PETROLEUM SYSTEMS OF THE EASTERN MARGIN OF THE ENDERBY TERRACE, DAMPIER SUB-BASIN, CARNARVON BASIN

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Abstract

This study examines the petroleum systems in the eastern part of the Dampier Sub-Basin - bounded by the Lewis Trough to the north and the coastline of Western Australia to the south. In particular it concentrates on Strike Oil's blocks WA-261-P, WA-340-P, TP/19 and EP 421. Key seismic horizons – the Aptian Unconformity, the Base Createaceous Unconformity, the top of the Mungaroo Formation and the top of the basement were mapped across the study area.

Geochemical analysis of oils and condensates in the area has concluded they have come from the *W. spectabilis* interval of the Dingo Claystone. Existing maturity studies were augmented by basin modelling of wells near to the acreage. It was determined that this source interval only reaches sufficient depths for significant petroleum generation in the area of the Lewis Trough, so long range migration is required to charge the area of interest.

Throughout the study area several reservoirs have been identified including the *M. australis* Sand, Neocomian Sands, Legendre Formation, Intra Athol Sands, Mungaroo Formation and the Base Locker Sand. All of these, with the exception of the Legendre Formation, are thought to be present in Strike Oil's blocks. The Muderong Shale, the Athol Formation and the Locker Shale are all potential seals within the acreage. There are potential traps within the lower Cretaceous and the Athol to Mungaroo Formations with some potential for additional Base Locker Sand plays.

The presence of fluorescence and hydrocarbon shows encountered in wells throughout the study area proves that there has been migration through these areas. Migration has occurred at lower Cretaceous, Jurassic and Triassic levels. Potential migration pathways from the source kitchen to Strike Oil's blocks have been identified and there is evidence of migration at Jurassic levels over long distances.

There is considerable uncertainty as to the presence of all of the petroleum system components in blocks WA-261-P, WA-340-P, TP/19 and EP 421 and any drilling in the area would be high risk. The petroleum component with the greatest uncertainty appears to be the presence of a migration pathway. It is recommended that a 2D or 3D basin model is constructed to investigate this further.

Statement of Confidentiality

Due to a confidentiality agreement between Strike Oil and the Australian School of Petroleum, this thesis is not available for public inspection or borrowing until 13th November 2008.

Acknowledgements

I would like to thank the staff of Strike Oil for allowing me carry out this project and providing me with the relevant data. In particular I would like to thank Rob Weeden and Glenn Simon for all their help and advice.

I am also grateful to the staff of the ASP especially my project advisor Peter Tingate. I would also like to thank Andy Mitchell for advice in regards to my seismic data and Ian West for all his technical help.

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1. Introduction

1.1 Background

The Dampier Sub-Basin is part of the Northern Carnarvon Basin *(Figure 1.1)*. The Northern Carnarvon Basin together with the Offshore Canning, Browse and Bonaparte Basins make up the area known as the North West Shelf of Australia. The area of interest for the project is the eastern flank of the Sub-Basin - bounded by the Lewis Trough to the north and the coastline of Western Australia to the south.

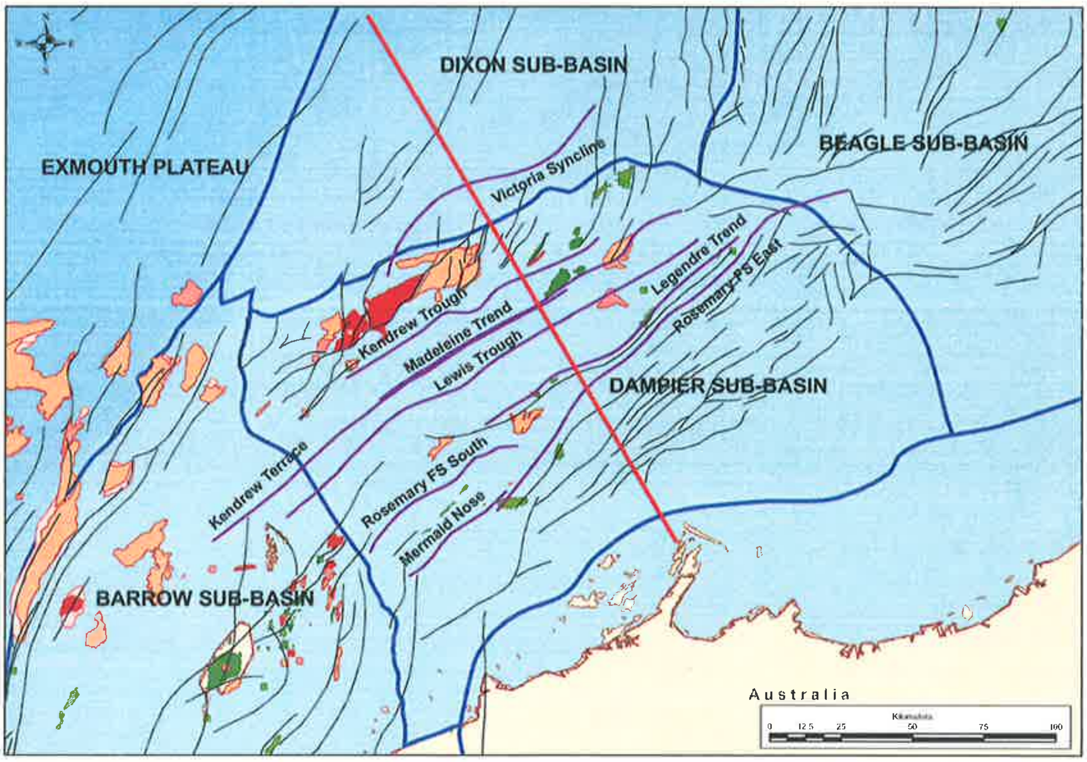

Figure 1.1: Map showing the location of the Dampier Sub-Basin within the Carnarvon Basin (from Marshall et al, 2006). The red line shows the location of the cross section in Figure 2.1.

