Bureau of Mineral Resources, Geology & Geophysics

RECORD

BMR RECORD 1991/79

DEEP STRUCTURE OF THE SOUTHERN NORTHWEST SHELF: POST-CRUISE REPORT

Project 121.17

by

H.M.J. Stagg, F.M. Brassil
& Survey 101 Shipboard Party

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Division of Marine Geosciences and Petroleum Geology

DEEP STRUCTURE OF THE SOUTHERN NORTH WEST SHELF: POST-CRUISE REPORT

Project 121.17

H.M.J. Stagg, F.M. Brassil
& Survey 101 Shipboard Party

BMR RECORD 1991/79

ISSN 0811-062X
ISBN 0 642 16594 7

CONTENTS

APPENDICES

FIGURES

EXECUTIVE SUMMARY

While the northern Carnarvon Basin of the southern North West Shelf is one of Australia's most hydrocarbon-rich provinces, relatively little is known of its deep structure and the control this deep structure has on hydrocarbon occurrences. BMR *Rig Seismic* Survey 101 was designed to acquire deep-crustal seismic data along a series of dip and strike lines in the region, with 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; and
* 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.

It is recognised that at least two cruises of deep-crustal seismic acquisition are needed to address these problems adequately on the southern North West Shelf (northern Carnarvon Basin and offshore Canning Basins). Survey 101, which departed Port Hedland on May 11 and arrived in Fremantle on June 10, 1991, was concentrated in the northern Carnarvon Basin. Technical difficulties prevented extension of the cruise into the offshore Canning Basin, as was originally intended.

During Survey 101, a total of 1654 km of presumably high-quality deep seismic data were recorded along 6 dip and 4 strike lines in the Dampier, Barrow, and Exmouth Sub-basins. These lines were tied to 20 exploration wells, thereby providing valuable modern regional ties of the principal seismic horizons throughout the region.

The seismic data were recorded from a 4800 m streamer, configured with 192 x 25 m active groups. The record length was 16 seconds, and the sample interval 4 msec. The seismic source consisted of dual 'sleeve' airgun arrays with a total volume of 50 l (3000 in^3). Shots were fired every 50 m at a ship speed of 4.5 knots, giving 48-fold coverage. Both streamer and airguns were towed at 10-11 m depth. Streamer noise levels were uniformly low, being generally less than 5-6 microbars for the first 32 channels, and less than 3 microbars for channels 33-192.

Navigation for the survey was provided by differential Global Positioning System (DGPS), using a shore reference station at Broome and a real-time satellite data link. DGPS data were recorded for 95.4% of the survey; during almost all the remaining time, stand-alone GPS was available. While detailed analysis of the navigation data has not yet been done, it is estimated that absolute positional accuracy should be better than +/- 10 metres.

In the Dampier Sub-basin, three dip lines were recorded, in the northwest, centre, and southwest of the sub-basin. These lines extended from the southern basin boundary to the inner Exmouth Plateau. Two dip lines were recorded across the Barrow Sub-basin, with one of the lines being extended to Jupiter-1 on the crest of the Exmouth Plateau. Shallow water at the near-shore ends of these lines precluded their being continued to the landward basin margin. In the Exmouth Sub-basin, a single dip line was recorded from the southern Exmouth Plateau to North West Cape, parallel to, and south of the Long Island Transfer Fault. Three linked strike lines were recorded from the Exmouth Sub-basin along the length of the Barrow and Dampier depocentres into the Beagle Sub-basin, to tie together the dip lines and to image the generally NW-SE cross trends at depth; these cross-trends (transfer fault direction) have probably had a major influence on the present-day structure of the southern North West Shelf. Advantage was taken of available transit time to record a second, shorter tie line from the Kangaroo Syncline to the deep-water Exmouth Sub-basin.

As the Tertiary carbonates on the North West Shelf make the area notoriously difficult for the recording of seismic data, particularly in shallow water, it was anticipated that only gross structural information would be visible in the monitor sections. This turned out to be the case and, while definite primary reflections can be identified down to 5-6 seconds TWT on some lines, strong water column and interbed reverberations generally overwhelm any deep information in the unprocessed data. The only open-file deep seismic data from the northern Carnarvon Basin (two lines across the central Dampier Sub-basin) show reflections down to 10-12 s TWT, with a shorter streamer and smaller seismic source than were used in Survey 101. We are therefore confident that, given the low streamer noise levels prevailing during the survey, the processed data should reveal valuable information on the basin-forming structures in the region.

ACKNOWLEDGEMENTS

The success of Survey 101 was due in no small part to the skill, enthusiasm, and cooperations of the Master of *Rig Seismic*, A.R. Codrington, and his crew.

The following companies were consulted during cruise preparation; we are grateful to those who contributed to the cruise proposal:

Ampol Exploration Ltd
Bridge Oil Ltd
BHP Petroleum 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 Ltd
Western Mining Corporation Ltd
Woodside Offshore Petroleum Pty Ltd

PROJECT BACKGROUND

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 (Petrel Sub-basin) - 2090 km of deep seismic data - completed April-May, 1991.

3) Northern Carnarvon Basin (Exmouth-Barrow-Dampier-Beagle Sub-basins) - 1654 km

of deep seismic data - completed May-June, 1991.

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

5) Offshore Canning Basin and follow-up work in the northern Carnarvon Basin - 2000 km of deep seismic data - tentatively scheduled for mid- to late-1992.

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 16 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 NW-SE 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 generally-accepted 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 2). 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 by Stagg & Willcox (1991) were 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, it was felt that the following geoscientific problems evident in the northern Carnarvon Basin and offshore Canning Basin could 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

Stagg & Willcox (1991) proposed that a regional grid of deep seismic lines be shot to address the problems outlined above (Appendix 1). Given the range of scientific problems to be addressed and the large area of interest, it was envisaged that two cruises would ultimately be required to adequately cover the northern Carnarvon and Offshore Canning Basins. The first of these cruises (Survey 101) concentrated in the northern Carnarvon Basin, 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 equipment utilised on Survey 101 is listed in Appendix 3, while the seismic recording parameters are listed in Appendix 4.

CRUISE NARRATIVE

All times are in Julian Day and GMT.

131.1000	Depart Port Hedland
131.2200	Commence deploying streamer to carry out noise tests and swap out noisy sections. Simultaneously with this, seismic amplifiers and IFP converter being modified and tuned.
136.2300	Helicopter delivery of spares and departure of Esau, Devenish, and Whitworth.
140.0700	Finish streaming 4800 m cable and airguns.
140.0733	Noise/oscillator/amplifier tests at SOL 10. Following seismic channels have reverse polarity - 48, 137, 142, 156, 172, 173, 180, 182.
140.2128	Seismic system crash; sailing a loop and repairing guns.
141.0220	Resume line 10
141.0901	EOL 10; noise/oscillator/amplifier tests run.
141.2025	SOL 9; noise/oscillator/amplifier tests.
142.0018	Fractured low stage crankshaft in Compressor-1. Running 3 compressors; shooting speed now 4.5 kn. This speed maintained for the remainder of the survey.
142.0250	Acquisition suspended due to water cooling problems on a second compressor; sailing a loop and repairing guns.
142.1019	Resume line 9.
143.0614	EOL 9; noise tests run.
143.1513	SOL 8.
143.1536	Port gun array turned off for 5 minutes to allow maintenance work on Christmas tree.
144.0204	Seismic system crash; sailing a loop and repairing guns.
144.0822	Resume line 8.
144.1343+	Seismic system crash, 17 shots lost; decided not to loop as near end of line.
144.1647	EOL 8; noise/oscillator/amplifier tests. During transit to line 7, all reverse polarity channels (except 172 & 173) corrected. Major computer problems in the seismic system delay start of line 7 by approximately 6 hours.
145.2047	SOL 7; noise/oscillator/amplifier tests not run.
146.0106	Seismic system hung up. Sailing a loop and repairing guns.
146.0701	Noise/oscillator/amplifier tests at resumption of line 7.
146.2033	Gun arrays out of spec.; sailing a loop for repairs.
147.0345	Resume line 7.
147.1342	Compressor clutch problems; sailing a loop for compressor and gun repairs.

147.2235	Resume line 7.
148.0354	EOL 7; no noise tests run, due to shallow and restricted waters.
148.1308	SOL 6; streamer not yet straight.
148.1315	Streamer now straight on line 6.
149.0458	EOL 6; noise/oscillator/amplifier tests.
149.0754	SOL 16. The reasons for shooting this line, which was not in the cruise proposal, are given elsewhere.
149.1810	Cable noise increasing in moderate head seas; speed reduced to 4 kn.
150.0246	EOL 16; noise/oscillator/amplifier tests run.
150.1048	SOL 5; Noise/oscillator/amplifier tests run.
150.1530+	Channels 97 & 98 go noisy, then dead; at the same time, streamer depth at bird 7 (on channel 97) goes deep, indicating that the for'ard half of active section 25 has been punctured and the section has filled with seawater as far back as the program plug (50 m). Approximately 200 m of cable is probablyrunning at 12-14 m.
151.0111	EOL 5. Line terminated early due to rapidly decreasing water depths.
151.0300+	Retrieved most of tow leader and reduced speed to 1.5 kn, to observe cable performance in the event of it having to be retrieved. Cable sinks at active section 25; conclude that some buoyancy will have to be attached before the cable can be retrieved.
151.0823	SOL 4; noise/oscillator/amplifier tests run.
151.0835	First good shot with cable straight on line 4.
151.1117	Seismic system deliberately aborted after gun controller problems. As seismic system was re-started after fewer than 10 shots were lost, the line was continued.
151.1623	Seismic system crash; sailing a loop for re-start and gun repairs.
152.0045	Helicopter delivery of replacement compressor crankshaft and minor electronics spares.
152.0120	Try running cable at 8 m; noise level still acceptable, and the punctured section generally running at 11-12 m, so will continue to run at these depths until faulty section is replaced, or until end of survey.
152.0140	Resume line 4; noise/oscillator/amplifier tests run.
152.0445	Seismic system crash; sailing a loop for re-start and gun repairs.
152.0921	Resume line 4.
152.1941	EOL 4; noise/oscillator/amplifier tests run.
153.0025	SOL 3
153.0731	EOL 3
153.0820	Retrieve tow leader; commence operation to swap out active section 25, which is full of seawater.
153.2000	Streamer redploynent completed.
153.2300	Test oscillator in seismic amplifiers dead.
154.0145	Noise/amplifier/oscillator tests at SOL 2.
154.1315	Acquisition suspended; sailing a loop for compressor/gun repairs
154.2216	Resume line 2.

154.2316	Cease acquisition again because of compressor problems; sailing a loop for repairs.
155.0354	Resume line 2.
155.2100	(Approx.) slight change of course to continue shooting along line 1.
156.0312	Suspend acquisition part-way along line 1.
156.0400	Commence retrieving streamer.
156.1400	Streamer retrieval completed.
161.0000	Arrive Fremantle.

SUMMARY OF DATA RECORDED

Listings of the way points for the survey and the exploration wells tied are included as Appendices 6 and 7. The locations of the seismic lines recorded are shown in Figure 11.

LINE 10
Dip line at the northeast end of the Dampier Sub-basin, from the Lambert Shelf, across the Enderby Trend, Rosemary Fault System, Legendre Trend, Lewis Trough, Madeleine Trend, Kendrew Trough, Rankin Trend, and Victoria Syncline, out to the Brigadier Trend. Ties to Lawley-1, Legendre-1, Lambert-1, and Brigadier-1.

LINE 9
Dip line across the central Dampier Sub-basin, from the Lambert Shelf, across the Enderby Trend, Rosemary Fault System, Legendre Trend, Lewis Trough, Madeleine Trend, Kendrew Trough, and Rankin Trend out to the Kangaroo Syncline. Ties to Strickland-1, Hampton-1, Rosemary-1, and Goodwyn-7.

LINE 8
Dip line at the southwest end of the Dampier Sub-basin, from the landward flank of the Mermaid Fault, across the Mermaid Nose, Rosemary Fault System, Lewis Trough, Parker Terrace, and Rankin Trend. Ties to Arabella-1 and Parker-1.

LINE 7
Dip line across the central Barrow Sub-basin, from southwest of Barrow Island, across the Barrow depocentre, Gorgon structure, and Kangaroo Syncline, to the crest of the Exmouth Plateau. Ties to Robot-1A, Gorgon-1, and Jupiter-1.

LINE 6
Dip line across the southern Barrow Sub-basin, from the Barrow Depocentre, across the Alpha Arch, to the Kangaroo Syncline. Ties to Rosaliy-1A and Zeepard-1.

LINE 16
Strike line joining the ends of lines 6 and 5, approximately along the axis of the Kangaroo Syncline. Ties to Zeewulf-1.

LINE 5

Dip line across the northern end of the Exmouth Sub-basin to the south of the Long Island Fault. No direct well ties but it does tie to line 4, close to Jurabi-1.

