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# High resolution seismic survey of the Exmouth, Barrow, and Dampier Sub-basins, North West Shelf, Australia

## Cruise Proposal



*By K.K. Romine*

## Record 1994/53





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AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

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**Marine, Petroleum and Sedimentary Resources Program**

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# HIGH RESOLUTION SEISMIC SURVEY OF THE EXMOUTH, BARROW, AND DAMPIER SUB-BASINS, NORTH WEST SHELF, AUSTRALIA

## CRUISE PROPOSAL

by

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## CONTENTS

## APPENDICES



## FIGURES

## EXECUTIVE SUMMARY

Exploration in the offshore northern Carnarvon Basin during the last two decades has resulted in a number of major oil and gas discoveries. Recent discoveries in the Dampier (di Toro, 1994; Delfos, 1994), Exmouth (Bauer et al., 1994; Lawry & Carter, 1994; Mitchelmore & Smith, 1994) and Barrow (Beacher et al., 1994; Sit et al., 1994) sub-basins ensure that exploration activity is likely to remain high in these areas for the near future. However, some of these discoveries have been small fields or individual wells with residual oil columns, indicating that still greater quantities of hydrocarbons have escaped from the traps. Recent work on oil-filled fluid inclusions (Lisk & Eadington, 1994) indicates that the loss of hydrocarbons from pre-Cretaceous reservoirs and traps occurred during the past 20 million years, beginning in the Miocene. These hydrocarbons may have been lost, but could potentially have been trapped in younger Cretaceous and Tertiary reservoirs. The Carnarvon Cretaceous/Tertiary Tie study proposes to address this issue by collecting and interpreting a regional high-resolution seismic survey, within the broad structural and tectonic framework provided by the Continental Margins Program Northwest Shelf Project. The main objectives are:

- construction of a regional, sequence-based chronostratigraphic framework for the Cretaceous and Tertiary within which the occurrence and distribution of potential seal and reservoir facies may be analyzed and predicted;

- assessment of the post-Valanginian fault reactivation history of the northern Carnarvon Basin and the implications for: (a) the migration of hydrocarbons from pre-Cretaceous traps and (b) the integrity of potential Cretaceous and Tertiary seals;

- determination of the probability of secondary migration and entrapment of hydrocarbons within Cretaceous and Tertiary strata.

Approximately 4240 km of high-resolution seismic data has been proposed for acquisition by AGSO's RV *Rig Seismic*. The data set will comprise 23 seismic lines tying 107 wells in the Exmouth, Barrow, Dampier and Beagle Sub-basins. These data will tie with and complement the deep-seismic grid previously acquired by AGSO in the Carnarvon Basin.

The seismic survey will be acquired using the latest high-resolution seismic technology. Data will be recorded using bubble-free GI air guns and with the following parameters: 3000m streamer; 12.5m group interval; 18.75m shot interval; recording frequency bandwidth of 4-180Hz; 2ms sample interval; 5.5 second record length; and 80-fold CDP multiplicity. The program layout includes 5 strike lines linking the Exmouth, Barrow, Dampier and Beagle sub-basins and 18 dip lines orthogonal to the principal Mesozoic sub-basin fault systems.

## INTRODUCTION

Western Australian sedimentary basins and, in particular, those of the North West Shelf offer the best prospects for hydrocarbon discoveries that will allow Australia to maintain a high level of energy self-sufficiency into the 21st century (Purcell & Purcell, 1994). Since 1988, exploration success in the northern Carnarvon Basin (Fig. 1) has increased Australia's estimated reserves by 35%, providing the most significant discoveries since those of the Gippsland Basin. At the recent West Australian Basins Symposium (Perth, August, 1994), presentations were made on several discoveries and fields in the northern Carnarvon Basin, e.g. Waneaea and Cossack (di Toro, 1994); Leatherback (Bauer et al., 1994); West Muiron (Mitchelmore & Smith, 1994); Maitland (Sit et al., 1994); Wandoo (Delfos, 1994); Rivoli (Lawry & Carter,1994); Nebo (Osborne, 1994); and several others. Some of these fields are small, or underfilled (e.g., West Muiron; Mitchelmore & Smith, 1994), and other discoveries sampled only residual oil columns (e.g. Leatherback; Bauer et al., 1994). In each example, a Miocene-age tectonic compressional event is invoked to explain the reactivation of faults and subsequent migration and leakage of hydrocarbons. Similarly, Woodside (1988) suggested that the main period of oil migration in the Barrow-Dampier Sub-basins was in the Middle to Late Miocene due to a "tectonic pulse" that reactivated many of the older faults.

Residual oil accumulations also have been documented in the Timor Sea (Whibley & Jacobson, 1990). In the Cartier Trough of the Vulcan Sub-basin, analysis of oil-filled fluid inclusions (Lisk & Eadington, 1994) has demonstrated that the most recent phase of oil migration was initiated in the Miocene, as in the northern Carnarvon Basin.

The compressional tectonic event responsible for reactivation of faults and oil migration has been related to collision and subduction along the northern boundary of the Australian continent during the Miocene (O'Brien et al., 1993). This event is the most recent in a series of tectonic events which have governed the sedimentary and structural history of the North West Shelf basins (AGSO North West Shelf Study Group, 1994). As part of its research program on the North West Shelf, the Marine, Sedimentary and Petroleum Resources Program of AGSO has acquired regional deep seismic data across and between the major sedimentary basins, in an effort to determine the linkages between the major structural elements and to facilitate the development of a regionally integrated structural and tectonic history for the region. Interpretation of these data demonstrate that the reactivation history of structures in North West Shelf basins has had a fundamental impact on the distribution of hydrocarbons. In the northern Carnarvon Basin, the proposed high-resolution seismic data will provide the basis for a study that will build on the tectonic and structural framework provided by the deep seismic data to address the following objectives:

- construction of a regional, sequence-based chronostratigraphic framework for the Cretaceous and Tertiary within which the occurrence and distribution of potential seal and reservoir facies may be analyzed and predicted;

- assessment of the post-Valanginian fault reactivation history of the northern Carnarvon Basin and the implications for: (a) the migration of hydrocarbons from pre-Cretaceous traps and (b) the integrity of potential Cretaceous and Tertiary seals;

- determination of the probability of secondary migration and entrapment of hydrocarbons within Cretaceous and Tertiary strata.

## 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 appraisal 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 within or overlying fault blocks of the Rankin Platform (Fig. 2). 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, Roller, Wanaea, Cossack, Ramillies, Wandoo), and the former distinction between an "inner oil trend" and an "outer gas trend" has become blurred.

## 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 an incipient rift system (Veevers, 1988). Within the northern Carnarvon Basin, the four principal shelf and upper slope depocentres - the Exmouth, Barrow, Dampier, and Beagle Sub-basins (Fig. 3) - 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

* Excerpted and modified from Stagg, 1992.

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.

## BOUNDARIES BETWEEN SUB-BASINS

The boundaries between the sub-basins of the southern North West Shelf are complex and not well-imaged or well-understood. In the southwest, the Exmouth Sub-basin is in *en echelon* arrangement with the Barrow Sub-basin (e.g., see figure 2 in Barber, 1988), 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 (Fig. 4). 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 complex junction is not imaged at depth, but probably overlies a broad NW-SE trending transfer fault zone.

In the northeast, the boundary between the Dampier and Beagle Sub-basins is taken at a feature that has been referred to as the 'De Grey Nose'. This feature is probably also a complex transfer fault zone that truncates the northeastern end of the Dampier Sub-basin. 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 the Beagle Sub-basin is strongly influenced by underlying orthogonal trends of the Offshore Canning Basin (the Roebuck Basin of Hocking, 1994), 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 Beagle Sub-basin is separated from the Bedout Sub-basin, Bedout High, and Rowley Sub-basin to the east and northeast by the N-S trending North Turtle Hinge.

## INTERNAL SUB-BASIN STRUCTURES (Fig. 4)

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 System in the north. Between these two fault systems (Flinders-Rosemary and Scholl Island-Hauy), is a complex fault zone 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 are deep (~3 km Tertiary-Cretaceous and

>5 km Jurassic, underlain by an unknown thickness of Triassic and Palaeozoics) and relatively unfaulted downwarps.

The seaward boundary of the Barrow-Dampier rift is formed by the structurally high Rankin Platform. The Rankin 'Trend' follows the southeastern edge of the Exmouth Plateau/Rankin Platform megacrustal block (Woodside, 1988). The Rankin Platform has the strongest gravity signature on the southern North West Shelf and is a fundamental structure of the rift system, as well as being host to the largest hydrocarbon reservoirs. For much of its length, the Rankin Platform is strongly fault-segmented, consisting of a series of NNE-trending pivotal Triassic horsts and grabens in an *en echelon* arrangement, suggesting that the trend formed in response to strike-slip movements (Woodside, 1988).

In the southwest, offshore from the Barrow Sub-basin, the Rankin Platform 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 well-known than that of the Rankin Trend, its gravity expression is as strong as that of the Rankin Platform, and it also appears to represent 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 elements are the ENE-trending Cossigny and Beagle Troughs and the NNE-trending fault blocks of the Beagle Platform (Blevin et al., 1994), which are analogous to the Lewis Trough and Rankin Platform, 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.

## TECTONIC FRAMEWORK

The evolution of the northern Carnarvon Basin was influenced by a series of tectonic events that controlled both the shape of the basin and the geometry and distribution of the basin fill. The basin's history can be subdivided into phases that are defined by these events (AGSO North West Shelf Study Group, 1994):

1) Late Devonian - Initiation of a major phase of intra-continental, upper-crustal extension that continued into the Early Carboniferous - In the northern Carnarvon, this event is expressed by growth on faults on the Candace Terrace.

2) Middle Carboniferous - Extension and the initiation of the Westralian Superbasin (Yeates & others, 1987) - Crustal extension primarily 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 an example of an extensional fault of this age (e.g. see figures 5 & 7 in Bentley, 1988).

3) Late Permian - Bedout Movement - A regional structuring event that gave rise to a varied set of structural styles in various parts of the northern Carnarvon. Extensional, transtensional and transpressional features are all observed.

4) Late Triassic - Fitzroy Movement - 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 non-systematic fault block rotations on the Rankin Trend, and fault discontinuity indicate strike-slip faulting, interpreted to be in a left-lateral sense. This was the period of initiation of the major Jurassic depocentres of the northern Carnarvon, the Exmouth, Barrow, Dampier and Beagle Sub-basins. Rapid subsidence regionally led to the deposition of source rocks in many basins and sub-basin depocentres on the North West Shelf at this time, including the northern Carnarvon. Structures formed at this time serve as traps for most of the large gas fields of the North West Shelf (North Rankin, Goodwyn, West Tryal Rocks, Gorgon).

5) Mid - Late Jurassic (Callovian - Oxfordian) - Argo Breakup - This event is associated with the initiation of sea-floor spreading in the Argo Abyssal Plain and is expressed in the northern Carnarvon Basin by minor compression and erosion. The formation of a regional unconformity referred to as the 'Main Unconformity' (MU) occurred at this time.

