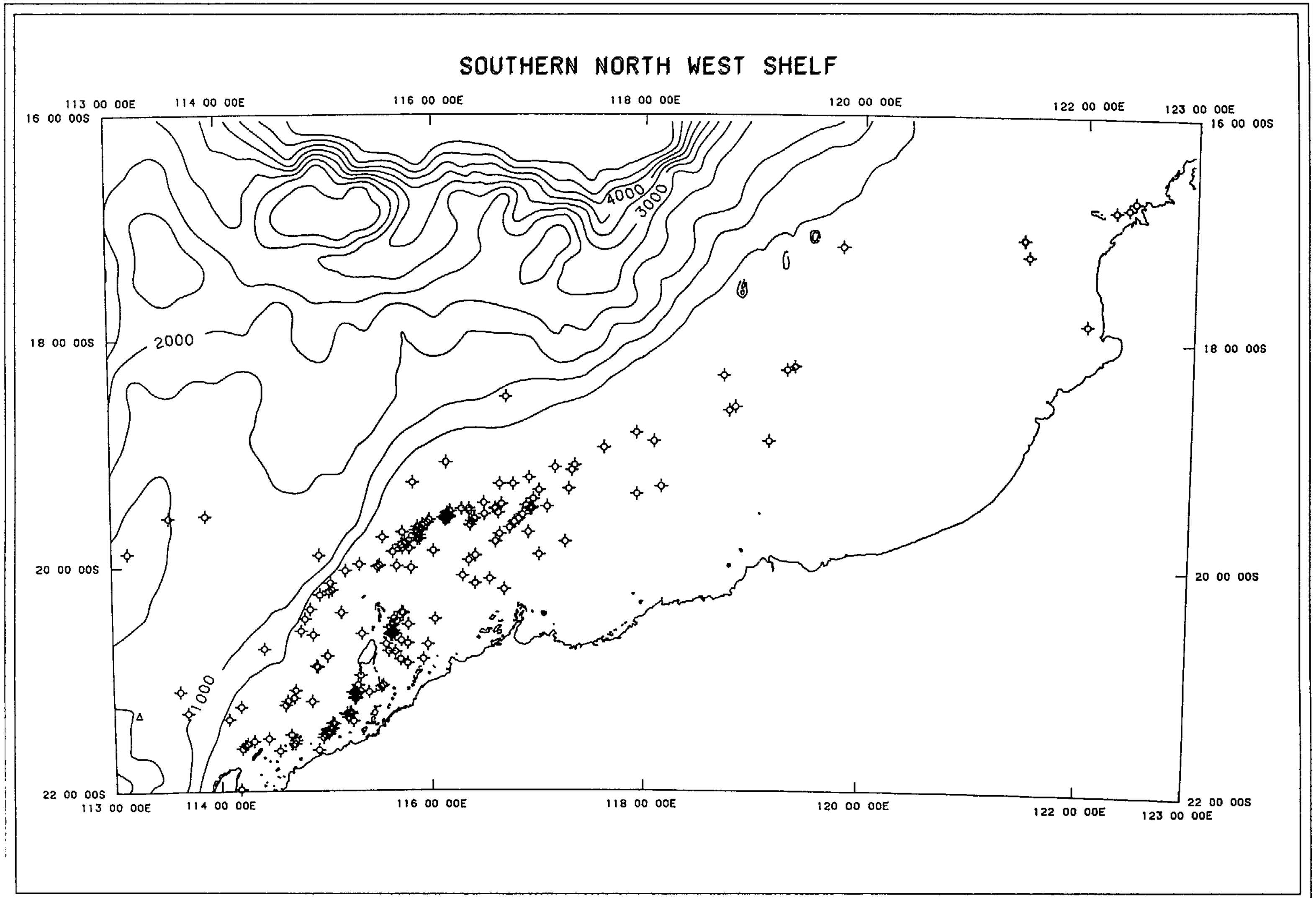


Figure 4: Locations of exploration wells on the southern North West Shelf.
Bathymetry contour interval 500 metres