LINES 4-2

Strike line from the northern end of the Exmouth Sub-basin, along the depositional axes of the Barrow and Dampier Sub-basins, into the southwest end of the Beagle Sub-basin. This line also includes the westernmost 50 km of line 1 of the cruise proposal (Stagg & Willcox, 1991). Ties to Jurabi-1, Bowers-1, Robot-1A, Tryal Rocks-1, and Angel-3.

SEISMIC STREAMER

The seismic streamer used for Survey 101 was a 288-channel analogue streamer built by the GECO subsidiary Fjord Instruments A/S in Norway. Each active section is 100 m long and contains 16 x 6.25m channels. Channels can be combined into 6.25 m, 12.5 m, or 25 m groups using program plugs installed at the centre of each active section. For Survey 101, 192 x 25 m groups were used, giving a total active cable length of 4800 m, and a CDP spacing of 12.5 m. Three 50 m stretch sections were used at the head of the streamer and a single stretch section was used at the tail, to provide mechanical de-coupling from the ship and tail-buoy. Typical offset to the first active group from the centre of the seismic source was 200 m.

Cable Depth & Balance

Cable depth was controlled by the length of armoured tow leader deployed (typically 85 m; logged at every change) and by Syntron RCL-3 remotely-controlled cable levellers ('birds'). The birds were attached every 400 m along the cable, with bird 1 attached to active channel 1, and bird 13 attached to the stretch section at the tail of the streamer (behind channel 192).

Cable balance was good for all lines except for lines 5, 4, and 3. Depths returned from the birds showed that the depth was 10 +/- 0.5 m for almost the entire survey, and usually 10 +/- 0.2 m. At the start of line 5, a fish bight at bird 7 (active section 25) caused that section to fill with seawater and become at least 20 kg heavy. This resulted in approximately 200 m of the centre of the streamer towing at up to 4-5 m deeper than the target depth. On part of line 4 and all of line 3, the target cable depth was changed to 8 m. At that depth, noise levels were still within specification, while the heavy section was towing at 10-12 m, thereby removing much of the effect of the ghost notch from the seismic band of interest. The damaged section was replaced at the end of line 3, and the target towing depth was subsequently reset to 10 m.

Dead/Reversed Channels

Following the extensive noise testing done during the first week of the survey, shooting commenced with no 'dead' channels, but up to 6 channels whose noise was outside the draft specifications for the survey. As we had almost run out of spare active sections during noise testing, it was decided to commence shooting. However, it should be noted that, while we were operating outside specification for the start of a survey, at all other times during the survey, noise levels and numbers of bad channels were within specification.

During the survey, channel 175 was frequently dead, while channels 97 and 98 were dead from the time of a fish bight at the start of line 5, until active section 25 was replaced at the end of line 3. Two channels (157 and 168) went dead late in the survey, for reasons unknown; these channels were not replaced.

Up to 8 channels suffered from reverse polarity (48, 137, 142, 156, 172, 173, 180, and 182). Six of these channels were corrected during the transit between lines 8 and 7, with problems being found in the ZIF plugs at the back of the instrument racks and in a new amplifier box. The remaining two channels, that were not diagnosed until late in the survey, have not yet been corrected.

Operational Problems

Only minimal problems were encountered during operations, once the noisy sections had been swapped out. These problems included:

1) Fish bight in active section 25 causing the section to fill with seawater and 2 of the 4 channels to go dead. This section was replaced.

2) Some birds would periodically show no reponse when interrogated by the Syntron Controller. This problem was particularly prevalent during turns and is hard to explain. In addition, bird 13 (mounted on the tail stretch section) was prone to failing and had to be replaced 3 times during the cruise using the Zoziac dinghy.

3) The original radar reflector on the tail buoy was lost after no more than 2 days. this was also replaced using the Zodiac.

Noise Levels

Cable noise levels were of particular concern early in the cruise - both in terms of the number of 'bad' channels and in the background noise level. Considerable time (8 days) was invested at the start of the survey in systemmatically removing noisy channels and trying to reduce the overall noise level. During the first week, approximately 18 section swaps were made; in some cases, even swapped sections proved to be noisy. The largest improvement in background noise levels was made when every second bird (previously every 200 m) was removed from the cable, leaving a bird every 400 m. This change reduced noise levels by up to 50%, and is a lesson well learnt. Initially, the birds that were removed were replaced by an additional 2 kg of lead. However, as the cable was found to have significant negative buoyancy during the cruise, these additional leads were removed on retrieval of the streamer at the end of the survey.

Typical streamer noise levels for the streamer at 4.5 kn during the survey are shown in Figure 12. Except for a few noisy channels that could not be eliminated, and additional noise at the bird channels, the cable noise level was in the range of 2-5 microbars. For most of the survey, the head and tail of the streamer were no noisier than the remainder.

ACQUISITION SYSTEMS

At the commencement of the cruise there was a significant number of equipment problems across a variety of instruments and computers. Without being certain, it is highly suggestive of power supply problems. Consequential problems dogged the systems throughout the survey.

Seismic System (MUSIC)

The new MicroVAX-based system was generally well received by the staff working in the instrument room. It is considered to be a significant improvement on the previous system from the observer's point of view, not least because it is substantially less fragile than its predecessor, being more forgiving of errors and increasing the confidence of the user in driving the system.

Computer

The MicroVAX 2 CPU was used as the seismic acquisition system computer for Survey 101. Attempts to use the MicroVAX 3 were aborted owing to an incompatibility between the tape drives and the MicroVAX 3 cpu, which was not anticipated. Use of the MicroVAX 2 meant that memory was restricted and hence for the record length required, we were limited to 4 millisecond sampling. This was not a serious problem owing to the deep crustal objectives of the cruise.

The cpu performed adequately most of the time, but it was given to unexpected crashes, where the operating system would re-boot sporadically without explanation. This was thought to be related to overload on the Q-Bus until it also happened on the transit to Perth when the MUSIC software was not actually running.

Advice from the previous cruise (Survey 100) was that the MicroVAX 2 CPU could crash in this way, and they advised against doing anything else beside running MUSIC when recording. Consequently, it was decided not to use the computer during acquisition, which severely restricted the available time for work on software. It is also the case that MUSIC loads the system down very heavily, and working during line changes, while possible, was very slow. For all these reasons, software development work was not as successful as it might have been.

The only significant problem with the VAX hardware occurred on 25 May when the software ceased to work. After much extensive hardware testing, it was determined that the DRQ3B board was faulty. This was replaced with a spare, and the system subsequently worked successfully for the remainder of the survey.

Tape Drives

At the start of the cruise, one tape drive showed problems with its diagnostics, indicating a fault in the servo control PCA. This was replaced, with mixed results, and it is not clear whether the board was faulty. The remaining two tape drives were used for the cruise, without significant problems. Reports of data writing errors were rare during acquisition.

Amplifier/Filter Banks

Considerable work was done on the IFP and amplifier filters by N. Esau, B. Devenish and R. Whitworth in the trial prior to the start of the cruise. The IFP system was extensively tuned and the performance of the system was carefully monitored. The IFP appeared to work without problems during the cruise. Tests were performed at the start of the cruise, and in the middle. However, the oscillator ceased to work soon after and useful tests could not be performed at the end of the cruise. There was, however, no reason to believe that there was any problem with the IFP system, based on the RMS values obtained during recording.

Water Breaks

Six water break channels were functioning during the cruise, including the nearest channel

Shot Sensors

Only one shot transducer channel was recorded during the cruise owing to insufficient numbers of good amplifier cards.

Software Development

As stated previously, software development was restricted by access to the computer during recording, for fear of causing a system crash. However, the following two programs were developed:

RMS_PLOT

This program draws a histogram of the RMS values on each channel, based on the calculations performed by MUSIC. It uses the data in the MUSIC shareable image, and hence can only function when MUSIC is running. The initial development was done during the trials, and it was completed in the first week of recording. The program is designed to be fully automatic so that it can be scheduled with minimum operator effort. The program resides in the directory [DEVELOP.MUSIC.PROGRAMS.RMS_PLOT]. However, it has been set up so that it can be run automatically by pressing PF4 on the system expert's terminal keypad.

The program could be improved by detecting the mode of operation of the system and setting the scales appropriately. At present the program scales automatically, which is inconvenient when one bad channel generates anomalous values. In addition, the mode could be reported on the plot, eliminating a source of error.

PLAYBACK

This program was written to enable seismic data tapes to be played back on the ship to verify the data on tape. This turned out to be a considerably more difficult task than originally anticipated, because of the complexities of the VAX IO system. However, it was finally made to work as the cruise was drawing to a close. It does the following things:

1) It will read a seismic tape and do RMS and average checks on the data and display these on the screen. In addition, it can list the actual data values, show values above a defined threshold, and indicate bad data values when they occur. The RMS and average gate can be set by the user. By default, the whole of the trace is included.

2) It will playback seismic data on the EPSON DX8000 printer. This enables whole shots or sections to be plotted as required by the user. The program will optionally apply a spherical divergence correction to the data, and a constant scalar can be applied as well.

This program can be used to verify that useful seismic data is actually being written to tape, and the ability to play back seismic data on the ship is something we have lacked for a considerable amount of time.

The program runs interactively from the system expert's console, by typing in the word PLAY. It is menu driven using VAX screen management facilities, and is very straightforward to use. However, there are a couple of problems which the user must be aware of. Firstly, the VAX system is very inflexible about mounting and allocating mass storage devices. PLAYBACK will mount and allocate the tape without problems, but the dismounting is not working. The trap here is that the tape drive remains allocated to the session after the program is halted, and if you want to run MUSIC, it cannot access the tape. The solution is either log off the system expert's code, or type in

$DISMOUNT MSA0: if using drive 0, or

$DISMOUNT MSB0: if using drive 1, when the program completes.

The program does both positive and negative values, producing a Variable area wiggle trace output, but the negative values look a little erratic at times, and this needs further investigation.

The program plots 1500 values as raster points. The principal limitation on its speed is the print speed of the plotter, which takes about 1.5 seconds per trace. However, the program allows the user to resample the data to plot every second point to double the width of the display window. It does not provide any interpolation facility to expand the scale. At 4 millisecond sample period, by default it plots 6 seconds of data.

Non-seismic Acquisition System (DAS)

The Hewlett-Packard based DAS suffered a variety of problems during the survey. Prior to departure from Port Hedland, the DAS started crashing for no apparent reason. uring the following 6 days, almost all components of the system, from CPU to individual ROMs were systematically replaced in an endeavour to obtain a working system. The problems were eventually traced to faulty Scientific Instruction Set (SIS) ICs mounted on the Firmware Expansion Module board, and to the Dual Channel Port Controller card in the I/O Extender.

A working DAS was achieved just prior to the start of seismic shooting. However, it quickly became apparent a number of peripherals were still 'down' (probably due to the same cause as produced the problems in the computer). As the essential requirement was to have a reliable navigation system while seismic data were being recorded, these peripherals were not re-connected, even after they were repaired, for fear of creating new problems in the DAS. Consequently, the DAS was only used to record navigation and gravity data; no bathymetry or magnetic data were recorded during the survey.

Navigation

The prime navigation system employed during Survey 101 was a differential Global Positioning System (DGPS) supplied by RACAL. The RACAL system uses a Trimble 4000DL Differential Locator and a RACAL Skyfix data link. The data link broadcasts range corrections from unmanned shore stations at either Broome or Singapore via the MARISAT satellite communication system. The data link was very reliable, with the only significant down time occurring when the telephone line carrying the correction data in Broome was accidentally dug up by Telecom.

The Trimble Locator is used in conjunction with a RACAL-designed Satellite Data Demodulator. Both devices feed data into a Compaq 386 PC which manipulates and displays the data. This display is adequate for the operator, giving all the essential information, and is straightforward to use. The Compaq stores raw data for post-processing onto optical disks which have a capacity of 300 Mb per side, giving enough storage for 6 days of data at about 48 Mb per day. The navigation data from the RACAL system were also fed into the DAS every 10 seconds to provide on-line high-quality navigation.

The secondary navigation system was the Magnavox T-Set stand-alone GPS navigator. The T-Set operated satisfactorily when required, although 2-satellite operation with clock-aiding was not possible due to the failure of the Rubidium Standard.

The final backup navigation systems were the Magnavox MX1107RS and MX1142 TRANSIT satellite navigators, with velocity and heading inputs from Magnavox and Raytheon dual-axis sonar dopplers, and headings from Sperry and Arma-Brown gyro-compasses. The reliability of the two GPS systems meant that TRANSIT satnav and dead-reckoning were rarely required.

An analysis of the availability of the different navigation systems is shown in Figures 13-17. These figures show that DGPS was available for almost 23 hours per day. Navigation for the remaining hour came from (on average) non-differential GPS using the RACAL system (45 minutes), T-Set GPS (14 minutes), and TRANSIT/dead-reckoning (7 minutes). While detailed analysis of the positional accuracy has not yet been carried out, it is expected to be better than +/- 10 metres.