6) Early Cretaceous (Valanginian) - Cuvier-Gascoyne Breakup - Sea-floor spreading in the Gascoyne and Cuvier Abyssal plains began at this time. Compression and erosion occurred in the Exmouth Sub-basin, but elsewhere the effects of this tectonic event are indistinct.

7) Mid-Cretaceous (Cenomanian) - Middle to Late Cretaceous faulting is 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.

8) Miocene - Collision along the northern margin of Australia commenced in the Mid-Oligocene, but the effects of that event began to be manifest along the southern half of the North West Shelf in the Miocene. A final episode of wrench movement and fault reactivation occurred 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. Intraplate stresses within the Australia-India plate had some influence on fault reactivation in the Late Miocene. In both the Timor Sea basins and in the northern Carnarvon Basin, these tectonic events are thought to be responsible for initiating periods of fault reactivation with associated hydrocarbon leakage and migration that resulted in residual oil columns in several fields.

During each phase of the basin's history, reactivation of pre-existing structures is an important consequence of the basin-forming tectonic events. The impact on timing of formation and modification of traps and fluid migration pathways is of critical importance to the petroleum exploration industry. The proposed high-resolution survey will provide the quality and resolution necessary to investigate this problem.

# STRATIGRAPHY*

A summary of general stratigraphy is provided in Figure 5. The North West Shelf is well-explored by Australian standards, and the stratigraphy is relatively well-documented, particularly in the Barrow and Dampier Sub-basins. This following 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 Late Triassic 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, and there are widespread Rhaetian shelf carbonates along the northern margin of the Exmouth Plateau (von Rad, Haq, et al., 1992).

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 Claystone 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. 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 was characterized by 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 diagrammatically in Howell (1988, figure 8) and Barber (1988, figure 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 (Cardabia Group, Giralia Calcarenite, Cape Range Group).

## HYDROCARBON ACCUMULATIONS*

The hydrocarbon fields of the northern Carnarvon Basin fall into two categories (Vincent & Tilbury, 1988) - those reservoired in the pre-'Main Unconformity' (pre-MU) section (Argo Breakup, Fig. 5), and those reservoired in the post-MU section (Appendix 1).

The pre-MU fields are characterised by the fault blocks of the southeastern edge of the Rankin Platform (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 1). 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

Acquisition of a regional, high-resolution seismic survey is required to achieve the objectives of this program:

- construction of a regional, sequence-based chronostratigraphic framework for the Cretaceous and Tertiary within which the occurrence and distribution of potential seal and reservoir facies may be analyzed and predicted;

- assessment of the post-Valanginian fault reactivation history of the northern Carnarvon Basin and the implications for: (a) the migration of hydrocarbons from pre-Cretaceous traps and (b) the integrity of potential Cretaceous and Tertiary seals;

- determination of the probability of secondary migration and entrapment of hydrocarbons within Cretaceous and Tertiary strata.

The existence of residual oil columns in the Timor Sea basins and the northern Carnarvon has been recognized for some time. However, there has been little effort spent investigating where the missing portions of the original hydrocarbon accumulations have gone. Studies presented recently provide evidence for migration of older hydrocarbons through Jurassic and Cretaceous strata (Lisk & Eadington, 1994; Ellis et al., 1994). In fact, the recent discovery of hydrocarbons in the lowermost Tertiary (Sit et al., 1994) has provided a new play concept for the northern Carnarvon Basin, and has highlighted the potential for hydrocarbon accumulations in younger-than-traditional targets. This discovery provided the impetus for the proposed survey to investigate the potential of younger traps to reservoir hydrocarbons after secondary migration.

## PROPOSED PROGRAM

The proposed lines for the high-resolution survey are shown in Figures 6-8. The survey is regional with an average line spacing over most of the area of less than 30 km. These lines total 4240 km and tie 107 wells (Appendix 2). The seismic grid has been designed to cover the area as evenly as possible, given the distribution of wells. Eighteen of the lines are perpendicular to structural strike; three long lines form regional strike transects. Two additional lines, 21 and 23, infill and tie some of the critical wells.

The seismic data will be acquired during a 30-day survey, weather conditions and equipment reliability permitting.

A summary of each line follows; way points for each line are included in Appendix 3:

**LINE 1** (110 km)
Dip line - NNW-SSE, crosses the southern end of the Exmouth Sub-basin intersecting AGSO deep seismic (DS) lines 110/11, 101/16 and 101/5. Ties Zeewulf 1 and Resolution 1 and high-resolution seismic (HIREZ) lines 19 and 20.

**LINE 2** (135 km)
Dip line - Southern Exmouth Sub-Basin. Intersects AGSO DS lines 101/16, 110/11 and 101/4. Ties Novara 1, West Muiron 2, 3, and 4 and HIREZ lines 19, 20 and 21.

**LINE 3** (155 km)
Dip line - Central Exmouth Sub-basin; southern end of line crosses Long Island Fault System and Rough Range Fault. Intersects AGSO DS lines 101/16, 110/12, 101/4 and 110/11. Ties Outtrim 1 and Hawksbill 1, and HIREZ lines 19, 20, and 21.

**LINE 4** (170 km)
Dip line - Northern Exmouth Sub-basin, crosses the Alpha Arch and the southern end of the Barrow Sub-basin. Intersects AGSO DS lines 110/08, 101/6, 101/4 and 110/12. Ties Zeepaard 1, Ramillies 1, Somerville 1 and Anchor 1, and HIREZ lines 19, 20, 21 and 22.

**LINE 5** (175 km)
Dip line - From northern end of Exmouth Sub-basin, crosses the Alpha Arch/Rankin Fault System and the southern Barrow Sub-basin. Intersects AGSO DS lines 110/8, 101/7, 101/4 and 101/6. Ties Minden 1, Rosily 1A and Cowle 1, and HIREZ lines 19, 20 and 22.

**LINE 6** (180km)
Dip line - Southern end of the Rankin Platform, across the Rankin Fault System and the Barrow Sub-basin. Intersects AGSO DS lines 110/8, 101/7 and 101/4. Ties North Gorgon 1, Spar 1, Kurrajong 1, Koolinda 1, and Saladin 1, and HIREZ lines 19, 20 and 22.

**LINE 7** (180 km)
Dip line - Southern Rankin Platform, across the Rankin Fault System and central Barrow Sub-basin. Intersects AGSO DS lines 110/8, 110/9, 101/3, 101/2 and 101/7. Ties West Tryal Rocks 2 and 3, Tryal Rocks 1, Maitland 1, West Pepper 1 and Chervil 3 and HIREZ lines 19, 20 and 22.

**LINE 8** (115 km)
Dip line - From the Rankin Platform across the northern Barrow Sub-basin, ending just north of Barrow Island. Intersects AGSO DS lines 110/8, 110/9 and 101/2. Ties Sultan 1 and HIREZ lines 19, 20, 22 and 23.

**LINE 9** (140 km)
Dip line - From the Rankin Platform, crosses the possible accommodation zone that separates the Barrow and Dampier Sub-basins. Intersects AGSO DS line 110/8. Ties Forrest 1A, Flag 1, Harriet 1 and Georgette 1, and HIREZ lines 19, 20, 22 and 23.

**LINE 10** (135 km)
Dip line - From the Rankin Platform across the southern end of the Dampier Sub-basin. Intersects AGSO DS lines 110/8 and 101/2. Ties Rankin 1, Dixon 1, Mawby 1A and Stag 1, and HIREZ lines 19, 20, 22 and 23.

**LINE 11** (130 km)
Dip line - From the Rankin Platform across the southern Dampier Sub-basin and southern Enderby Trend. Intersects AGSO DS lines 110/8 and 101/2. Ties Goodwyn 3 and 6, Dampier 1, Montebello 1 and Enderby 1, and HIREZ lines 19, 20, 22 and 23.

**LINE 12** (140 km)
Dip line - From the Rankin Platform, across the central Dampier Sub-basin and Enderby Trend. Intersects AGSO DS lines 110/8 and 101/2. Ties Gandara 1, North Rankin 5 and 6, Miller 1 and Orion 1, and HIREZ lines 19, 20 and 22.

**LINE 13** (134 km)
Dip line - From the Rankin Platform, across the central Dampier Sub-basin and Enderby Trend. Intersects AGSO DS lines 110/8 and 101/2. Ties Montague 1, Wanaea 5, Baleena 1, Lewis 1A and Kanji 1, and HIREZ lines 19, 20 and 22.

**LINE 14** (125 km)
Dip line - From the Rankin Platform, crosses the northern Dampier Sub-basin and Enderby Trend. Intersects AGSO DS lines 110/8 and 110/2. Ties Angel 2, Forestier 1 and Cygnus 1, and HIREZ lines 19, 20 and 22.

**LINE 15** (140 km)
Dip line - Northern Rankin Platform, crosses the northern end of the Dampier Sub-basin and Enderby Trend, and ends on the Lambert Shelf. Intersects AGSO DS lines 110/8 and 110/2. Ties Finucane 1, Talisman 1 and Hauy 1, and HIREZ lines 19, 20 and 22.

**LINE 16** (105 km)
Dip line - Northern end of Rankin Platform, crosses possible accommodation zone between the Dampier and Beagle Sub-basins, and ends on the southern flank of De Grey Nose. Intersects AGSO DS lines 110/8 and 110/1. Ties Sable 1, Aurora 1 and De Grey 1, and HIREZ lines 19 and 22.

**LINE 17** (155 km)
Dip line - Western Beagle Sub-basin, crosses Cossigny Trough and ends on the Lambert Shelf. Intersects AGSO DS lines 110/8, 110/1 and 110/4. Ties Jarman 1 and HIREZ lines 19 and 22.

**LINE 18** (120 km)
Dip line - NW-SE across the Beagle Sub-basin, crosses the Beagle Trough and ends west of the North Turtle Hinge. Intersects AGSO DS lines110/8, 110/4 and 110/1. Ties Nebo 1 and Depuch 1, and HIREZ lines 19 and 22.

**LINE 19** (570 km)
Strike line - Along the northwestern flank of the Exmouth Sub-basin, the southeastern edge of the Rankin Platform, the northwestern flank of the Dampier Sub-basin and into the Beagle Sub-basin along the northern flank of the Cossigny and Beagle Troughs. Intersects AGSO DS lines 110/11, 110/12, 101/6, 101/7, 110/9, 101/8, 101/9, 101/10, 110/3, 110/2 and 110/7. Ties Resolution 1, Zeepaard 1, Central Gorgon 1, North Gorgon 1, Bluebell 1, West Tryal Rocks 3, Sultan 1, North Tryal Rocks 1, Malus 1, Echo 1, Goodwyn 2, 7 and 8, North Rankin 1, Miller 1, Eaglehawk 1, Bounty 1, Finucane 1, Sable 1, Ronsard 1 and Nebo 1. Ties HIREZ dip lines 1 through 18.