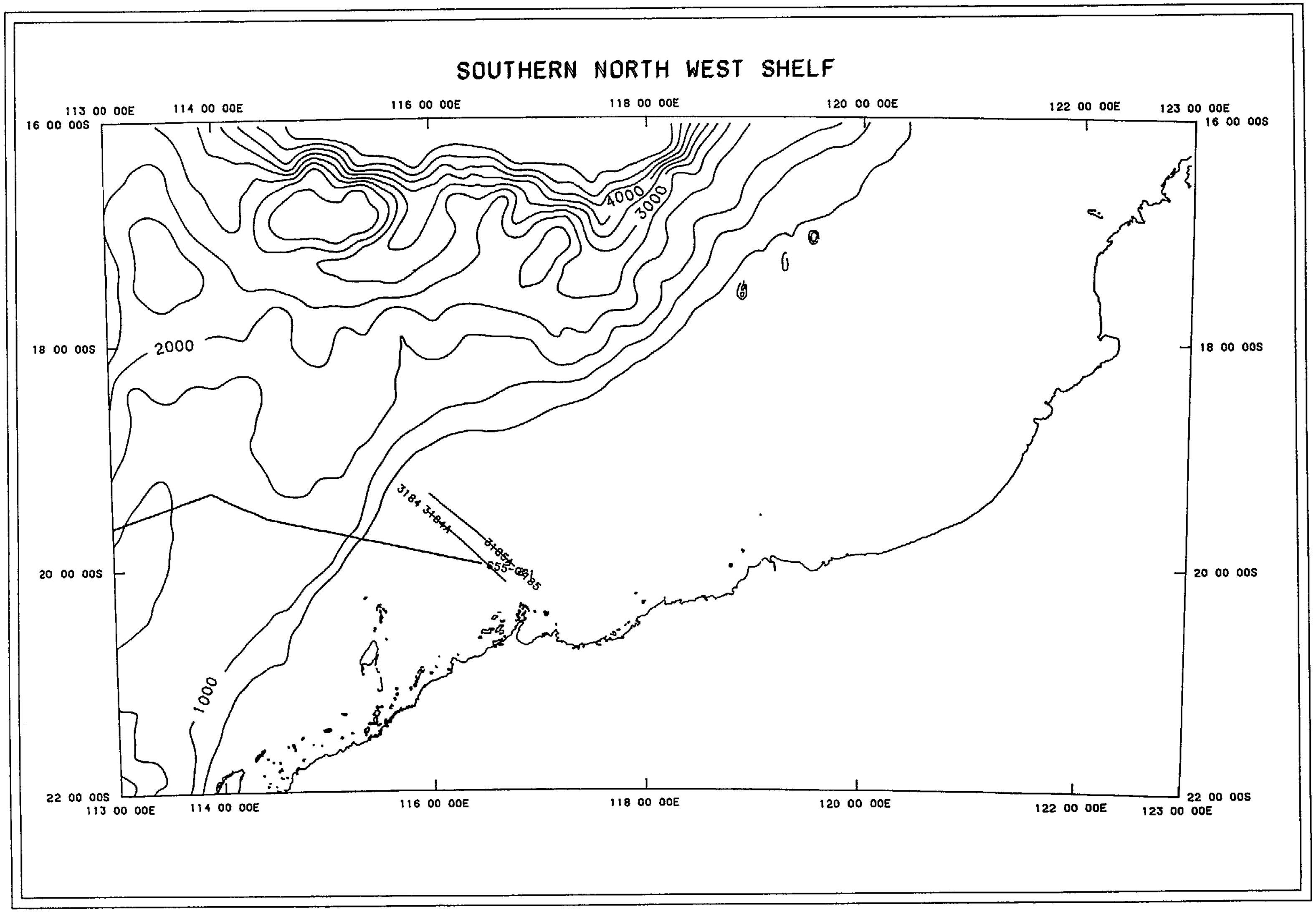


Figure 5: Location of deep seismic profiles on the southern North West Shelf. Bathymetry contour interval 500 metres.