MECHANICAL

Compressors

The survey requirement was to run two arrays of 150 cubic inch sleeve guns at 10 meters depth. After two days of shooting, No. 1 compressor shut down due to a broken crankshaft on the low pressure stage. The unit was stripped and prepared for reassembly when a new crankshaft became available. Late in the survey, a new crankshaft was delivered by helicopter, and the compressor was rebuilt and brought back on-line. A new crankshaft was delivered by helicopter and the compressor was rebuilt and brought back on line. Shortly after restarting, the compressor shut down again due to loss of oil pressure. On investigation it was discovered that a new part fitted during the repair work was faulty.

After several hours of running, problems again occurred with No. 1 compressor. The flexible coupling attached to the new crankshaft had come loose on its taper and damaged the shaft. The shaft may need to be removed and reground to repair the damage. The cause was the loosening of the nut on the end of the shaft despite all correct procedures being followed. Since this has occurred before, the method of retaining the nut has to be considered unsatisfactory.

A short time later, No. 2 compressor shut down due to the failure of the PTO drive shaft. The unit was stripped and it was discovered that the shaft had broken at the pilot bearing end. This caused the shaft to twist out of alignment destroying the bearings and the clutch plate. A new shaft was fitted complete with new bearings and clutch plate. The PTO was reinstalled and the compressor was brought back on line.
previous survey. The engines gave no further problems throughout the cruise.

Airgun Arrays

<u>Airguns</u>
The airguns performed well except for occasional bad timing errors that were generally restricted to a few airguns. The remaining airguns performed well throughout the entire survey. The reason for the consistant bad timing error is not obvious since the guns were serviced thoroughly and regularly during overhauls.

<u>Airgun Bundles</u>
No major problems occured with the airgun bundles and their condition is still acceptable. Some work was required on the netting where it had been damaged from contact with the arrays.

<u>Buoys</u>
No buoys were lost during the survey. However, two stainless steel bouy cones failed due to cracking at the weld area. The damage was detected early and corrective measures taken.

ELECTRONICS

Seismic Amplifiers

Prior to, and at the start of the survey, extensive work was put into the seismic amplifier system by Marine Division and Engineering Services Unit staff. This work included:

1) Installation of 3 Hz filters to the front end of the amplifiers to remove very low frequency (<1 Hz) streamer noise that swamped all signals when the low-cut filters were out. These filters were very successful.

2) Amplifier noise levels were roughly halved to 250 microvolts by replacing all amplifier-Phoenix cables with well-shielded cable of the appropriate length that were routed to minimise pickup.

3) The IFP amplifier was carefully tuned and tested. The best adjustment was achieved with a 7.5 microsecond conversion rate. Cross-talk was about 55 dB down with 3 V RMS input.

4) An apparent missing bit on the Phoenix input gave distorted RMS output levels on oscillator tests. The problem was traced to the error trap routine in the IFP conversion and a faulty relay on the oscillator card. Integer and IFP cards now give consistent values throughout the acceptable input range.

5) The spare IFP cards were checked and tuned to provide adequate spares for the survey.

Some problems arose (or were first identified) during the survey. These included:

1) Reversed channels were identified from the 'cycling' monitor and traced to either wiring at the back of the instrument racks or to one of the new amplifier boxes. These were corrected and logged during the survey.

2) The digital-to-analogue converter on the amplifier oscillator board failed due to a fault on the +/-18 V supply rails. No replacement was available.

BMR Digital Multiplexer

This device interfaces BCD-output instruments (magnetometers and echo-sounders) to the DAS. The 5 V power supply failed during a power surge, together with an IC on the channel select board and two of the data bus ICs. While the multiplexer was repaired during the survey, it was not re-connected to the DAS due to the fragility of that system. Hence no magnetic or digital bathymetry data were recorded during the survey.

Gyro-log Multiplexer

This device connects the sonar dopplers, paddle log, and gyro-compasses to the DAS. As with the BMR multiplexer, this unit failed during a power surge and was also repaired during the cruise. It was not re-connected to the DAS for the same reasons as the digital multiplexer (see above).

Other Equipment Failures

Other equipment which failed during the cruise and which were not repaired included a W & W strip-chart recorder (burnt-out power supply) and the HP Rubidium standard used to provide clock-aiding for the T-Set GPS.

REFERENCES

Barber, P.M., 1988 - The Exmouth Plateau deep water frontier: a case history. In P.G. & R.R. Purcell (eds) *The North West Shelf Australia: Proceedings of Petroleum Exploration Society Australia Symposium, Perth, 1988*, 173-88.

Bentley, J., 1988 - The Candace Terrace - a geological perspective. In P.G. & R.R. Purcell (eds) *The North West Shelf Australia: Proceedings of Petroleum Exploration Society Ausralia Symposium, Perth, 1988*, 157-72.

BMR, 1989 - Australia's petroleum potential. In *Petroleum in Australia: The First Century: Australian Petroleum Exploration Association*, 48-89.

Cockbain, A.E., 1989 - The North West Shelf. *APEA J.*, 29 (1), 529-45.

Crostella, A. & Barter, T., 1980 - Triassic-Jurassic depositional history of the Dampier and Beagle Sub-basins, Northwest Shelf of Australia. *APEA J.*, 20 (1), 25-33.

Etheridge, M., McQueen, H., & Lambeck, K., 1991 - The role of intraplate stress in tertiary (and Mesozoic) deformation of the Australian continent and its magins: a key factor in petroleum trap formation. *Exploration Geophysics*, 22, 123-8.

Exon, N.F. & Willcox, J.B., 1980 - Geology and petroleum potential of Exmouth Plateau off Western Australia. *Am. Ass. Pet. Geol. Bull.*, 62 (1), 40-72.

Gradstein, F.M., Ludden, J., & Leg 123 Shipboard Scientific Party, in press - Proceedings ODP Leg 123. *ODP Initial Report*, 123, College Station, Texas.

Howell, E.A., 1988 - The Harriet oilfield. In P.G. & R.R. Purcell (eds) *The North West Shelf Australia: Proceedings of Petroleum Exploration Society Australia Symposium, Perth, 1988*, 391-401.

Kopsen, E. & McGann, G., 1985 - A review of the hydrocarbon habitat of the eastern and central Barrow-Dampier Sub-basin, Western Australi. *APEA J.*, 25(1), 154-76.

Leven, J.H., in prep. - Regional structure of the Offshore Canning Basin: pre-cruise report. *Bureau of Mineral Resources Geology & Geophysics Record.*

Lister, G.S., Etheridge, M.A., & Symonds, P.A., 1986 - Application of the detachment fault model to the formation of passive continental margins. *Geology*, 14, 246-50.

Parry, J.C. & Smith, D.N., 1988 - The Barrow and Exmouth Sub-basins. In P.G. & R.R. Purcell (eds) *The North West Shelf Australia: Proceedings Petroleum Exploration*

Society Australia Symposium, Perth, 1988, 129-45.

Stagg, H.M.J. & Willcox, J.B., 1991 - Deep structure of the southern North West Shelf: cruise proposal. *Bureau of Mineral Resources Geology & Geophysics Record* 1991/15.

Veevers, J.J., 1988 - Morphotectonics of Australia's northwestern margin: a review. In P.G. & R.R. Purcell (eds) *The North West Shelf Australia: Proceedings Petroleum Exploration Society Australia Symposium, Perth, 1988*, 19-27.

Vincent, P. & Tilbury, L., 1988 - Gas and oil fields of the Rankin Trend and northern Barrow-Dampier Sub-basin. In P.G. & R.R. Purcell (eds) *The North West Shelf Australia: Proceedings Petroleum Exploration Society Australia Symposium, Perth, 1988*, 341-70.

Woodside Offshore Petroleum, 1988 - A review of the petroleum geology and hydrocarbon potential of the Barow-Dampier Sub-basin and environs. In P.G. & R.R. Purcell (eds) *The North West Shelf Australia: Proceedings Petroleum Exploration Society Australia Symposium, Perth, 1988*, 115-28.

Yeates, A.N., Bradshaw, M.T., Dickins, J.M., Brakel, A.T., Exon, N.F., Langford, R.P., Mulholland, S.M., Totterdell, J.M., & Yeung, M., 1987 - The Westralian Superbasin: an Australian link with Tethys. In K.G. McKenzie (ed.) *Shallow Tethys 2: International Symposium on Shallow Tethys 2. Wagga Wagga, Proceedings*, 199-213.

APPENDIX 1
EXECUTIVE SUMMARY FROM CRUISE PROPOSAL

(After Stagg & Willcox, 1991)

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 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 2950 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 (1602 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 (2 lines). 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.

APPENDIX 2
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

APPENDIX 3
EQUIPMENT 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

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

Bodenseewerk Geosystem KSS-31 marine gravity meter

Differential GPS (RACAL Skyfix)

Magnavox T-Set stand-alone GPS

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 4
SEISMIC ACQUISITION PARAMETERS

<u>Seismic Cable Configuration</u>

Standard	length -	4800 m
	group length -	25 m
	no. channels -	192

<u>Seismic Source</u>

Airgun capacity	50 litres (3000 cu in)
Airgun pressure	1800 psi (normal)
	1600 psi (minimum)
Shot interval	50 m
Shot rate	19.4 s @ 5 kn
	21.6 s @ 4.5 kn

<u>Fold</u>

Standard - 4800%

<u>Recording Parameters</u>

Record length -	16 s
Sample interval -	4 ms

APPENDIX 5
CREW LIST

Scientific Crew

H.M.J. Stagg	Cruise Leader
F.M. Brassil	Deputy Cruise Leader/Systems Expert
E.C. Chudyk	Systems Expert
R. Curtis-Nuthall	Electronics Technician
N. Ford	Electronics Technician
J. Bedford	Science Technician
A. Hunter	Science Technician
T. Mueller	Science Technician
H. Reynolds	Science Technician
K. Revill	Science Technician
A. Warnes	Science Technician
R. Bodger	Mechanical Technician
M. Collins	Mechanical Technician
C. Dyke	Mechanical Technician
C. Green	Mechanical Technician
A. Radley	Mechanical Technician

Crew of the R/V *Rig Seismic*

A.R. Codrington	Master
R.T. Walters	Mate
C. Hellier	2nd Mate
N.E.C. Luscombe	AB
J.C. Fraser	AB
M.J. Pitcher	AB
E.B. Troke	Ch Eng
I.J. McCarthy	2nd Eng
R.A. Dickman	Electrical Eng
D.R. Brown	AB/ERA
W. Fowler	Ch Cook
G.R. Conley	Cook
M.J. Perrett	Steward
M.E. Cumner	Steward

APPENDIX 6
WAY POINTS FOR LINES AS SHOT

(Positions in WGS-84)

Line	Latitude	Longitude	Comments
BMR-10	20 04.243	117 11.982	SOL
BMR-10	19 54.347	117 00.535	Lawley-1
BMR-10	19 40.317	116 43.925	Legendre-1
BMR-10	19 27.387	116 29.383	Lambert-1
BMR-10	19 05.813	116 08.158	Brigadier-1
BMR-10	18 58.506	116 01.448	EOL
BMR-9	18 58.086	115 11.796	SOL
BMR-9	19 37.695	115 57.613	Goodwyn-7
BMR-9	19 57.272	116 20.685	Rosemary-1
BMR-9	20 07.075	116 32.790	Hampton-1
BMR-9	20 12.523	116 41.037	Strickland-1
BMR-9	20 14.232	116 43.607	EOL
BMR-8	20 32.555	116 05.245	SOL
BMR-8	20 28.200	116 01.867	Arabella-1
BMR-8	20 00.132	115 40.132	Parker-1
BMR-8	19 29.190	115 15.980	EOL
BMR-7	19 30.199	113 26.164	SOL
BMR-7	19 34.883	113 31.967	Jupiter-1
BMR-7	20 34.720	114 46.365	Gorgon-1
BMR-7	20 48.230	115 01.102	Robot-1A
BMR-7	20 54.635	115 12.719	EOL
BMR-6	21 16.434	114 56.456	SOL
BMR-6	21 12.133	114 52.017	Rosaliy-1A
BMR-6	20 44.232	114 25.367	Zeepard-1
BMR-6	20 22.696	114 05.970	EOL
BMR-16	20 22.519	114 11.211	SOL
BMR-16	21 06.461	113 37.294	Zeewulf-1
BMR-16	21 25.659	113 17.264	EOL
BMR-5	21 17.212	113 04.997	SOL
BMR-5	21 42.001	114 09.417	EOL

Line	Latitude	Longitude	Comments
BMR-4	21 46.555	114 02.613	SOL
BMR-4	21 37.202	114 11.927	Jurabi-1
BMR-4	21 06.232	114 42.900	Bowers-1
BMR-4	20 48.230	115 01.102	Robot-1A
BMR-4	20 43.055	115 06.216	EOL
BMR-3	20 49.535	115 02.151	SOL
BMR-3	20 24.720	115 09.240	Tryal Rocks-1
BMR-3	20 22.798	115 09.785	EOL
BMR-2	20 32.685	115 01.853	SOL
BMR-2	19 32.508	116 37.548	Angel-3
BMR-2	19 23.572	116 50.943	Course change
BMR-2/1	19 13.736	117 16.211	Acquisition suspended on line 1

APPENDIX 7
WELLS TIED BY SEISMIC LINES

(Locations of wells are noted in Appendix 6.)