**LINE 20** (440 km)
Strike line - Follows the southeastern flank of the Exmouth Sub-basin, crosses the Alpha Arch into the northwestern Barrow Sub-basin, and continues along the northwestern flank of the Lewis Trough (Dampier Sub-basin). Intersects AGSO DS lines 101/5, 110/11, 110/12, 101/6, 101/7, 101/3, 101/2, 101/8, 101/9 and 101/10. Ties Novara 1, Vlaming Head 1, York 1, Minden 1, East Spar 2, Maitland 1, Forrest 1A, Withnell 1, Dampier 1, Madeleine 1, Wanaea 1, 2 and 3, Cossack 1, Angel 1A and 2, and HIREZ lines 1 through 15.

**LINE 21** (90 km)
Strike line - Between the Exmouth and Barrow Sub-basins. Intersects AGSO DS lines 110/11, 110/12 and 101/4. Ties Leatherback 1, Outtrim 1, Griffin 1 and Hilda 1A, and HIREZ lines 2, 3 and 4.

**LINE 22** (490 km)
Strike line - Parallel to the Barrow Sub-basin depositional axis, passing on the northwest side of Barrow Island, along the southeastern flank of the Dampier and Beagle depocentres (troughs). Intersects AGSO DS lines 110/12, 101/6, 101/7, 101/8, 101/9, 101/10, 110/3, 110/2, 110/4 and 110/1. Ties Rosily 1A, Flag 1, Campbell 2, Mawby 1A, Rosemary 1, Rosemary North 1,

Baleena 1, Samson 1, Legendre 1, Legendre 2, Forestier 1, Nelson Rocks 1, Talisman 2, Talisman 1, Alpha North 1, Cossigny 1 and North Turtle 1. Ties HIREZ dip lines 4 through 18.

**LINE 23** (100 km)

Strike line - Northeast flank of the southern Dampier Sub-basin. Intersects AGSO DS lines 110/9 and 101/8. Ties Venture 1, Wilcox 1, Wilcox 2, Lowendal 1, Fisher 1, Rankin 1, Dockrell 1, Pueblo 1 and Tidepole 1, and HIREZ dip lines 8 through 11.

Acquisition parameters and equipment to be used on this cruise are included in Appendices 4 and 5.


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# APPENDIX 1

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

### PRE-BREAKUP FIELDS

| Basin | Year | Company | Age | Trap[1] |
|---|---|---|---|---|
| Barrow Deep | 1973 | Wapet | Ju | A |
| Dockrell | 1979 | Woodside | Tr | TiFB |
| Eaglehawk | 1972 | Woodside | Tr | HB |
| Goodwyn | 1971 | Woodside | Tr, Ju | TiFB |
| Goodwyn South | 1973 | Woodside | Tr | TrFB |
| Gorgon | 1981 | Wapet | Tr | HB |
| Nebo* | 1993 | Kufpec | Ju | F-C,A |
| North Rankin | 1971 | Woodside | Tr, Ju | HB |
| N Rankin West | 1972 | Woodside | Ju | FB |
| Rankin | 1971 | Woodside | Tr | TiFB |
| Tidepole | 1975 | Woodside | Tr | TiFB |
| West Tryal Rocks | 1973 | Wapet | Tr | HB |
| Wilcox | 1983 | Woodside | Tr | FB |

### POST-BREAKUP FIELDS

| Basin | Year | Company | Age | Trap[1] |
|---|---|---|---|---|
| Angel | 1972 | Woodside | Ju | D |
| Bambra | 1982 | Bond | Cret | A |
| Barrow Island | 1964 | Wapet | Ju, Cret | A |
| Campbell | 1986 | Bond | Cret | A |
| Chervil | 1983 | WMC | Cret | FA |
| Cossack* | 1990 | Woodside | Ju | A |
| Cowle* | | Wapet | Cret? | F-C |
| Dixon | 1984 | Woodside | Ju | D |
| Egret | 1973 | Woodside | Ju | F-C |
| Harriet | 1983 | Bond | Cret | F-C |
| Lambert | 1974 | Woodside | Ju | R |
| Legendre | 1968 | Woodside | Cret | FA |
| Macedon-Pyrenees* | 1992 | BHP/Ampol | Cret | FA |
| North Herald | 1983 | WMC | Cret | FA |
| Rivoli* | 1989 | Minora | Cret | FA |
| Roller* | | Wapet | Cret | A |
| Rosette | 1987 | Bond | Cret | A |
| Saladin | 1985 | Wapet | Cret | F-C |
| Scarborough | 1979 | Esso | Cret | Dome |
| Skate* | | Wapet | Cret | A |
| Sinbad* | 1990 | Hadson | Cret | F-C |

| Basin | Year | Company | Age | Trap[1] |
|---|---|---|---|---|
| South Chervil | 1983 | WMC | Cret | FA |
| South Pepper | 1983 | WMC | Cret | FA |
| Spar | 1976 | Wapet | Cret | R |
| Stag* | 1993 | Hadson | Cret | A |
| Talisman | 1984 | Marathon | Cret | F-C |
| Tanami* | 1991 | Hadson | Cret | A |
| Tubridgi | 1981 | Otter | Cret | A |
| Ulidia* | 1992 | Hadson | Cret | A |
| Wandoo* | 1991 | Ampolex | Cret | D |
| Wanaea* | 1989 | Woodside | Ju | A |
| Yammaderry* | | Wapet | Cret | F-C |

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 |

* Discoveries post Cockbain, 1989

## APPENDIX 2

## WELLS TO BE TIED

| WELLNAME | OPERATOR | DATE | TD | AGE AT TD |
|---|---|---|---|---|
| ALPHA NORTH 1 | MARATHON | 7/89 | 2200 | M. JURASSIC |
| ANCHOR 1 | WAPET | 8/69 | 3049 | |
| ANGEL 1A | BURMAH OIL | 11/72 | 3411 | U. JURASSIC |
| ANGEL 2 | BURMAH OIL | 5/72 | 4397 | L. JURASSIC |
| AURORA 1 | MARATHON | 12/90 | 3020 | |
| BALEENA 1 | PHILLIPS | 6/93 | | |
| BLUEBELL 1 | WAPET | 4/83 | 4605 | U. TRIASSIC |
| BOUNTY 1 | MARATHON | 7/83 | 3524 | U. JURASSIC |
| CAMPBELL 2 | BOND CORP | 3/86 | 2796 | CRETACEOUS |
| CENT. GORGON 1 | WAPET | 7/83 | 4598 | |
| CHERVIL 3 | WESMINCO | 5/85 | 1350 | E. CRETACEOUS |
| COSSACK 1 | WOODSIDE | 1/90 | 3030 | JURASSIC |
| COSSIGNY 1 | WOODSIDE | 11/72 | 3203 | M. TRIASSIC |
| COWLE 1 | WAPET | 12/89 | 1180 | CRETACEOUS |
| CYGNUS 1 | ARCO AUST | 8/89 | 2470 | |
| DAMPIER 1 | BURMAH OIL | 5/69 | 4143 | U. JURASSIC |
| DE GREY 1 | BURMAH OIL | 10/71 | 2088 | TRIASSIC |
| DEPUCH 1 | WOODSIDE | 3/74 | 4300 | L. JURASSIC |
| DIXON 1 | WOODSIDE | 5/84 | 4357 | U. TRIASSIC |
| DOCKRELL 1 | WOODSIDE | 3/73 | 3895 | U. TRIASSIC |
| EAGLEHAWK 1 | WOODSIDE | 12/72 | 3490 | U. TRIASSIC |
| EAST SPAR 2 | WMC | 9/93 | | |
| ECHO 1 | WOODSIDE | 10/88 | 3775 | TRIASSIC |
| ENDERBY 1 | BURMAH OIL | 10/70 | 2149 | ?PERMIAN |
| FINUCANE 1 | WOODSIDE | 11/78 | 3300 | M. JURASSIC |
| FISHER 1 | WOODSIDE | 8/81 | 3762 | U. TRIASSIC |
| FLAG 1 | WAPET | 1/70 | 3800 | JURASSIC |
| FORESTIER 1 | WOODSIDE | 9/86 | 2514 | U. JURASSIC |
| FORREST 1A | PHILLIPS | 10/92 | 3426 | U. JURASSIC |
| GANDARA 1 | HUDBAY | 7/79 | 4361 | U. TRIASSIC |
| GEORGETTE 1 | OCCIDENTAL | 9/83 | 2392 | M. JURASSIC |
| GOODWYN 2 | BURMAH OIL | 5/72 | 3750 | M. TRIASSIC |
| GOODWYN 3 | WOODSIDE | 2/73 | 3658 | U. TRIASSIC |
| GOODWYN 6 | WOODSIDE | 12/81 | 4664 | U. TRIASSIC |
| GOODWYN 7 | WOODSIDE | 9/85 | 3445 | U. TRIASSIC |
| GOODWYN 8 | WOODSIDE | 5/86 | 3197 | U. TRIASSIC |
| GRIFFIN 1 | BHP | 2/90 | 3400 | |
| HARRIET 1 | OCCIDENTAL | 11/83 | 2711 | |
| HAUY 1 | WOODSIDE | 12/72 | 825 | |
| HAWKSBILL 1 | HADSON | 12/93 | | |
| HILDA 1A | WAPET | 9/74 | 3466 | U. TRIASSIC |
| JARMAN 1 | WOODSIDE | 2/78 | 2906 | M. JURASSIC |
| KANJI 1 | AMPOLEX | 2/94 | 1288 | |
| KOOLINDA 1 | WAPET | 3/78 | 3732 | JURASSIC |
| KURRAJONG | AMPOLEX | 12/93 | | |
| LEATHERBACK | LASMO OIL | 6/91 | 2258 | TRIASSIC |
| LEGENDRE 1 | BURMAH OIL | 6/68 | 3473 | M. JURASSIC |
| LEGENDRE 2 | BURMAH OIL | 12/70 | 3618 | L. JURASSIC |