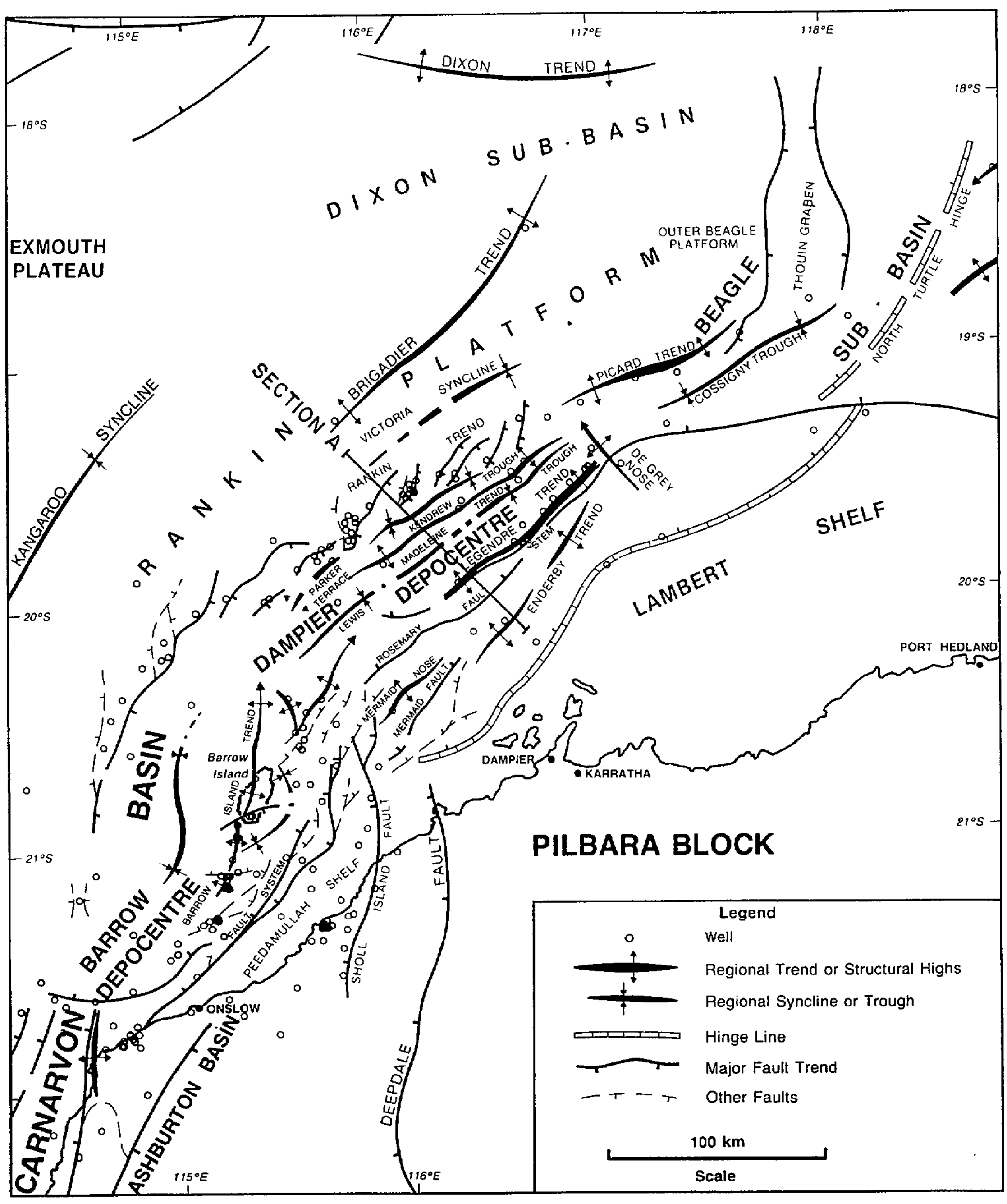


Figure 6: Tectonic elements of the southern North West Shelf (after Woodside, 1988).