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
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
Jupiter-1	Phillips	1979	4946	U. Tr	Dry
Jurabi-1	Esso	1982	3712	U. Tr	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
Parker-1	Woodside	1979	4737	Lw. Ju	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
Tryal Rocks-1	Wapet	1970	3695	Ju	Dry
Zeepard-1	Esso	1980	4215	U. Tr	Dry; show gas
Zeewulf-1	Esso	1979	3500	U. Tr	Dry; show cond/gas.

APPENDIX 8
FIELD TAPE LISTING

Line	Tape From	Tape To	SP From	SP To	Comments
10	1	1	102	143	Noise/osc tests only
10A	2	34	103	2545	
10B	35	50	3001	4160	Noise/amp/osc tests on tape 50
9A	51	65	101	1171	Noise/amp/osc tests on tape 51
9B	66	110	2018	5361	Noise/amp/osc tests on tape 110
8A	111	134	102	1901	
8B	135	153	2001	3402	Noise/amp/osc tests on tape 153
7A	154	163	101	820	
7B	164	194	1002	3263	Noise/amp/osc tests on tape 164
7C	195	217	3502	5163	
7D	218	229	5501	6384	
6	230	265	101	2771	241 & 242 mis-labelled as 141 & 142; noise/amp/osc tests on tape 265
16	266	306	102	3141	Noise/amp/osc tests only on tape 306
5	307	338	102	2499	Noise test on tape 307
4A	339	357	102	1543	Noise/amp/osc tests on tape 339
4B	358	364	2002	2515	Noise/amp/osc tests on tape 358
4C	365	387	3002	4719	Noise/amp/osc tests on tape 387

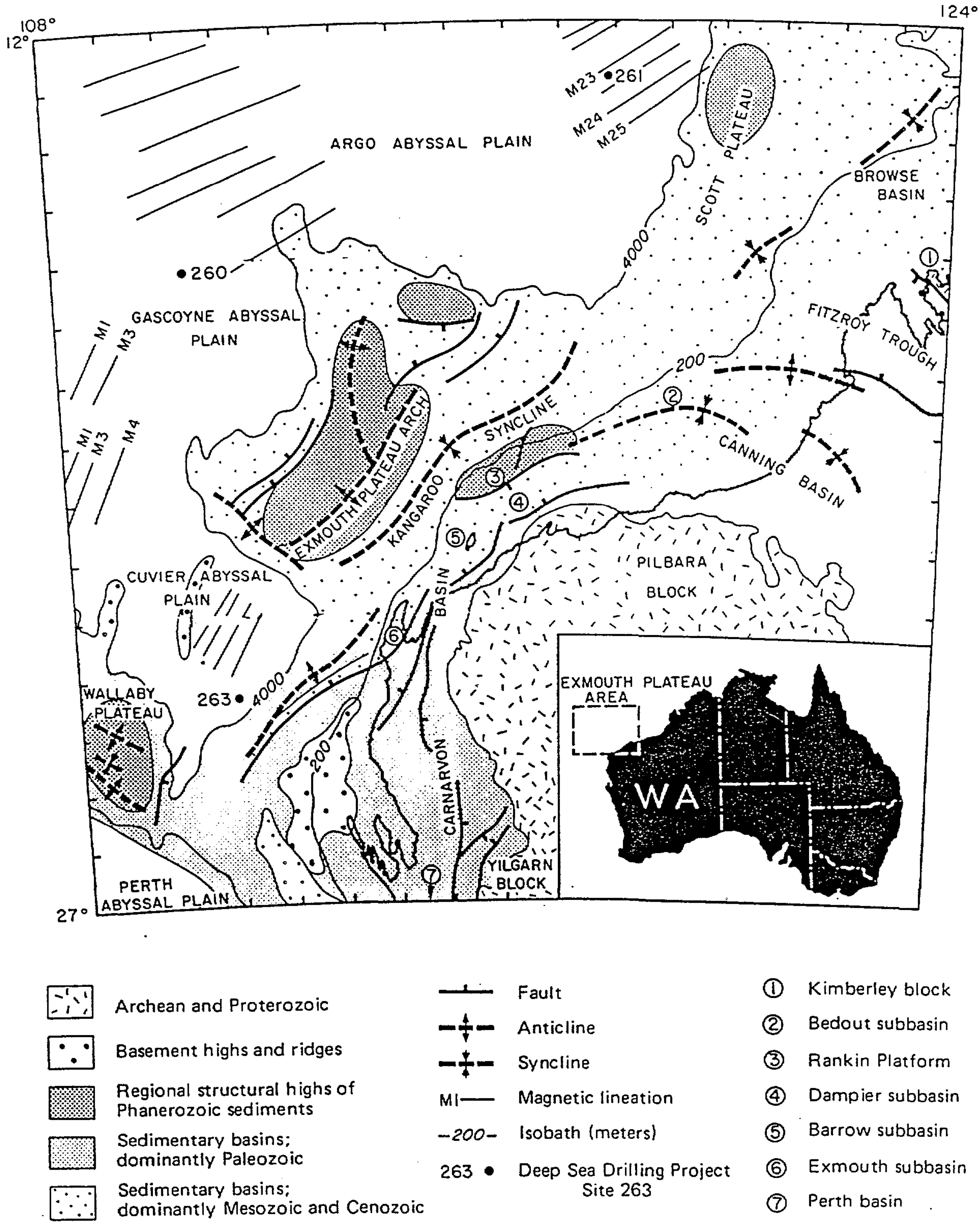

Figure 1: Regional setting of the North West Shelf (after Exon & Willcox, 1980).

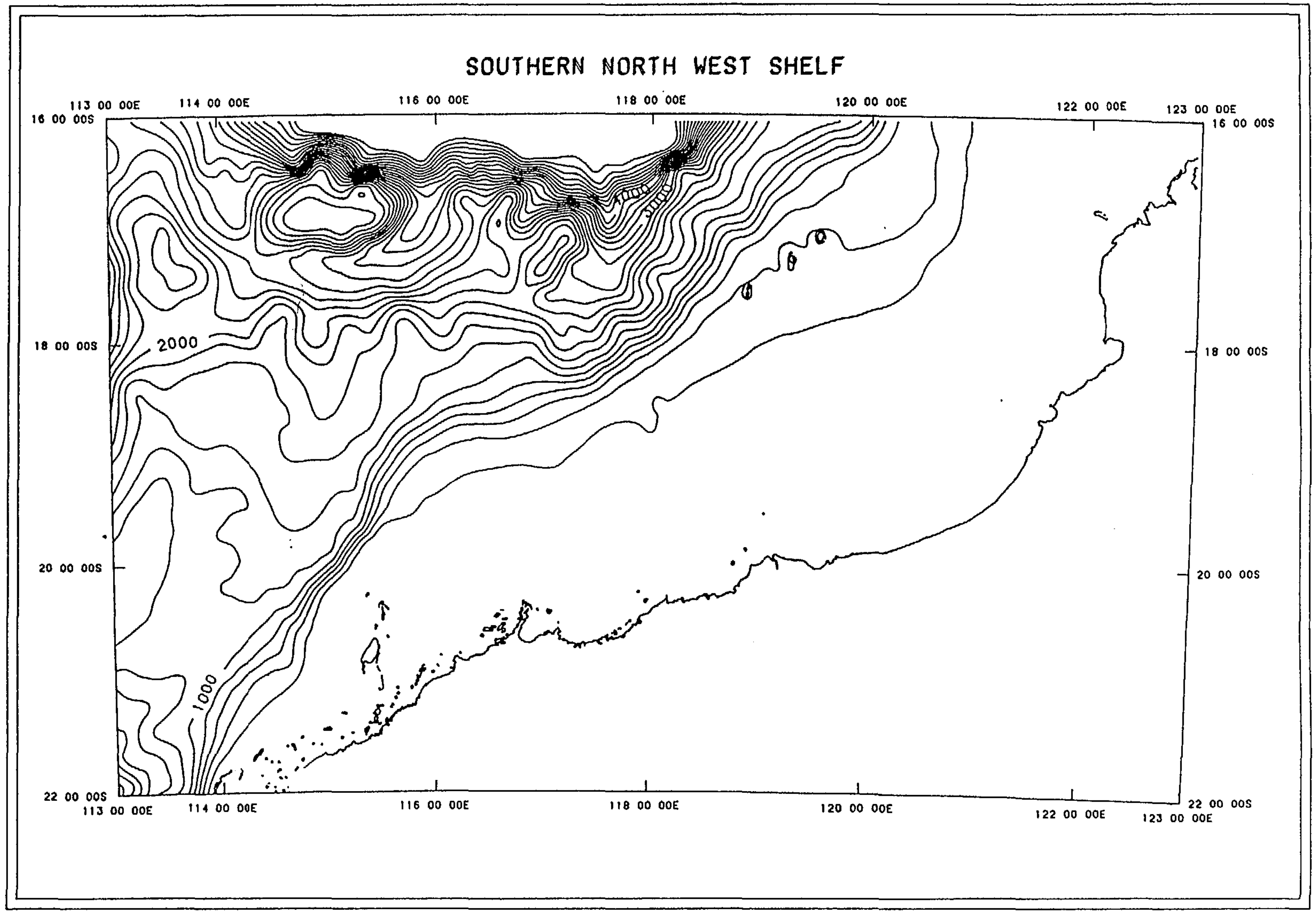

Figure 2: Bathymetry of the southern North West Shelf. Contour interval 200 metres.

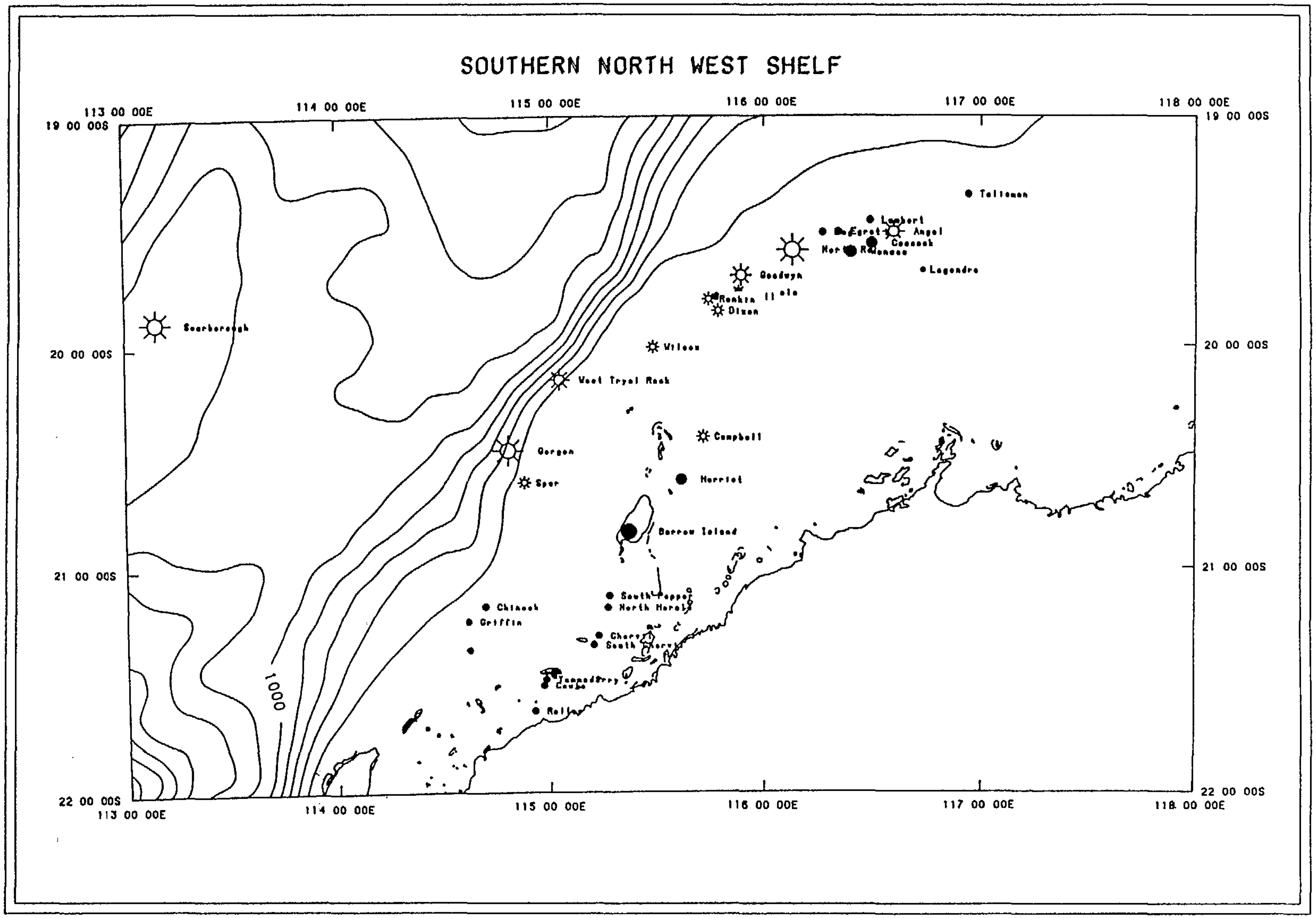

Figure 3: Locations of oil and gas fields on the southern North West Shelf. Bathymetry contour interval 500 metres.