| WELLNAME | OPERATOR | DATE | TD | AGE AT TD |
|---|---|---|---|---|
| LEWIS 1A | BURMAH OIL | 2/76 | 3400 | M. JURASSIC |
| LOWENDAL 1 | WOODSIDE | 3/74 | | |
| MADELEINE 1 | BURMAH OIL | 12/69 | 4429 | JURASSIC |
| MAITLAND 1 | WMC | 9/92 | 1502 | JURASSIC |
| MALUS 1 | WOODSIDE | 11/72 | 3658 | U. TRIASSIC |
| MAWBY 1A | WOODSIDE | 3/91 | 2100 | JURASSIC |
| MILLER 1 | WOODSIDE | 5/78 | 3520 | U. TRIASSIC |
| MINDEN 1 | BHP | 5/91 | 4022 | L. CRETACEOUS |
| MONTAGUE 1 | WOODSIDE | 3/85 | 4362 | U. TRIASSIC |
| MONTEBELLO 1 | BHP | 12/89 | 2750 | M. JURASSIC |
| NEBO 1 | KUFPEC | 4/93 | 3132 | M. JURASSIC |
| NELSON ROCKS 1 | WOODSIDE | 7/73 | 2190 | U. JURASSIC |
| N. GORGON 1 | WAPET | 12/82 | 4500 | TRIASSIC |
| N. RANKIN 1 | BURMAH OIL | 6/71 | 3534 | M. TRIASSIC |
| N. RANKIN 5 | WOODSIDE | 2/77 | 3500 | U. TRIASSIC |
| N. RANKIN 6 | WOODSIDE | 4/81 | 3900 | U. TRIASSIC |
| N. TRYAL RCKS 1 | WAPET | 7/72 | 3658 | |
| N. TURTLE 1 | BP | 9/82 | 4420 | U. TRIASSIC (?) |
| NOVARA 1 | ESSO EX | 10/82 | 2753 | L. CRETACEOUS |
| ORION 1 | WOODSIDE | 8/90 | 2500 | M. JURASSIC |
| OUTTRIM 1 | ESSO EX | 7/84 | 1725 | U. JURASSIC |
| PUEBLO 1 | WOODSIDE | 4/79 | 3485 | U. TRIASSIC |
| RAMILLIES 1 | BHP | 12/90 | 3151 | |
| RANKIN 1 | BURMAH OIL | 9/71 | 4111 | TRIASSIC |
| RESOLUTION 1 | ESSO | 11/79 | 3883 | TRIASSIC |
| RONSARD 1 | WOODSIDE | 11/73 | 2848 | L. JURASSIC |
| ROSEMARY 1 | WOODSIDE | 3/73 | 3909 | JURASSIC |
| ROSEMARY N. 1 | WOODSIDE | 11/82 | 2263 | U. JURASSIC |
| ROSILY 1A | WAPET | 5/82 | 3066 | L. CRETACEOUS |
| SABLE 1 | WOODSIDE | 10/72 | 3972 | U. TRIASSIC |
| SALADIN 1 | WAPET | 6/85 | 1830 | U. JURASSIC |
| SAMSON 1 | WOODSIDE | 10/84 | 3750 | M. JURASSIC |
| SOMERVILLE 1 | BHP | 2/87 | 1749 | L. CRETACEOUS |
| SPAR 1 | WAPET | 9/76 | 3721 | L. CRETACEOUS |
| STAG 1 | HADSON | 6/93 | 933 | |
| SULTAN 1 | WAPET | 3/79 | 3620 | U. TRIASSIC |
| TALISMAN 1 | MARATHON | 8/84 | 2924 | |
| TALISMAN 2 | MARATHON | 6/85 | 2326 | U. JURASSIC |
| TANAMI 2 | HADSON | 10/91 | | |
| TIDEPOLE 1 | BURMAH OIL | 11/75 | 3491 | U. TRIASSIC |
| TRYAL ROCKS 1 | WAPET | 8/70 | 3695 | U. JURASSIC |
| VENTURE 1 | WAPET | 10/90 | 3324 | |
| VLAMING HEAD | CANADA NW | 9/82 | 2068 | L. CRETACEOUS |
| WANAEA 1 | WOODSIDE | 5/89 | 4154 | M. JURASSIC |
| WANAEA 2 | WOODSIDE | 3/90 | 3000 | JURASSIC |
| WANAEA 3 | WOODSIDE | 7/90 | 2991 | JURASSIC |
| WANAEA 5 | WOODSIDE | 7/92 | 3210 | U. JURASSIC |
| W. MUIRON 2 | WAPET | 10/75 | 3320 | |
| W. MUIRON 3 | BHP | 10/92 | 1200 | JURASSIC |
| W. MUIRON 4 | BHP | 5/93 | | |
| W. PEPPER 1 | WMC | 5/91 | 1470 | |
| W. TRYAL RKS 2 | WAPET | 11/74 | 3825 | U. TRIASSIC |

| WELLNAME | OPERATOR | DATE | TD | AGE AT TD |
|---|---|---|---|---|
| W. TRYAL RKS 3 | WAPET | 12/81 | 4035 | U. TRIASSIC |
| WILCOX 1 | WOODSIDE | 2/83 | 4024 | U. TRIASSIC |
| WILCOX 2 | WOODSIDE | 8/85 | 4117 | U. TRIASSIC |
| WITHNELL 1 | BURMAH OIL | 6/76 | 4650 | M. JURASSIC |
| YORK 1 | BHP | 6/93 | | |
| ZEEPAARD 1 | ESSO | 10/80 | 4215 | U. TRIASSIC |
| ZEEWULF 1 | ESSO | 5/79 | 3500 | U. TRIASSIC |

## APPENDIX 3

## WAY POINTS CARNARVON HIGH RESOLUTION SURVEY

| LINE NO. | SHOT POINT | LATITUDE | LONGITUDE | TIE POINTS |
|---|---|---|---|---|
| 1 | 1 | 21 00.7083S | 113 34.8367E | SOL |
| | 2 | 21 06.4600S | 113 37.2933E | ZEEWULF 1 |
| | 3 | 21 17.8583S | 113 41.4817E | RESOLUTION 1 |
| | 4 | 21 49.6400S | 113 59.7233E | EOL |
| 2 | 1 | 20 49.6450S | 113 44.7283E | SOL |
| | 2 | 21 21.3543S | 114 04.5825E | NOVARA 1 |
| | 3 | 21 32.4950S | 114 12.1750E | WEST MUIRON 4 |
| | 4 | 21 34.1767S | 114 13.2050E | WEST MUIRON 3 |
| | 5 | 21 35.5650S | 114 13.5917E | WEST MUIRON 2 |
| | 6 | 21 48.9783S | 114 18.7600E | EOL |
| 3 | 1 | 20 32.4900S | 113 59.2217E | SOL |
| | 2 | 21 31.7993S | 114 27.1237E | OUTTRIM 1 |
| | 3 | 21 41.4900S | 114 31.7383E | HAWKSBILL 1 * |
| | 4 | 21 43.6933S | 114 32.7533E | EOL |
| 4 | 1 | 20 15.4566S | 114 15.5400E | SOL |
| | 2 | 20 44.1500S | 114 25.4400E | ZEEPARD 1 |
| | 3 | 21 15.4250S | 114 36.1717E | RAMILLIES 1 |
| | 4 | 21 29.8350S | 114 40.0867E | SOMERVILLE 1 |
| | 5 | 21 32.8500S | 114 42.6167E | ANCHOR 1 * |
| | 6 | 21 36.2650S | 114 45.6133E | EOL |
| 5 | 1 | 20 10.0930S | 114 28.1750E | SOL |
| | 2 | 20 49.4228S | 114 43.3750E | MINDEN 1 |
| | 3 | 21 12.0983S | 114 52.0783E | ROSILY 1A |
| | 4 | 21 31.3317S | 114 58.1750E | COWLE 1 |
| | 5 | 21 33.0817S | 114 58.5533E | EOL |
| 6 | 1 | 20 00.5217S | 114 44.0900E | SOL |
| | 2 | 20 22.9903S | 114 51.7710E | NORTH GORGON 1 |
| | 3 | 20 36.7833S | 114 53.1800E | SPAR 1 |
| | 4 | 20 51.1017S | 114 56.5850E | KURRAJONG 1 * |
| | 5 | 21 23.6817S | 115 03.2983E | KOOLINDA 1 |
| | 6 | 21 26.4183S | 115 03.2633E | SALADIN 1 |
| | 7 | 21 28.4617S | 115 03.1133E | EOL |
| 7 | 1 | 19 52.6367S | 114 55.7633E | SOL |
| | 2 | 20 09.2200S | 115 03.0200E | WEST TRYAL ROCKS 3 |
| | 3 | 20 12.8623S | 115 04.0043E | WEST TRYAL ROCKS 2 |
| | 4 | 20 24.7167S | 115 09.2500E | TRYAL ROCKS 1 |
| | 5 | 20 33.6633S | 115 10.5350E | MAITLAND 1 |
| | 6 | 21 05.1650S | 115 12.6450E | WEST PEPPER 1 * |
| | 7 | 21 17.7817S | 115 13.7733E | CHERVIL 3 |
| | 8 | 21 20.1800S | 115 13.7917E | EOL |

| | | | | |
|---|---|---|---|---|
| 8 | 1 | 19 47.5650S | 115 03.5600E | SOL |
| | 2 | 20 02.5617S | 115 11.4300E | SULTAN 1 |
| | 3 | 21 39.7808S | 115 28.0222E | EOL |
| 9 | 1 | 19 39.1650S | 115 14.1263E | SOL |
| | 2 | 20 13.6095S | 115 32.3327E | FORREST 1A |
| | 3 | 20 27.8333S | 115 38.8167E | FLAG 1 |
| | 4 | 20 36.1317S | 115 36.8517E | HARRIET 1 |
| | 5 | 20 46.7072S | 115 39.5300E | GEORGETTE 1 |
| 10 | 1 | 19 30.5450S | 115 26.7167E | SOL |
| | 2 | 19 47.8550S | 115 44.6017E | RANKIN 1 |
| | 3 | 19 50.9167S | 115 47.2750E | DIXON 1 |
| | 4 | 20 13.1233S | 116 06.2767E | MAWBY 1A |
| | 5 | 20 17.2300S | 116 15.4817E | STAG 1 |
| | 6 | 20 17.7217S | 116 16.5750E | EOL |
| 11 | 1 | 19 25.2367S | 115 33.0033E | SOL |
| | 2 | 19 43.3150S | 115 51.2783E | GOODWYN 6 |
| | 3 | 19 44.0717S | 115 52.7500E | GOODWYN 3 |
| | 4 | 19 52.2667S | 116 00.9000E | DAMPIER 1 |
| | 5 | 20 05.2667S | 116 17.4717E | MONTEBELLO 1 |
| | 6 | 20 09.3450S | 116 24.4833E | ENDERBY 1 |
| | 7 | 20 09.7817S | 116 25.3200E | EOL |
| 12 | 1 | 19 14.6476S | 115 47.3700E | SOL |
| | 2 | 19 16.4350S | 115 49.3300E | GANDARA 1 |
| | 3 | 19 32.6683S | 116 08.5167E | NORTH RANKIN 6 |
| | 4 | 19 34.2333S | 116 09.5850E | NORTH RANKIN 5 |
| | 5 | 19 34.6700S | 116 10.0017E | MILLER 1 |
| | 6 | 19 52.3233S | 116 31.6050E | ORION 1 |
| | 7 | 20 01.3467S | 116 42.7250E | EOL |
| 13 | 1 | 19 08.3217S | 115 59.3467E | SOL |
| | 2 | 19 31.6083S | 116 22.5500E | MONTAGUE 1 |
| | 3 | 19 35.2117S | 116 24.6900E | WANAEA 5 |
| | 4 | 19 45.8417S | 116 34.4200E | BALEENA 1 * |
| | 5 | 19 47.5250S | 116 37.4333E | LEWIS 1A |
| | 6 | 20 03.5650S | 116 50.4933E | KANJI 1 * |
| | 7 | 20 04.1117S | 116 52.2400E | EOL |
| 14 | 1 | 18 57.9973S | 116 15.0217E | SOL |
| | 2 | 19 27.8945S | 116 39.4920E | ANGEL 2 |
| | 3 | 19 35.6835S | 116 49.2543E | FORESTIER 1 |
| | 4 | 19 42.6562S | 116 54.6228E | CYGNUS 1 |
| | 5 | 19 46.6103S | 116 57.5593E | EOL |
| 15 | 1 | 18 54.9195S | 116 26.8528E | SOL |
| | 2 | 19 17.3200S | 116 45.9750E | FINUCANE 1 |
| | 3 | 19 29.6442S | 116 56.4737E | TALISMAN 1 |
| | 4 | 19 47.5733S | 117 15.3360E | HAUY 1 |
| | 5 | 19 49.6430S | 117 17.2538E | EOL |