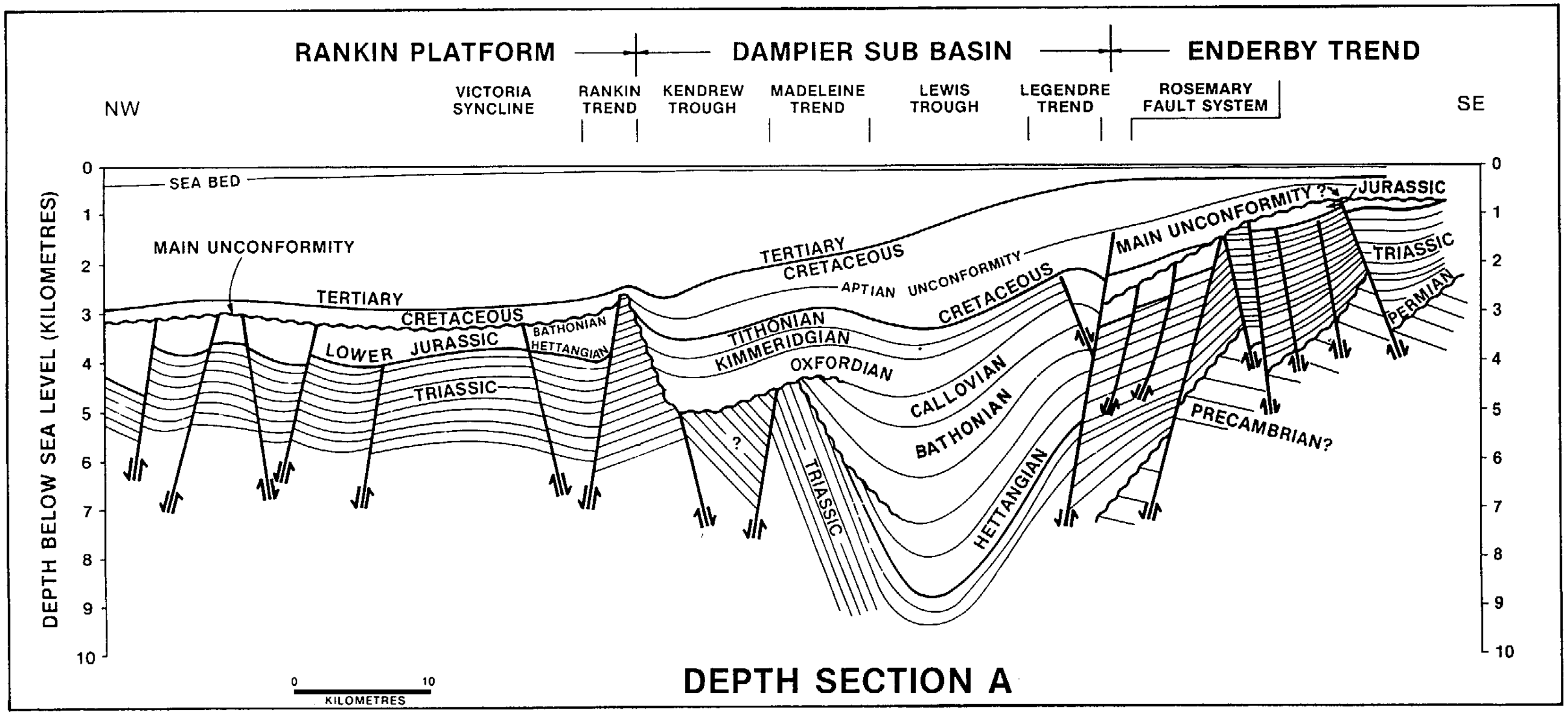


Figure 7: Depth profile across the Dampier Sub-basin (after Woodside, 1988).