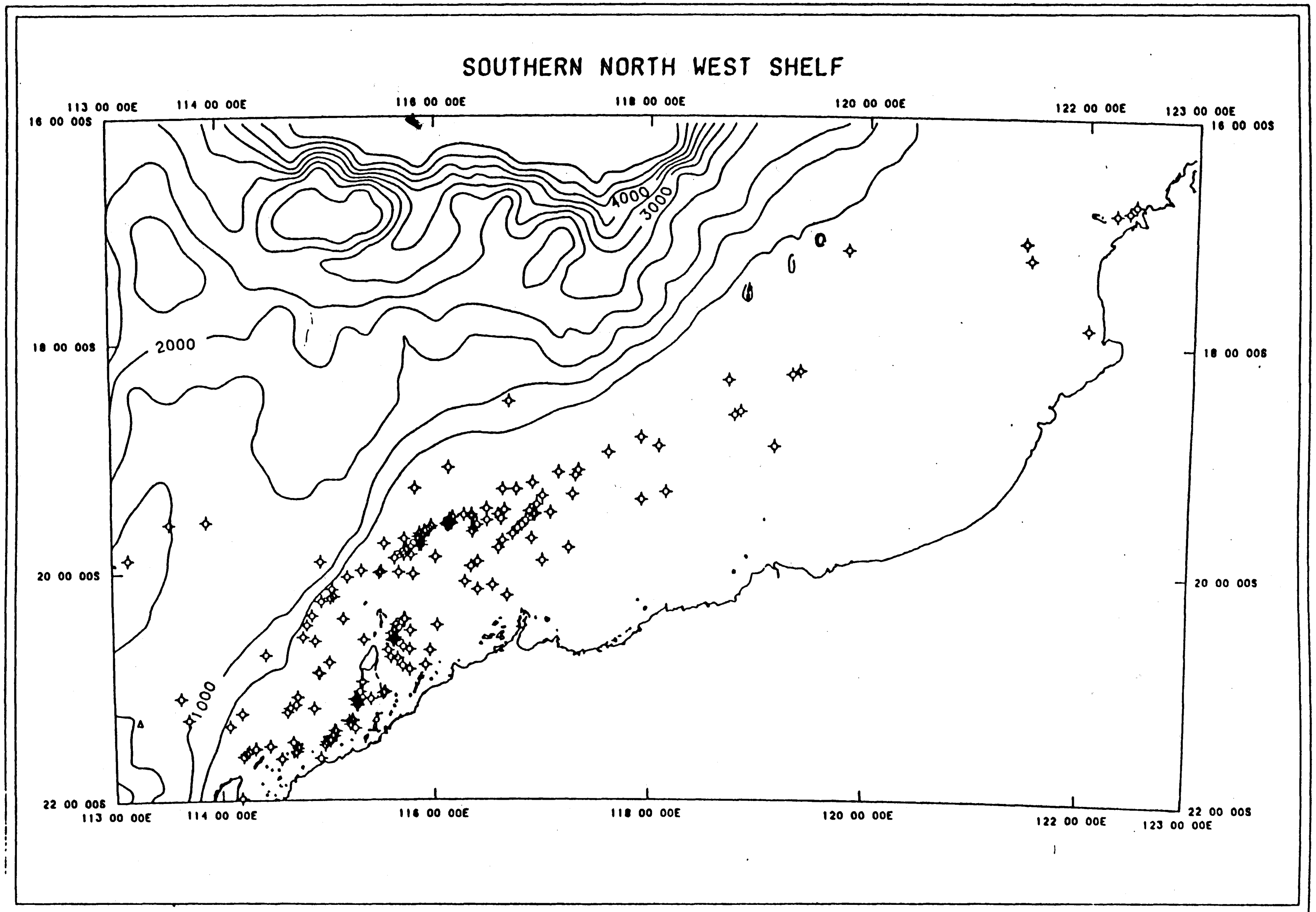

Figure 4: Locations of exploration wells on the southern North West Shelf. Bathymetry contour interval 500 metres.

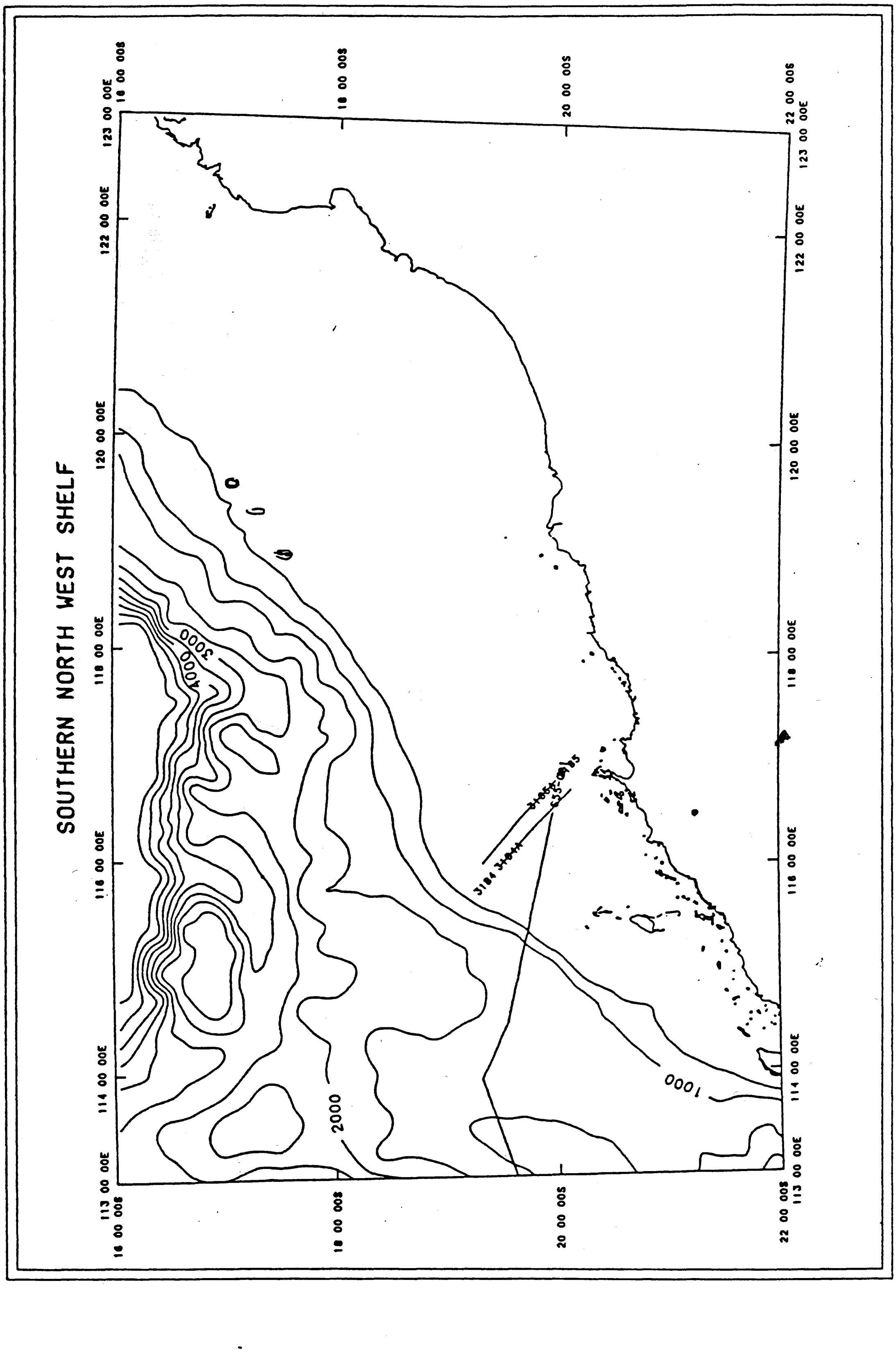

Figure 5: Locations of available deep seismic profiles on the southern North West Shelf. Bathymetry contour interval 500 metres.

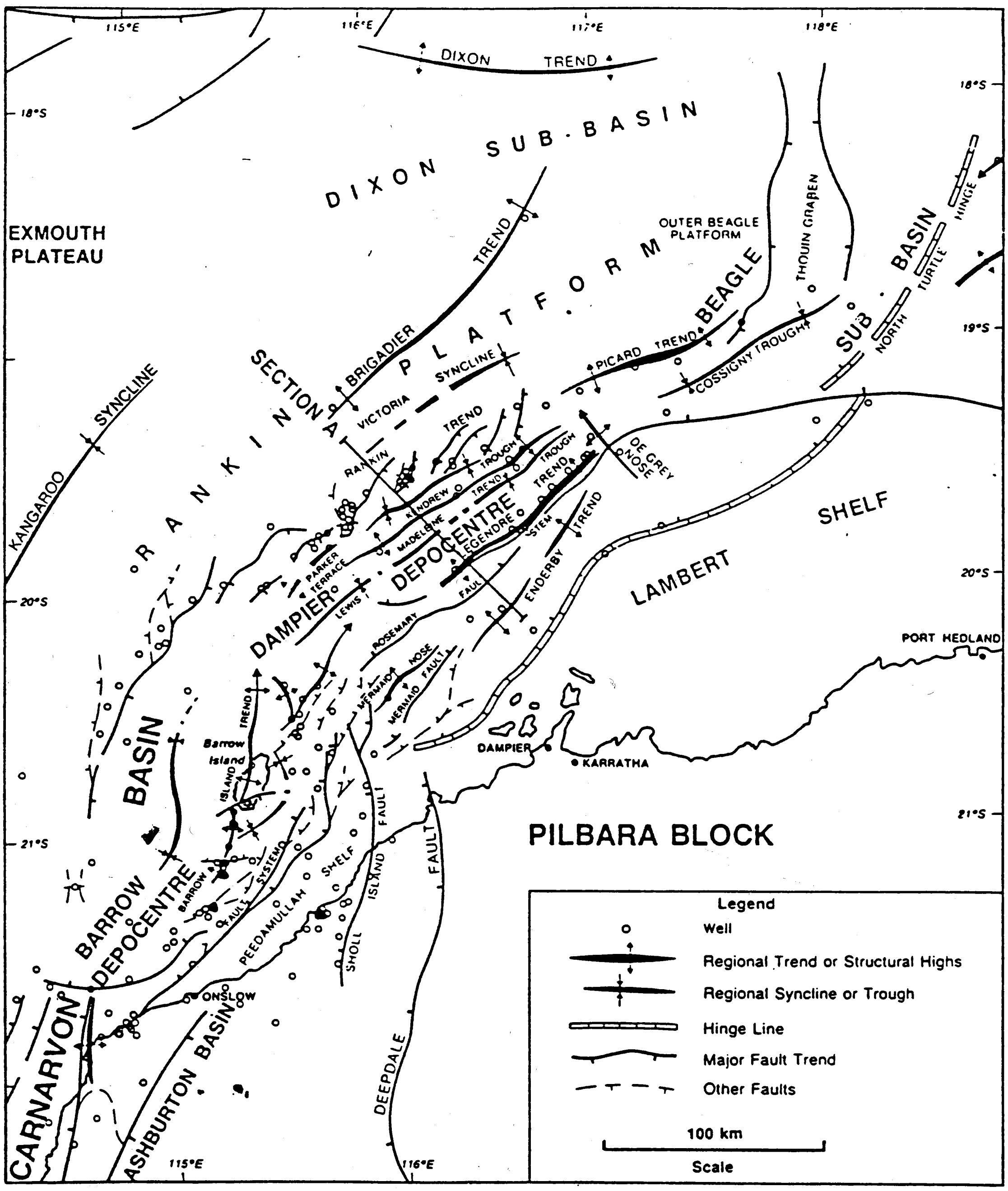

Figure 6: Tectonic elements of the southern North West Shelf (after Woodside, 1988).