| | | | | |
|---|---|---|---|---|
| 16 | 1 | 18 49.7173S | 116 37.3505E | SOL |
| | 2 | 19 13.9817S | 116 55.0650E | SABLE 1 |
| | 3 | 19 20.6520S | 117 00.7620E | AURORA 1 |
| | 4 | 19 29.2600S | 117 05.2117E | DE GREY 1 |
| | 5 | 19 34.0185S | 117 07.7613E | EOL |
| 17 | 1 | 18 39.5322S | 117 00.5528E | SOL |
| | 2 | 19 12.1273S | 117 20.7705E | JARMAN 1 |
| | 3 | 19 43.7258S | 117 47.5238E | EOL |
| 18 | 1 | 18 29.2092S | 117 21.0657E | SOL |
| | 2 | 18 46.7617S | 117 49.7217E | NEBO 1 |
| | 3 | 18 50.0292S | 117 55.3940E | DEPUCH 1 |
| | 4 | 19 02.5523S | 118 15.3848E | EOL |
| 19 | 1 | 21 21.7557S | 113 36.4417E | SOL |
| | 2 | 21 17.8583S | 113 41.4817E | RESOLUTION 1 |
| | 3 | 20 44.1500S | 114 25.4400E | ZEEPARD 1 |
| | 4 | 20 28.0783S | 114 48.6283E | CENTRAL GORGON 1 |
| | 5 | 20 22.9903S | 114 51.7710E | NORTH GORGON 1 |
| | 6 | 20 15.4183S | 114 57.1500E | BLUEBELL 1 |
| | 7 | 20 09.2200S | 115 03.0200E | WEST TRYAL ROCKS 3 |
| | 8 | 20 02.5617S | 115 11.4300E | SULTAN 1 |
| | 9 | 19 59.2950S | 115 19.1800E | NORTH TRYAL ROCKS1* |
| | 10 | 19 45.1800S | 115 32.1183E | MALUS 1 |
| | 11 | 19 42.6290S | 115 43.4395E | ECHO 1 |
| | 12 | 19 39.8050S | 115 51.9550E | GOODWYN 2 |
| | 13 | 19 38.6667S | 115 54.6500E | GOODWYN 8 |
| | 14 | 19 37.6150S | 115 57.6917E | GOODWYN 7 |
| | 15 | 19 35.8300S | 116 07.5767E | NORTH RANKIN 1 |
| | 16 | 19 34.6700S | 116 10.0017E | MILLER 1 |
| | 17 | 19 30.4150S | 116 16.6917E | EAGLE HAWK 1 |
| | 18 | 19 17.2833S | 116 38.4500E | BOUNTY 1 |
| | 19 | 19 17.3200S | 116 45.9750E | FINUCANE 1 |
| | 20 | 19 13.9817S | 116 55.0650E | SABLE 1 |
| | 21 | 19 08.4283S | 117 09.7233E | RONSARD 1 |
| | 22 | 18 46.7617S | 117 49.7217E | NEBO 1 |
| | 23 | 18 38.8510S | 118 04.1070E | EOL |
| 20 | 1 | 21 37.2022S | 113 47.7670E | SOL |
| | 2 | 21 21.3543S | 114 04.5825E | NOVARA 1 |
| | 3 | 21 14.7215S | 114 11.5232E | VLAMING HEAD 1 |
| | 4 | 20 57.0175S | 114 35.5061E | YORK 1 |
| | 5 | 20 49.4228S | 114 43.3750E | MINDEN 1 |
| | 6 | 20 39.7133S | 114 59.8550E | EAST SPAR 2 * |
| | 7 | 20 33.6637S | 115 10.5350E | MAITLAND 1 |
| | 8 | 20 13.6095S | 115 32.3327E | FORREST 1A |
| | 9 | 20 01.1097S | 115 48.3213E | WITHNELL 1 |
| | 10 | 19 52.2667S | 116 00.9000E | DAMPIER 1 |
| | 11 | 19 38.9077S | 116 21.5862E | MADELEINE 1 |
| | 12 | 19 36.8233S | 116 24.6740E | WANAEA 2 * |
| | 13 | 19 35.5080S | 116 26.1213E | WANAEA 1 |
| | 14 | 19 34.6968S | 116 27.0015E | WANAEA 3 |
| | 15 | 19 33.2827S | 116 29.8355E | COSSACK 1 |
| | 16 | 19 30.2550S | 116 35.8748E | ANGEL 1A |
| | 17 | 19 27.8945S | 116 39.4920E | ANGEL 2 |
| | 18 | 19 20.4128S | 116 51.6648E | EOL |

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|---|---|---|---|---|
| 21 | 1 | 21 48.7882S | 114 17.6778E | SOL |
| | 2 | 21 41.0525S | 114 21.9888E | LEATHERBACK 1 |
| | 3 | 21 31.7993S | 114 27.1237E | OUTTRIM 1 |
| | 4 | 21 14.0590S | 114 37.2788E | GRIFFIN 1 |
| | 5 | 21 11.9127S | 114 38.2990E | HILDA 1A |
| | 6 | 21 07.9618S | 114 40.0493E | EOL |
| 22 | 1 | 21 25.5452S | 114 37.6255E | SOL |
| | 2 | 21 12.0983S | 114 52.0783E | ROSILY 1A |
| | 3 | 20 27.8333S | 115 38.8167E | FLAG 1 |
| | 4 | 20 24.8455S | 115 43.8138E | CAMPBELL 2 |
| | 5 | 20 13.1233S | 116 06.2767E | MAWBY 1A |
| | 6 | 19 57.1913E | 116 20.7635E | ROSEMARY 1 |
| | 7 | 19 54.6502S | 116 24.7133E | ROSEMARY NORTH 1 |
| | 8 | 19 45.8417S | 116 34.4200E | BALEENA 1 * |
| | 9 | 19 43.5667S | 116 38.5565E | SAMSON 1 |
| | 10 | 19 40.2367S | 116 44.0033E | LEGENDRE 1 |
| | 11 | 19 37.3762S | 116 46.8953E | LEGENDRE 2 |
| | 12 | 19 35.6835S | 116 49.2543E | FORESTIER 1 |
| | 13 | 19 33.5340S | 116 51.2990E | NELSON ROCKS 1 |
| | 14 | 19 30.2736S | 116 55.6679E | TALISMAN 2 |
| | 15 | 19 29.6442S | 116 56.4737E | TALISMAN 1 |
| | 16 | 19 28.1625S | 116 58.1536E | ALPHA NORTH 1 |
| | 17 | 19 19.8076S | 117 17.5121E | COSSIGNY 1 |
| | 18 | 18 54.5067S | 118 05.3717E | NORTH TURTLE 1 |
| | 19 | 18 54.0413S | 118 06.2225E | EOL |
| 23 | 1 | 20 11.8675S | 115 14.8042E | SOL |
| | 2 | 20 08.4410S | 115 19.1282E | VENTURE 1 |
| | 3 | 20 00.4533S | 115 29.0977E | WILCOX 1 |
| | 4 | 19 59.6663S | 115 30.5102E | WILCOX 2 |
| | 5 | 19 52.8062S | 115 38.0353E | LOWENDAL 1 |
| | 6 | 19 49.3363S | 115 42.6133E | FISHER 1 |
| | 7 | 19 47.8550S | 115 44.6017E | RANKIN 1 |
| | 8 | 19 47.1988S | 115 46.8658E | DOCKRELL 1 |
| | 9 | 19 45.9515S | 115 51.8112E | PUEBLO 1 |
| | 10 | 19 46.0422S | 115 53.1750E | TIDEPOLE 1 |
| | 11 | 19 46.0855S | 115 57.0493E | EOL |

* WELLS WITH A STAR ARE NOT CONVERTED TO WGS-84

## APPENDIX 4

## SEISMIC ACQUISITION PARAMETERS

Seismic Cable Configuration

| | |
|---|---|
| Streamer length | 3000 m |
| Group length | 12.5 m |
| No. of groups | 240 |

Seismic Source

| | |
|---|---|
| Airgun capacity | 1200 cu. in. |
| Airgun pressure | 1800 psi |
| No. of guns | 8 |
| Shot interval | 18.75m |

Fold

| | |
|---|---|
| Standard | 8000% |

Recording Parameters

| | |
|---|---|
| Record length | 5.5 sec |
| Sample interval | 2.0 msec |

# APPENDIX 5

## 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 levelers; individual remote control and depth readout

Sodera GI Guns, 8 x 150 cubic inch airguns giving a total of 1200 cubic inches normal operating volume

Air compressor system: 6 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 AGSO: 16-bit floating point, SEG-Y output on cartridge tape

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

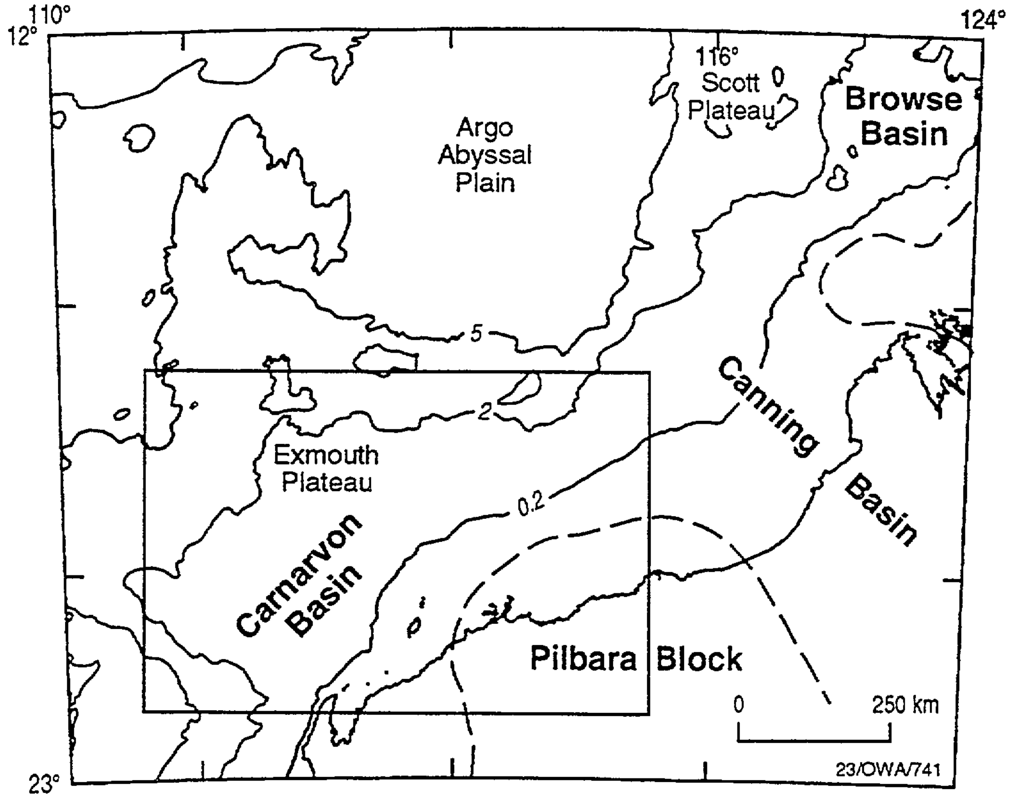
Geometrics G801/803 magnetometer/gradiometer