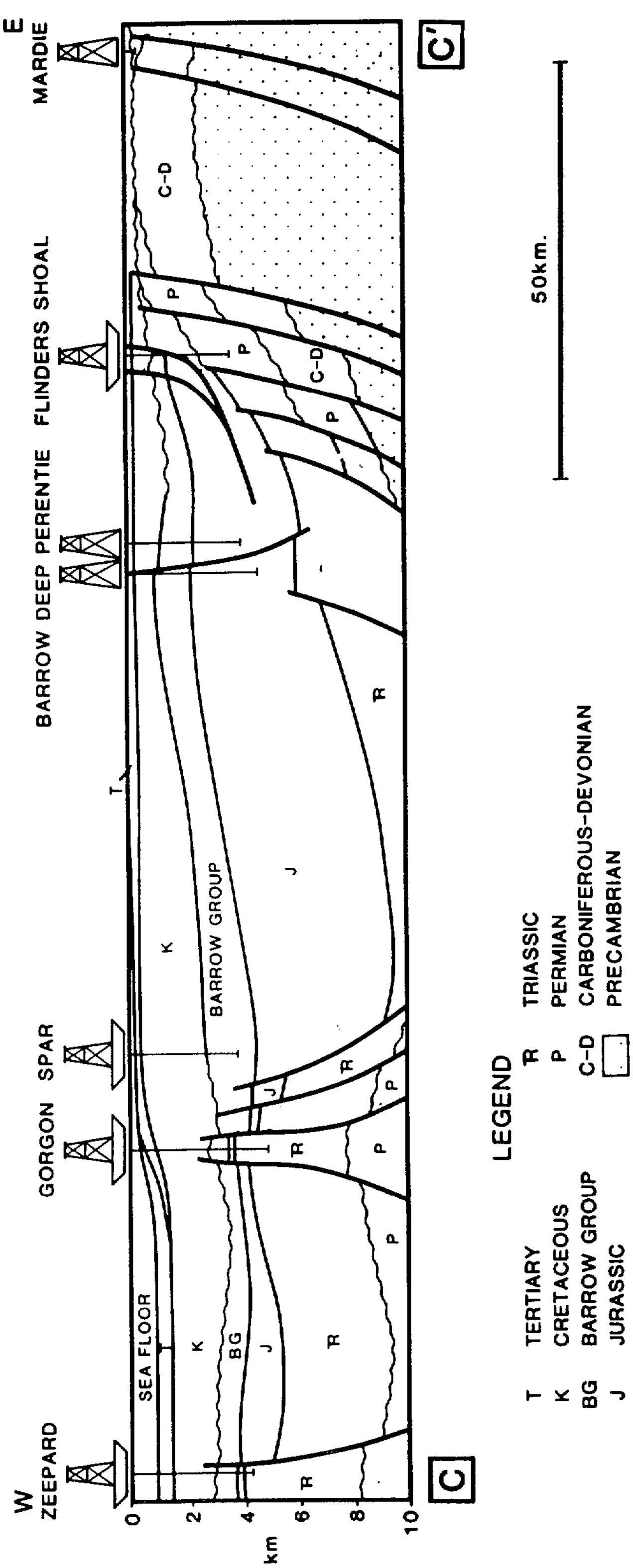


Figure 8: Depth profile across the Barrow Sub-basin (after Parry & Smith, 1988).