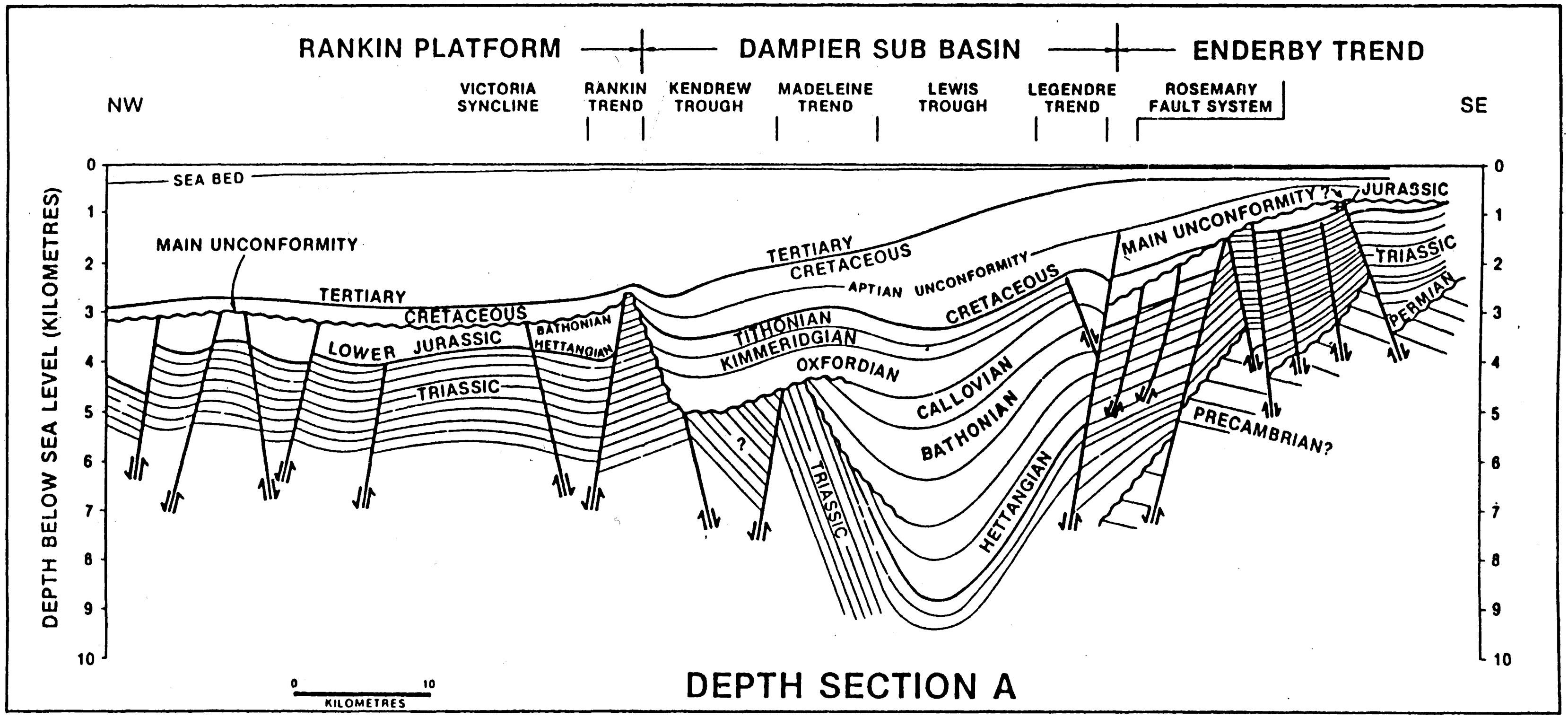

Figure 7: Depth profile across the Dampier Sub-basin (after Woodside, 1988).

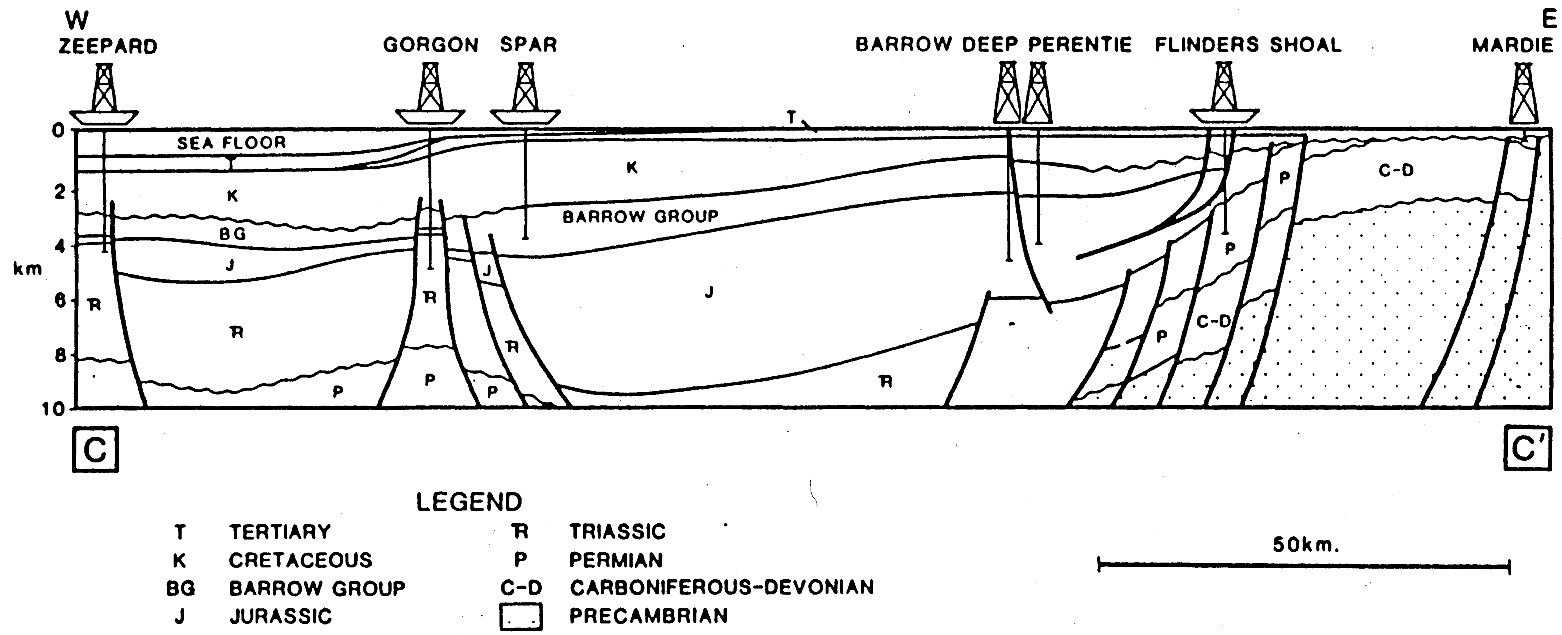

Figure 8: Depth profile across the Barrow Sub-basin (after Parry & Smith, 1988).

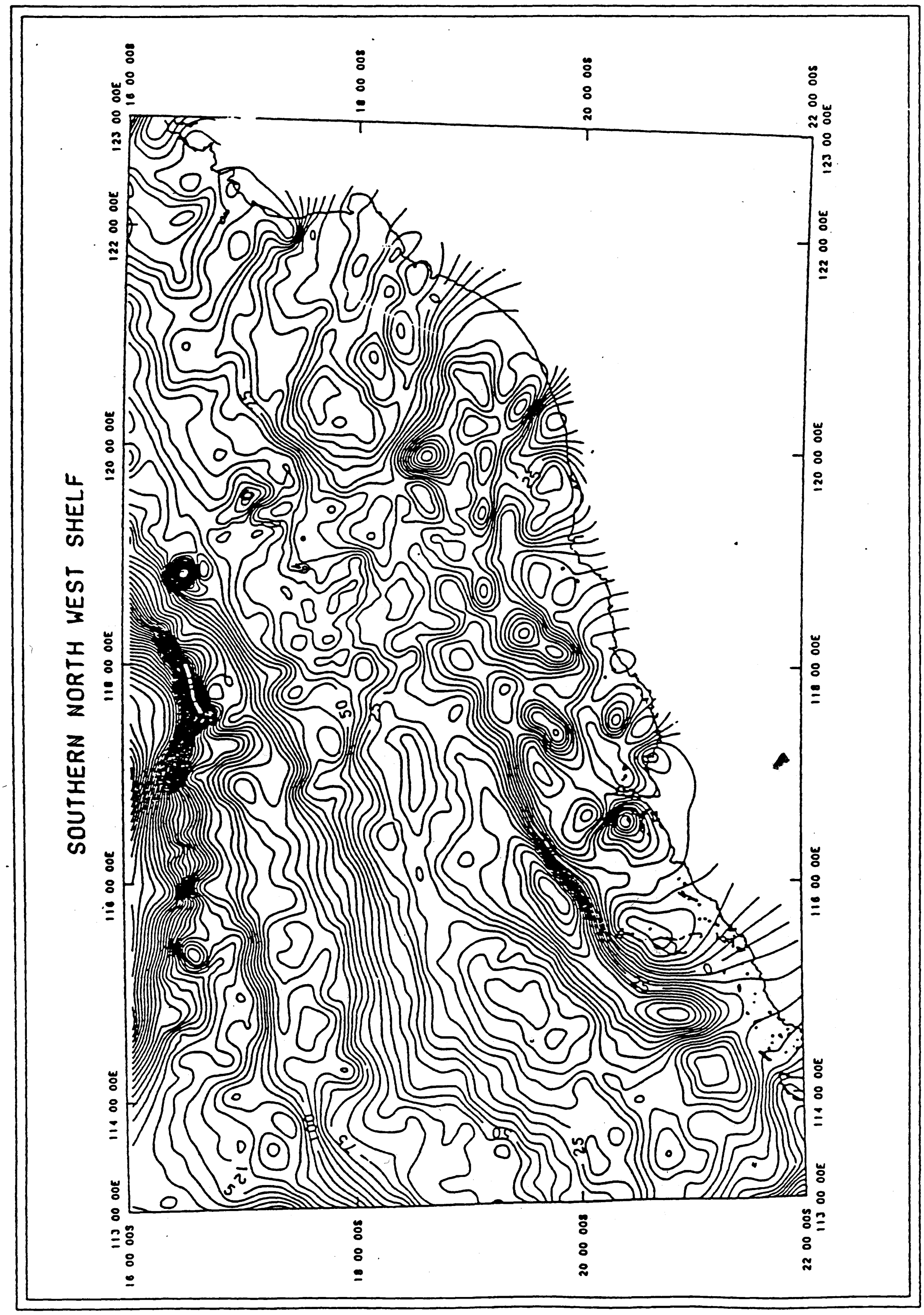

Figure 9: Bouguer gravity anomalies on the southern North West Shelf. Contour interval 5 milligals.

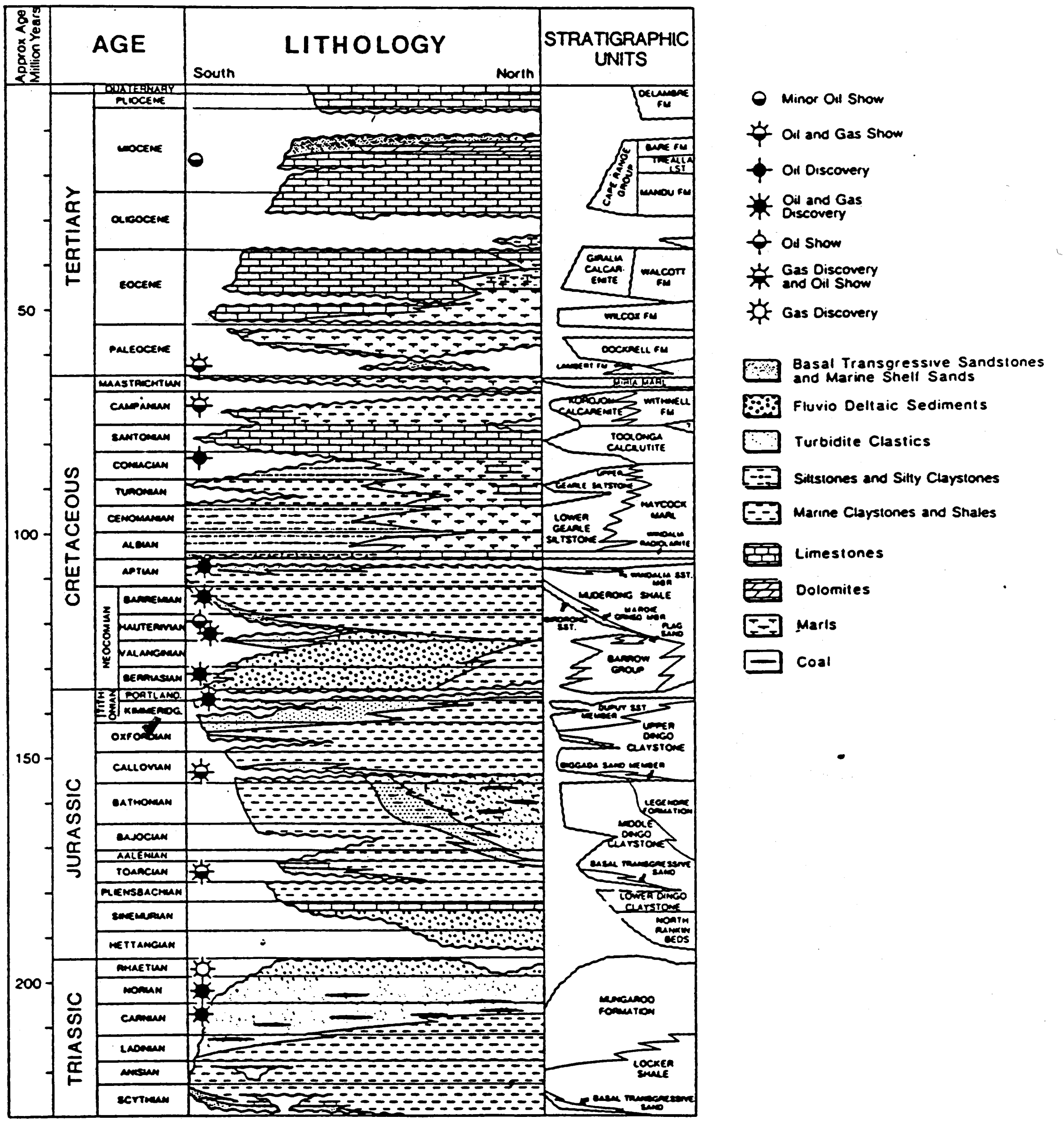

Figure 10: Stratigraphy of the southern North West Shelf (after Woodside, 1988).