Bodenseewerk Geosystem KSS-31 marine gravity meter

Racal 'Skyfix' differential GPS

Magnavox T-Set stand-alone GPS receiver

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




1. Location map showing the northern Carnarvon Basin and North West Shelf (from Stagg & Colwell, 1994).

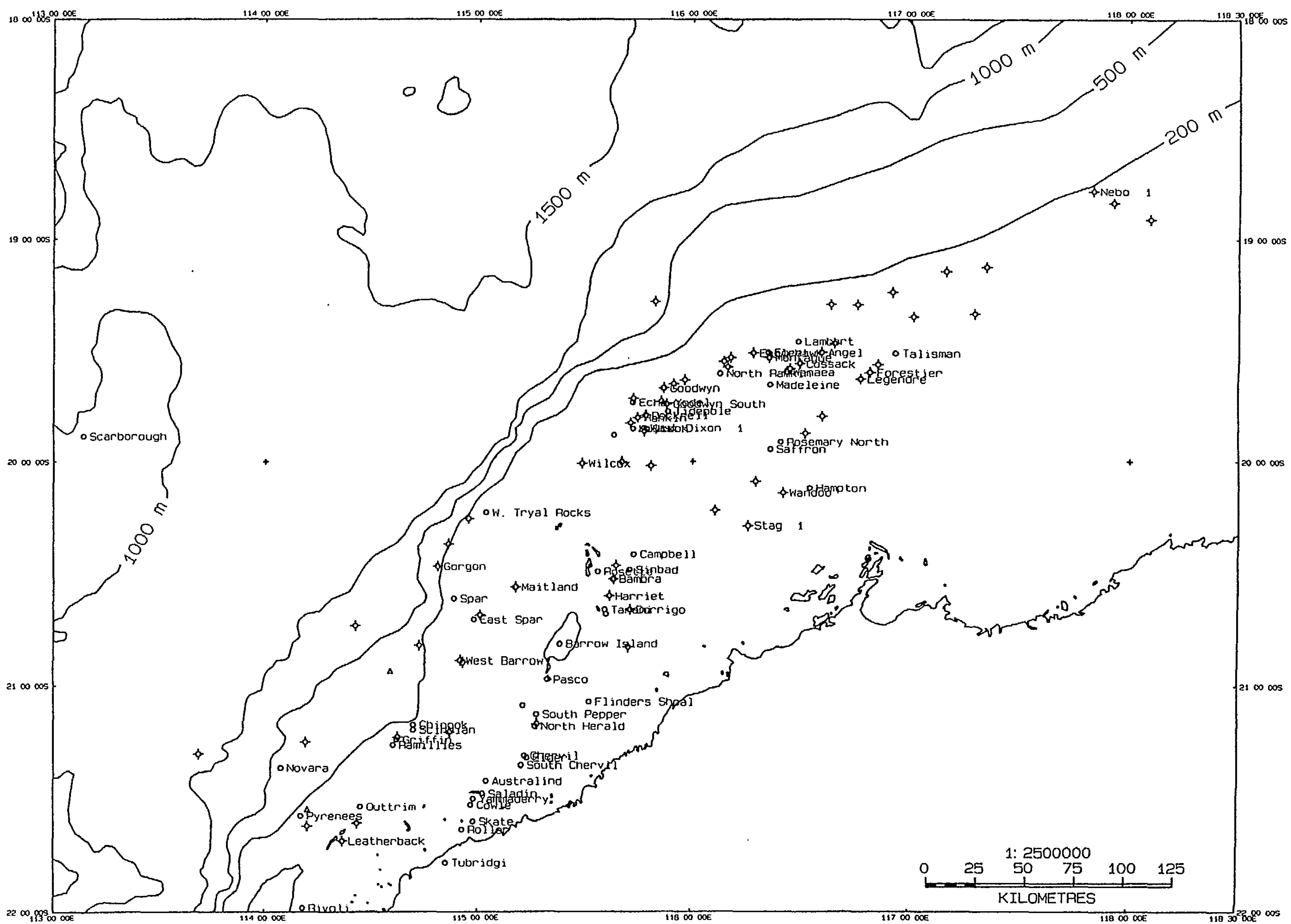



Figure 2 - Locations of hydrocarbon accumulations in the northern Carnarvon Basin

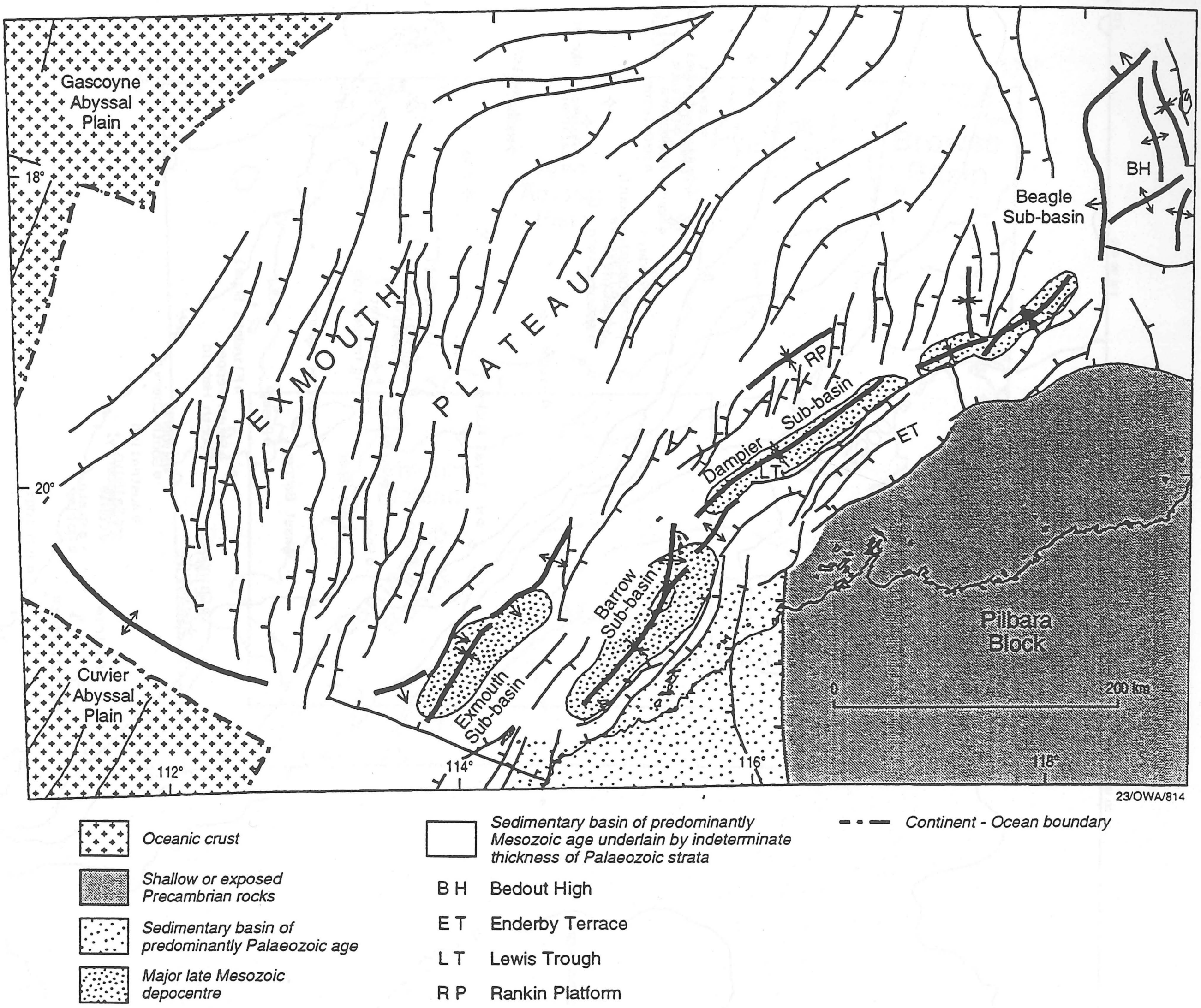



Figure 3 - Location of sub-basin depocentres of the northern Carnarvon Basin (from Stagg & Colwell, 1994).