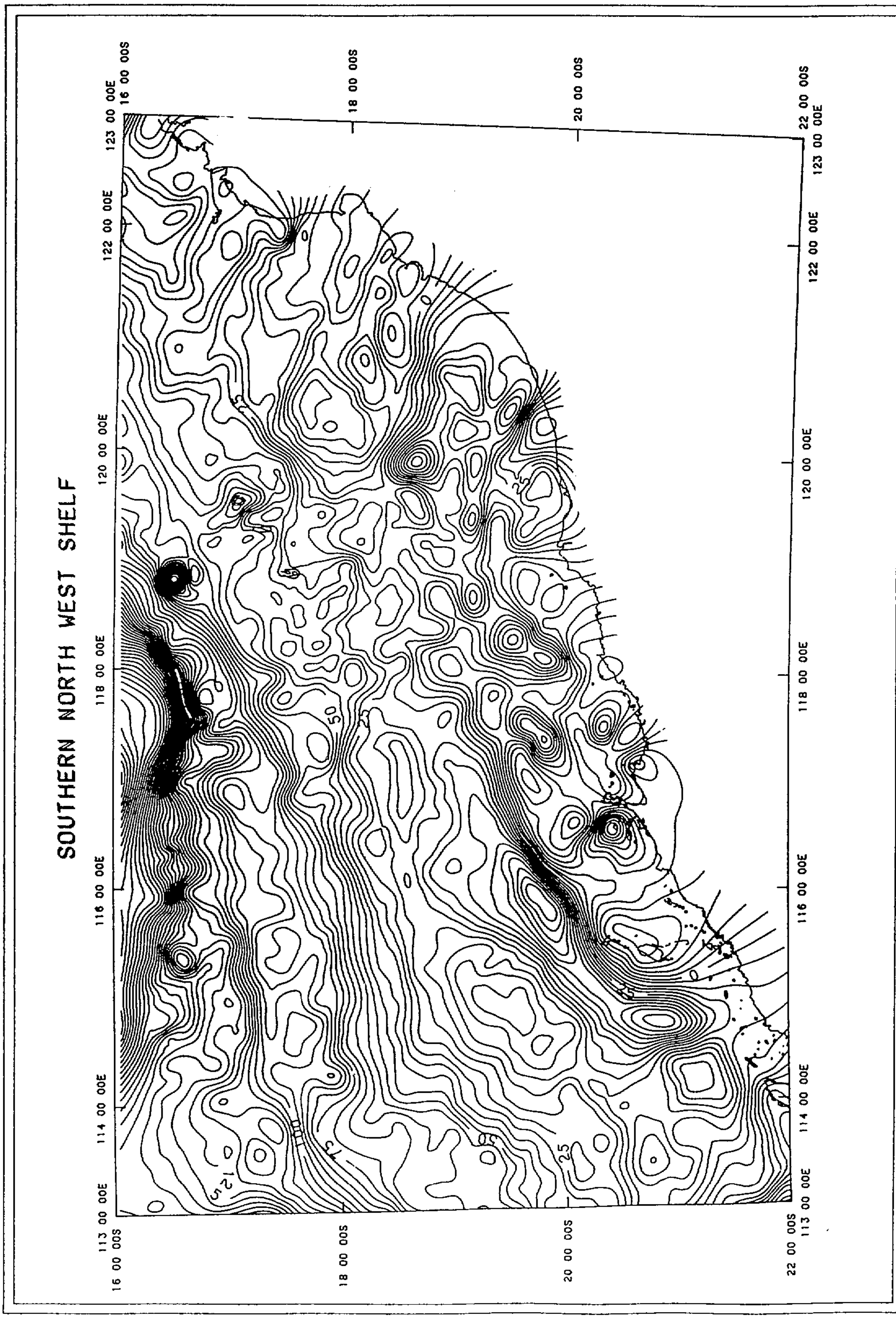


Figure 9: Bouguer gravity anomalies on the southern North West Shelf.
Contour interval 5 mgal.