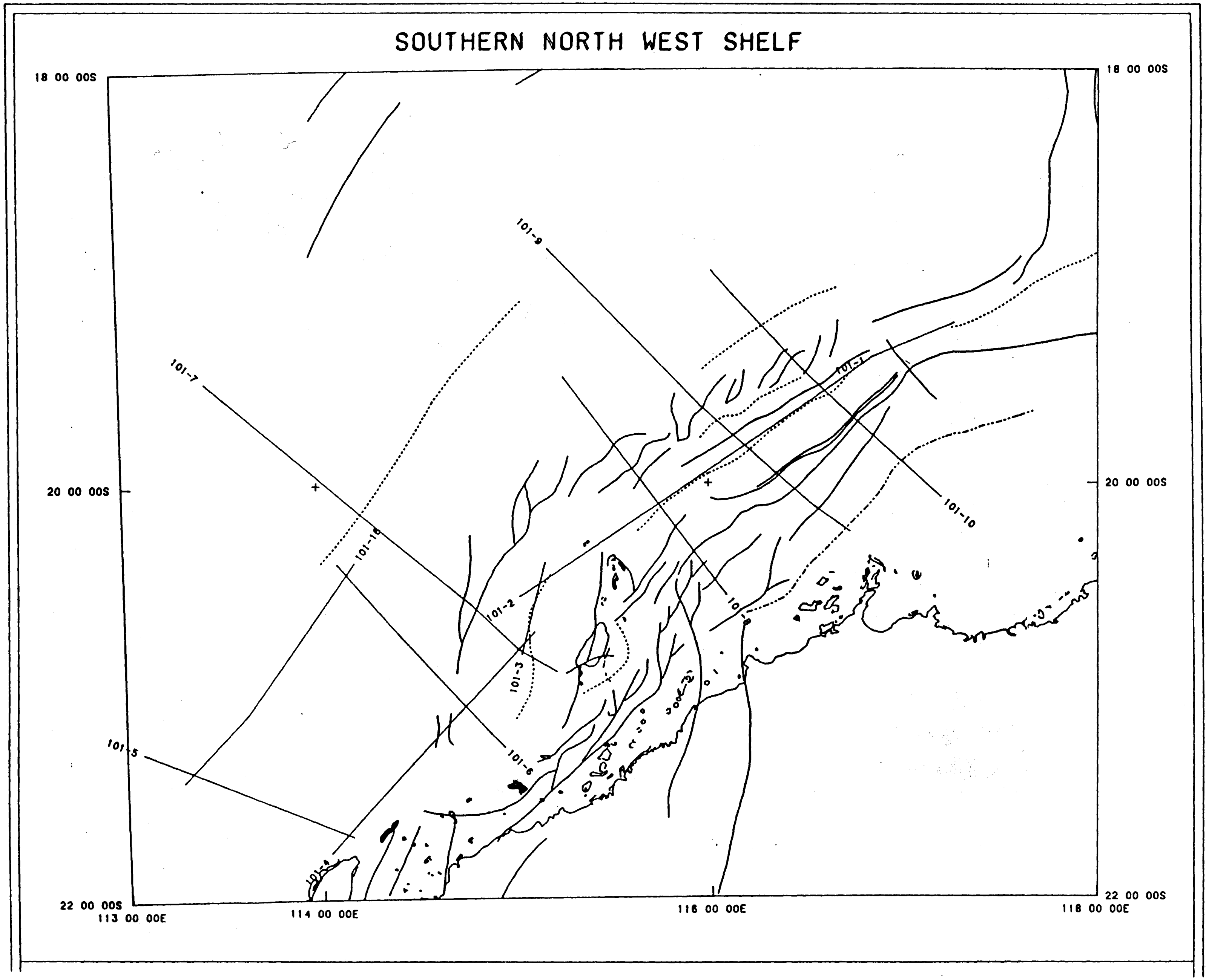

Figure 11: Locations of deep seismic profiles recorded during Survey 101. Locations of tectonic elements by permission of Woodside Offshore Petroleum Pty Ltd.

BMR SEISMIC ACQUISITION SYSTEM — MAY 91

Survey 101 Line 0 29-MAY-1991 5: 0:58 Shot: 2747 Number of Channels: 192 Gain: 256 with 13 birds

RMS values in mV for shot 2747

99.7	53.1	21.9	26.2	26.6	70.3	31.4	37.4	27.5	31.0	27.8	29.3	28.2	30.8	28.3	55.3
52.8	34.1	24.1	31.6	27.6	33.7	33.5	30.1	23.7	26.6	26.5	26.2	34.4	68.6	20.7	25.2
70.1	49.8	30.4	41.1	29.1	36.1	28.3	35.2	29.8	24.4	24.7	26.6	23.5	27.1	22.6	26.9
48.3	21.8	18.5	25.1	12.5	64.1	39.0	30.9	45.4	172.6	37.9	84.3	36.3	42.5	31.4	137.9
93.2	71.9	34.2	44.1	31.5	34.0	27.7	38.7	27.6	27.5	25.2	33.9	33.8	35.9	38.7	47.9
118.9	54.3	34.4	47.3	34.7	58.7	38.7	36.2	40.6	43.4	35.9	44.1	30.2	46.2	41.1	39.5
54.0	30.0	24.2	40.0	25.6	37.3	30.9	35.5	40.4	37.7	30.2	33.0	40.2	39.7	42.7	52.9
80.3	37.8	34.4	42.0	35.4	43.1	38.3	40.8	42.0	48.4	25.4	31.9	33.2	32.9	29.8	41.0
68.1	35.6	32.4	34.6	34.3	36.2	29.4	32.2	34.3	36.3	30.2	40.7	25.9	33.4	30.9	39.1
73.8	37.0	34.8	37.3	39.8	46.7	29.8	41.6	31.2	34.3	28.2	32.5	30.0	41.5	27.4	30.1
41.5	25.4	28.6	29.0	26.2	36.2	28.9	31.2	27.4	28.9	28.5	32.2	24.3	33.7	33.7	42.1
93.1	38.1	30.9	43.3	28.5	39.6	29.7	46.4	39.1	30.1	30.0	35.5	29.8	30.1	27.0	43.4

Mean RMS = 38.649 mV Std Dev RMS = 18.900 mV

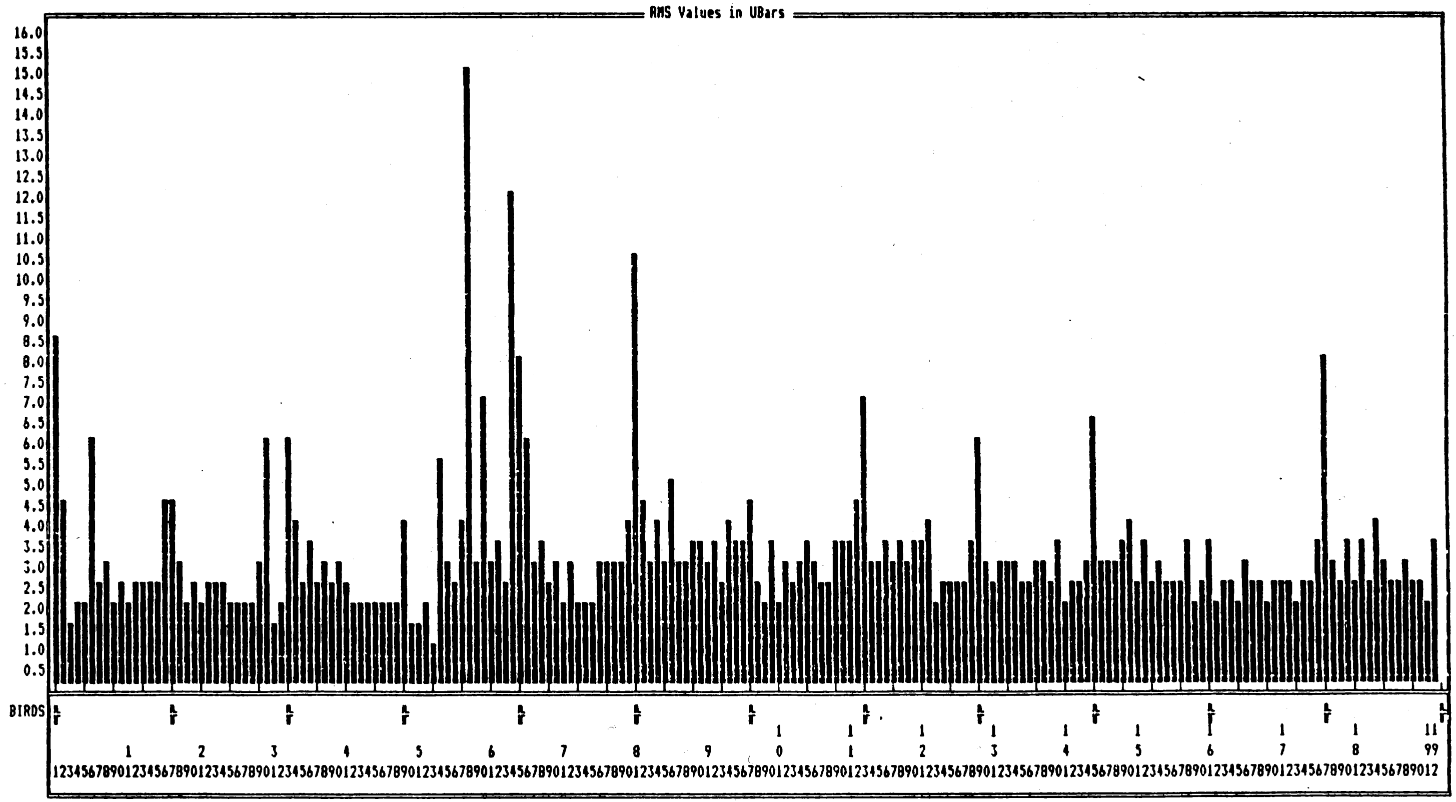

Figure 12: Example of typical seismic streamer noise levels during Survey 101.