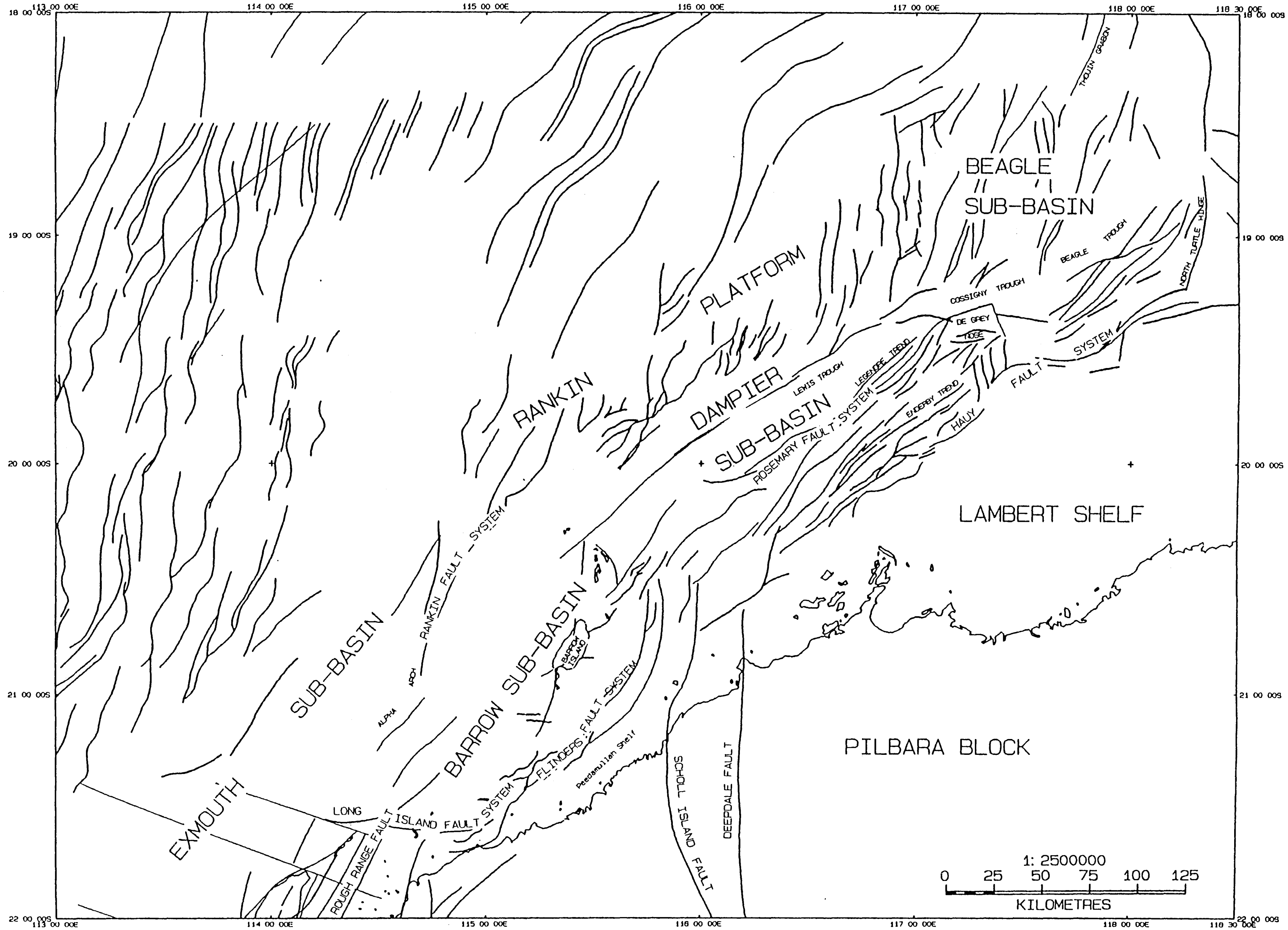



Figure 4 - Tectonic elements of the northern Carnarvon Basin

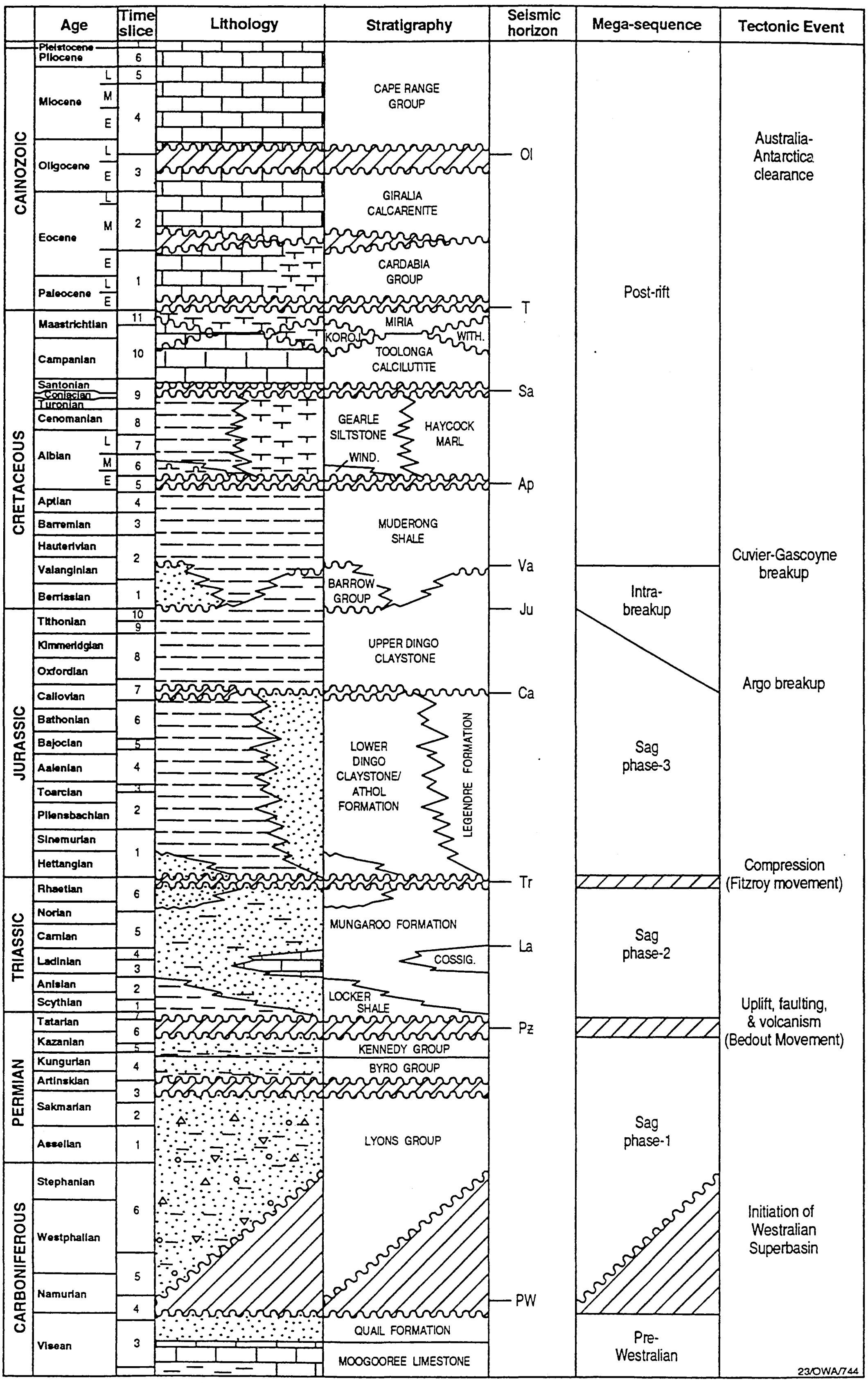



Figure 5 - Stratigraphy of the southern North West Shelf (from Stagg & Colwell, 1994)