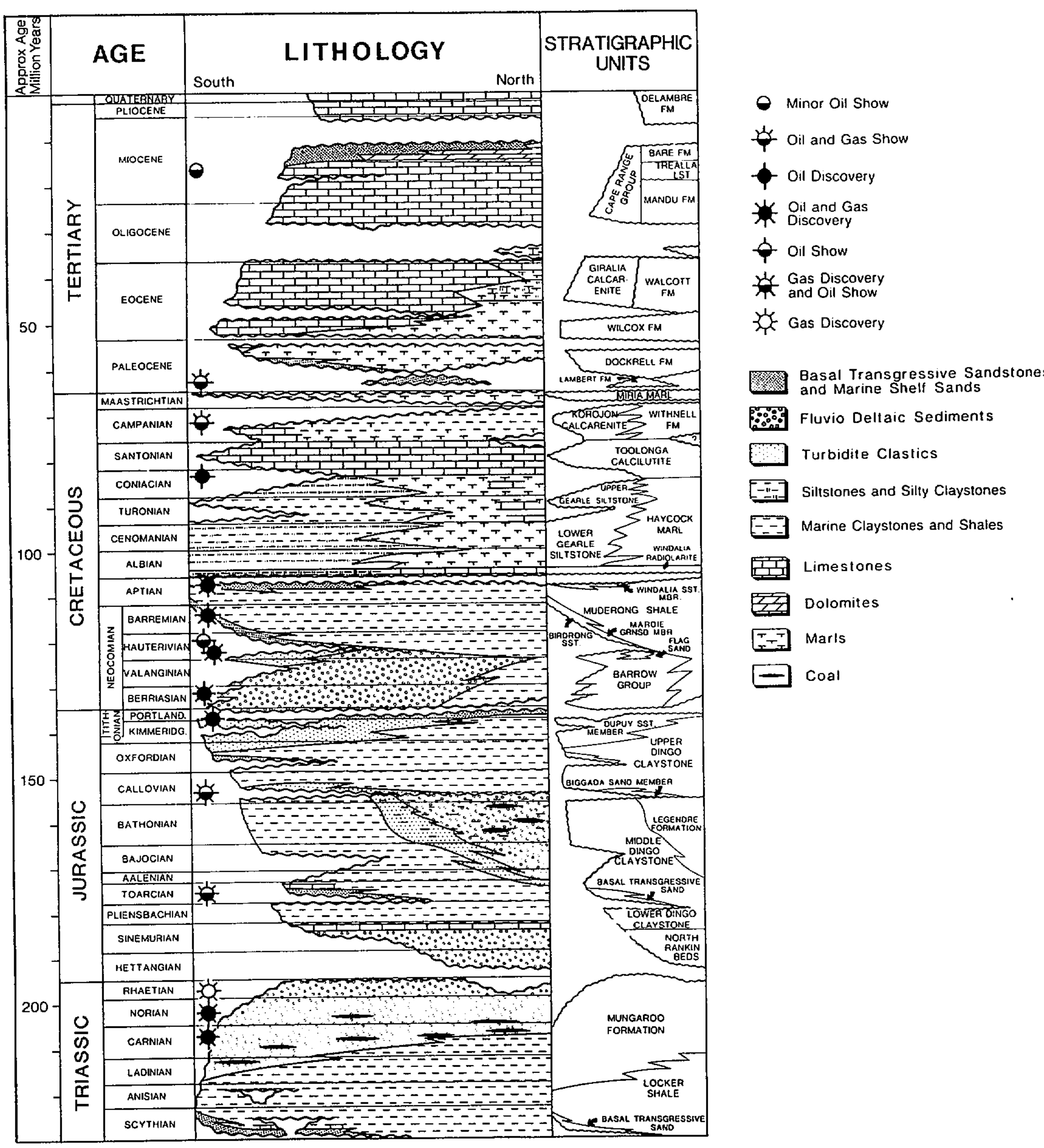
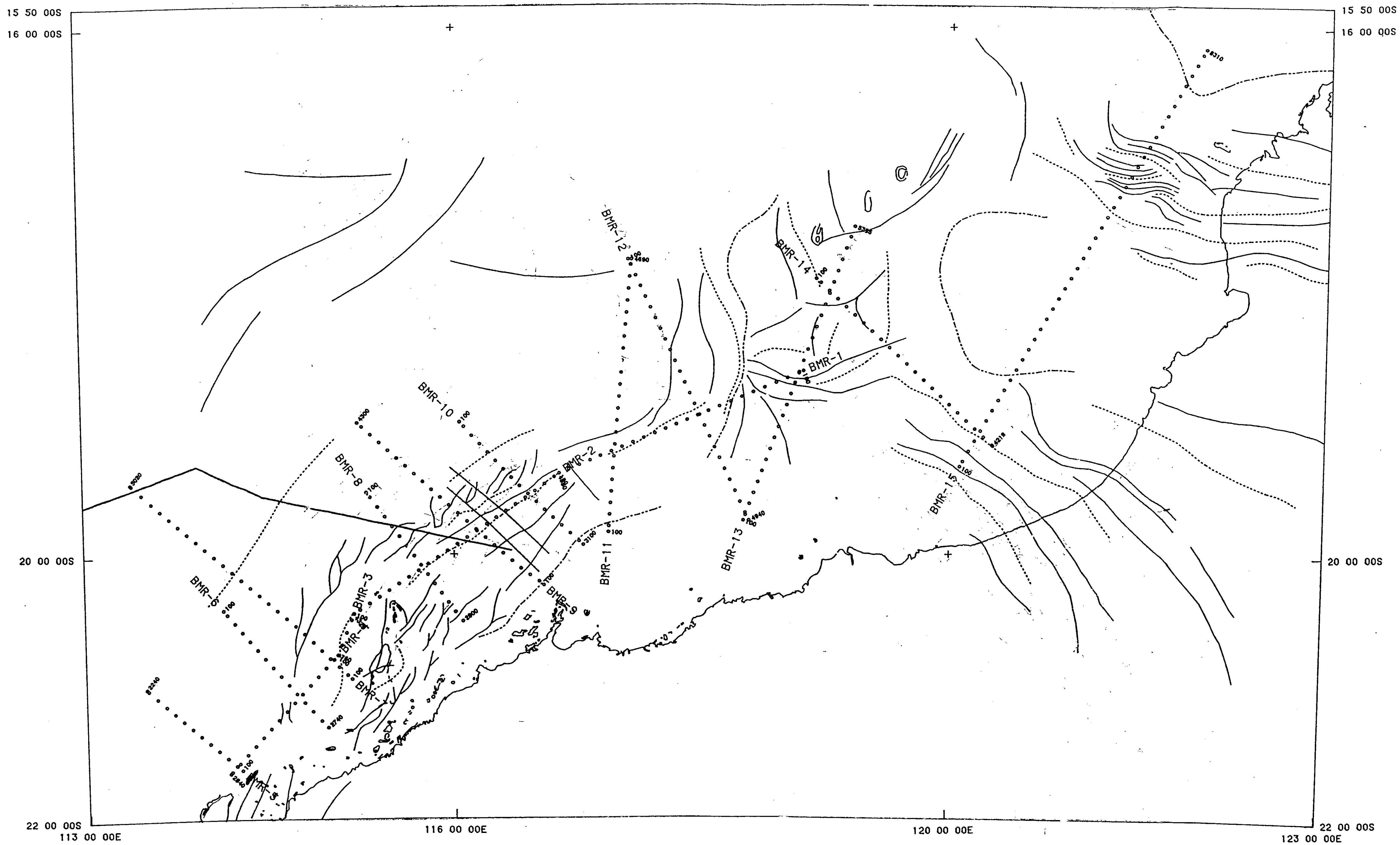


Figure 10: Stratigraphy of the southern North West Shelf (after Woodside, 1988).

SOUTHERN NORTH WEST SHELF



BUREAU OF MINERAL RESOURCES		
TECTONIC ELEMENTS AND SEISMIC LINES (TECTONICS AFTER WOODSIDE, JNOC) PLATE 1		