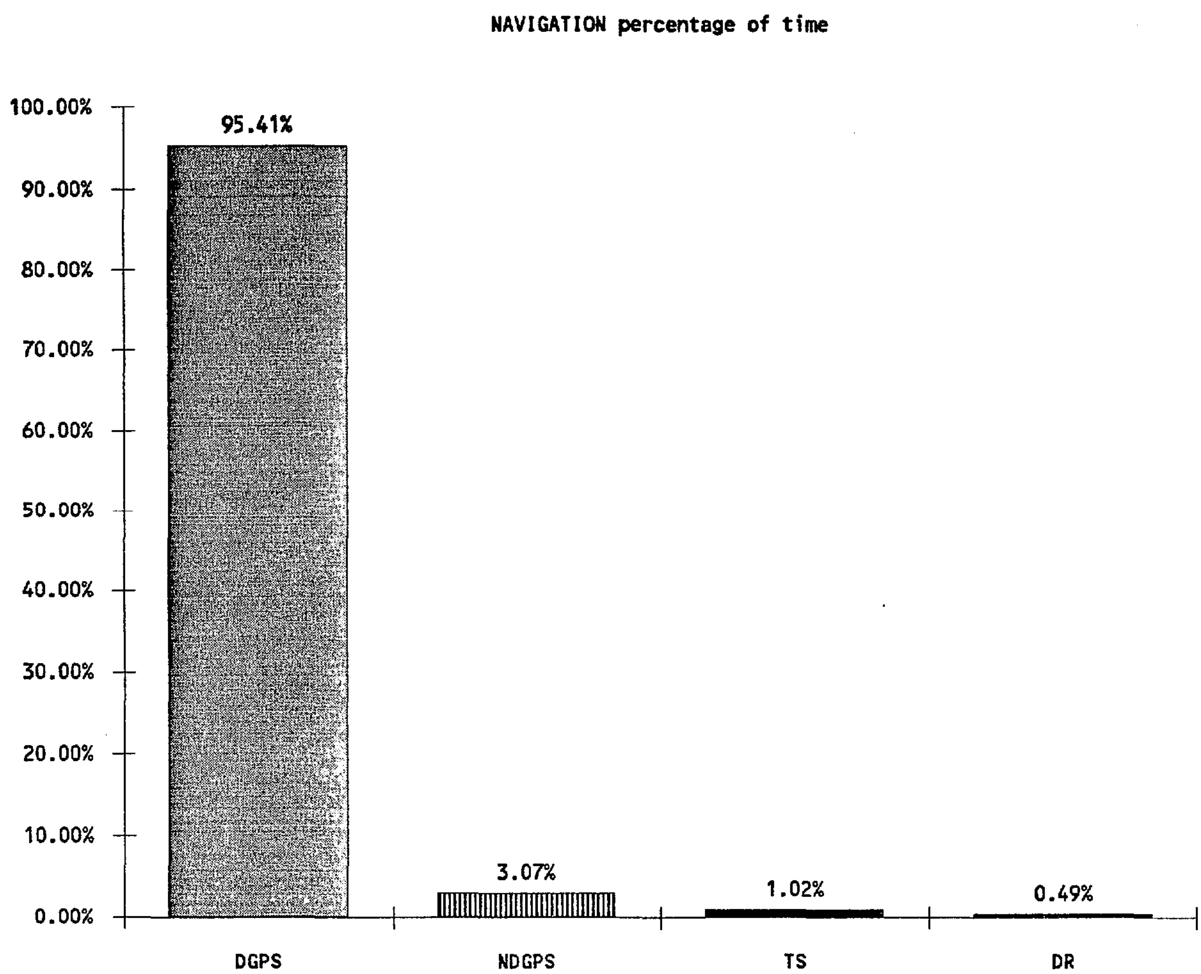

Figure 13: Navigation systems - percentage of time that each system was in use.

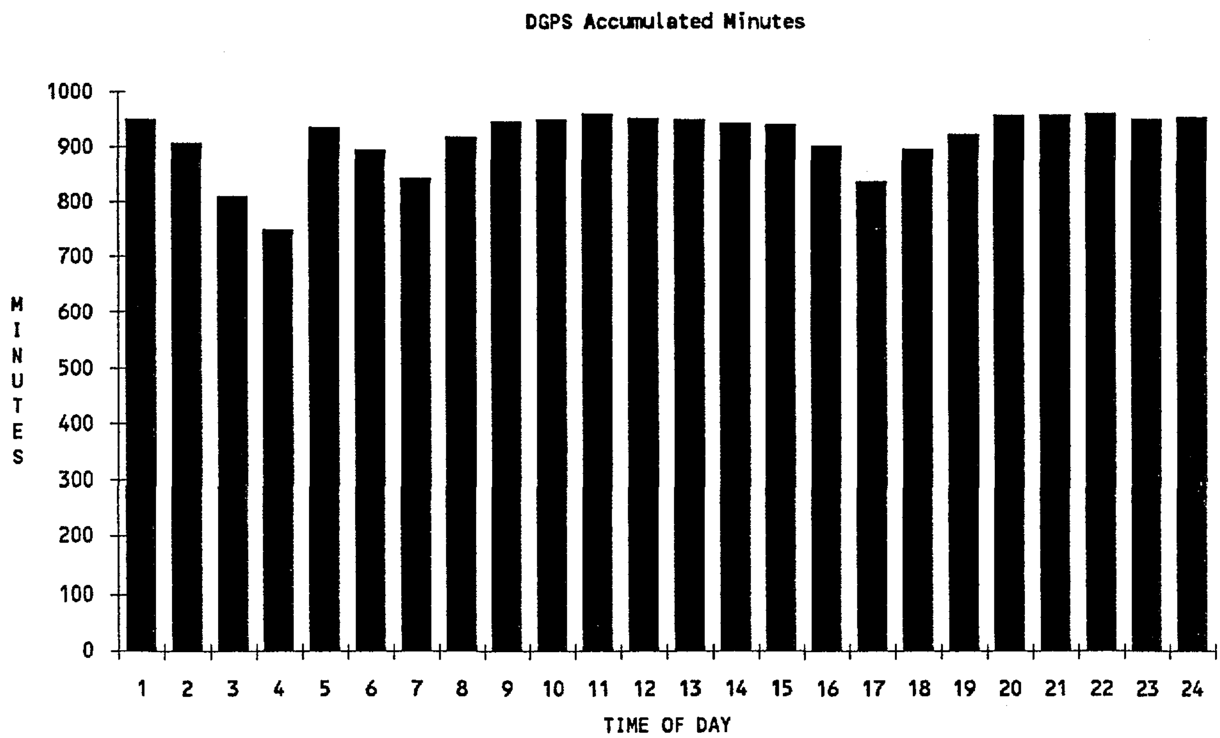

Figure 14: Differential GPS - accumulated minutes per hour.

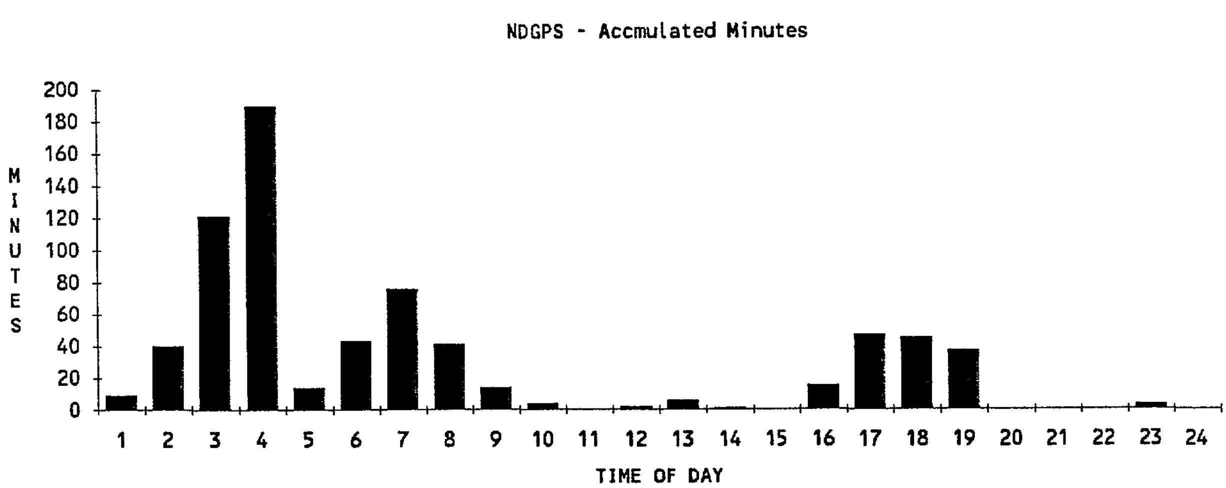

Figure 15: Non-differential GPS (RACAL) - accumulated minutes per hour.

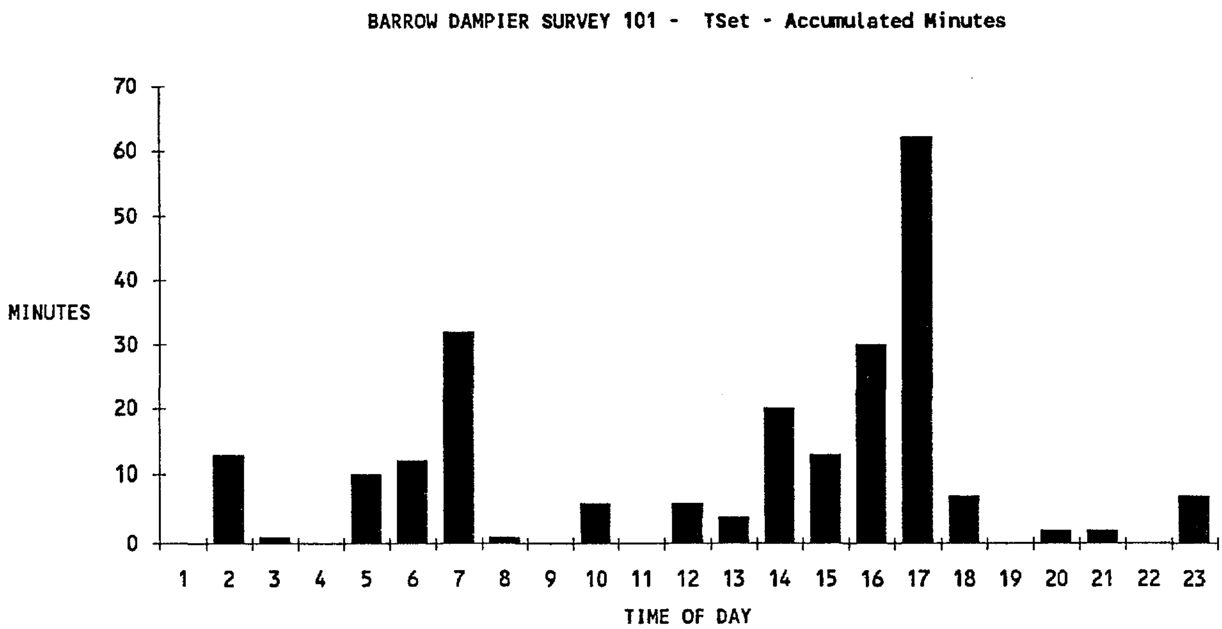

Figure 16: Non-differential GPS (Magnavox T-Set) - accumulated minutes per hour.

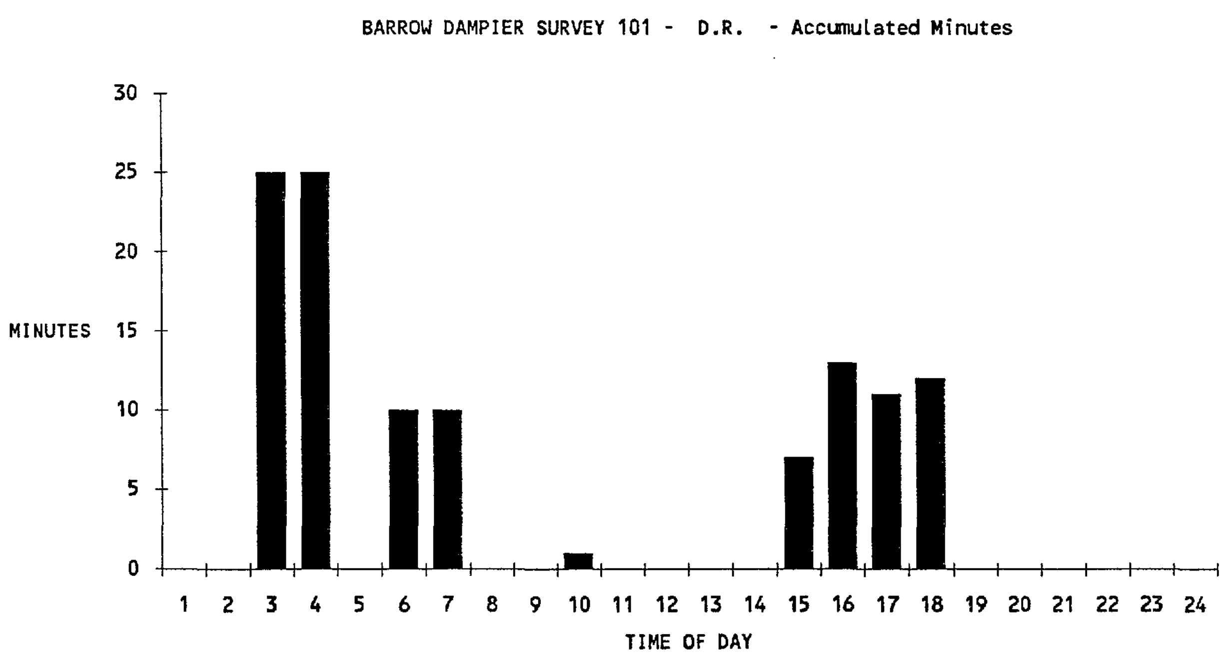

Figure 17: TRANSIT/dead-reckoning - accumulated minuted per hour.