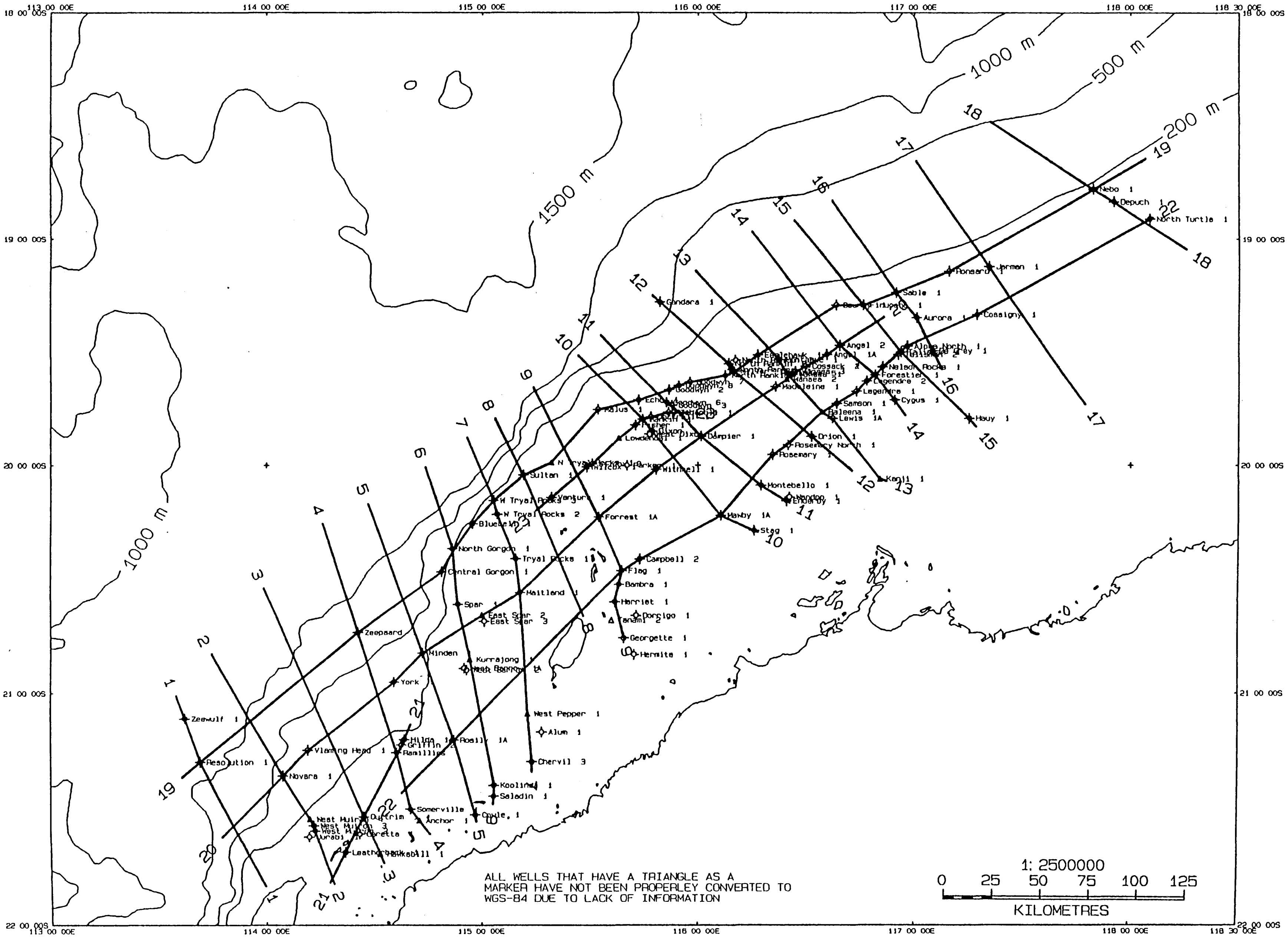



Figure 6 - Proposed seismic lines, wells, and bathymetry

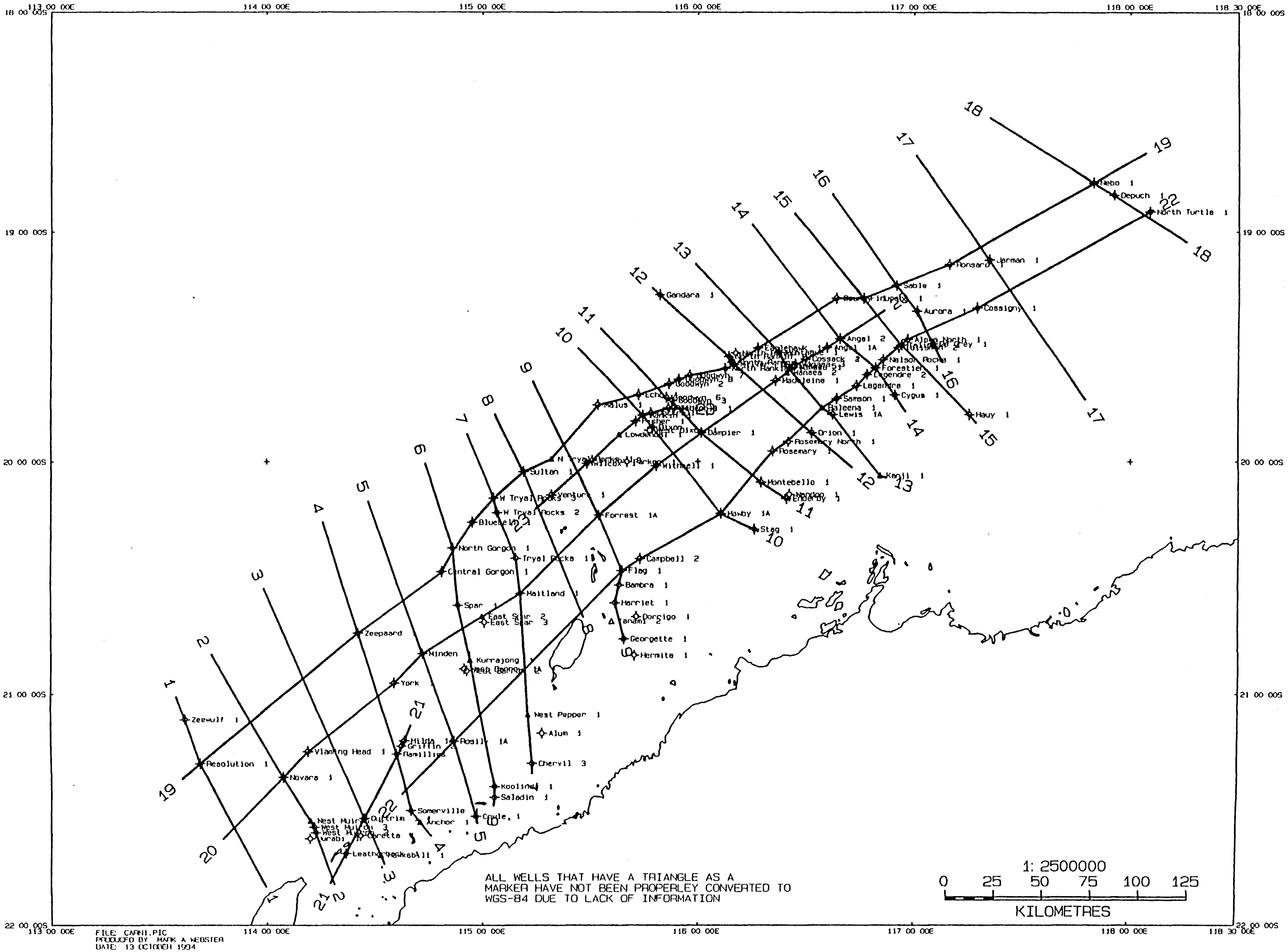



Figure 7 - Proposed seismic lines and tie wells

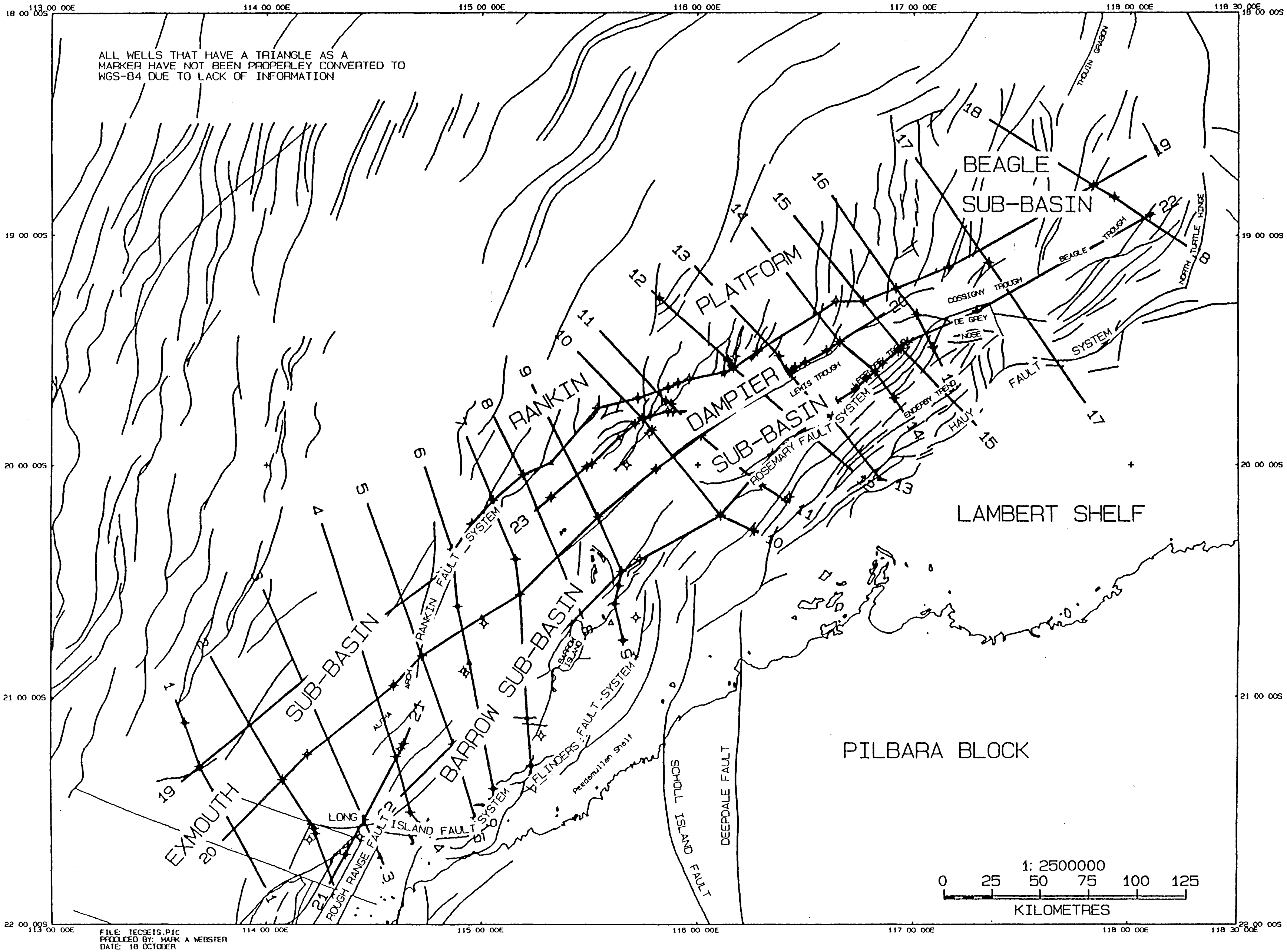



Figure 8 - Proposed seismic lines, well locations and tectonic elements, northern Carnarvon Basin

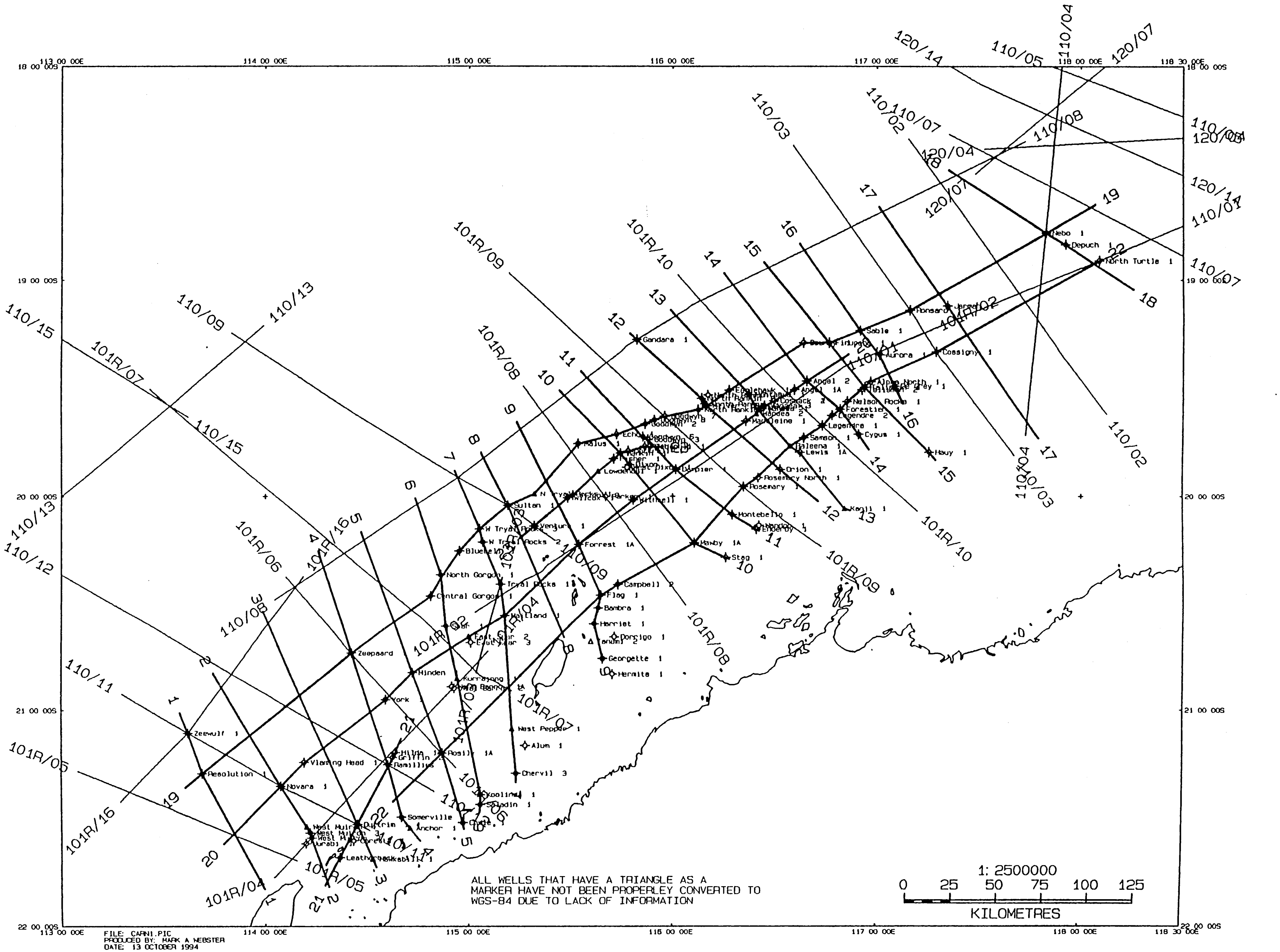



Figure 9 - Proposed seismic lines, well locations, and existing AGSO deep seismic surveys