The first well drilled in the study area was Legendre 1 in 1968. The oil found was not commercial at the time but it encouraged exploration in the area. The first major discovery in the Dampier Sub-Basin was North Rankin 1 in 1971, north of the study area. In the 1980s exploration activity increased resulting in the discovery of the Talisman oil field. In 1991 Wandoo 1 discovered the first oil on the Enderby Terrace. This was followed a couple of years later by the discovery of the Stag Oil Field. The 90s also saw the re-evaluation of earlier discoveries on the Legendre Trend resulting in the discovery of the Reindeer and Corvus Gas Fields *(Geoscience Australia, 2006)*.

Historically the economic success rate for drilling in the eastern part of the Dampier Sub-basin has been around 8%. This is relatively poor when compared to the whole Sub-Basin (22%) and the entire North West Shelf (12%) *(Thomas et al, 2004)*.

1.2 Aims

This study aims to take an integrated petroleum systems approach to the eastern margin of the Dampier Sub-Basin to reduce the risk of drilling in the area. In particular it will focus on the blocks WA-261-P, WA-340-P, TP/19 and EP 421 which are the project sponsor Strike Oil's interests in the area.

This study will define key reservoirs, seals, source rocks and migration pathways using wireline logs, biostratigraphy, source rock analyses, basin modelling and seismic data in the Cretaceous, Jurassic, Triassic and Permian sections of the Enderby Terrace.

It is commonly agreed that to have an effective petroleum system the following elements must be in place:

1. Source
2. Reservoir
3. Seal
4. Trap
5. Migration Pathway

Therefore for any play to be successful it must have all of these elements present. This project will look at each of these factors in turn to evaluate whether a valid petroleum system is present for Strike Oil's blocks WA-261-P, WA-340-P, TP/19 and EP 421.

2. Geological Background

2.1 Structure of the Dampier Sub-Basin

The Dampier Sub-Basin is part of the Northern Carnarvon Basin which itself is part of the area known as the North West Shelf. It is bordered to the north-east by the Beagle Sub-Basin and to the south-west by the Barrow Sub-Basin.

The Dampier Sub-Basin is a north-east trending feature which can be divided into several components as shown in *Figure 2.1*. The Enderby Terrace (sometimes known as the Enderby Trend) is the main area of interest for this project. It is a terrace with relatively shallow basement which consists of several, predominantly south-east dipping listric growth faults. Movement on these is thought to have occurred between the Permian and the Middle Jurassic (with most movement during the Early Triassic) *(Woodside Offshore Petroleum, 1988)*. To the north-west is the Legendre Trend – an anticlinal structure that is the location for most of the hydrocarbon accumulations in the study area. Beyond this is the Lewis Trough - a south-west plunging asymmetric syncline that forms the main depocentre of the Dampier Sub-Basin.

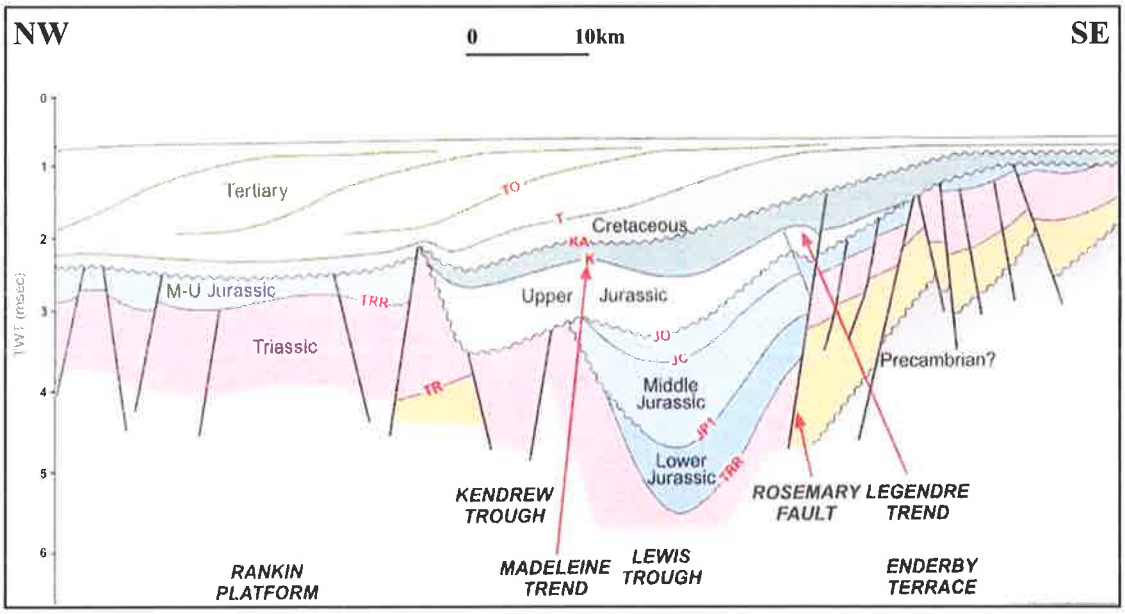

Figure 2.1: Cross section of the Dampier Sub-Basin showing structural components – location shown as red line in Figure 1.1 (altered from Thomas et al, 2004).

2.2 Geological History

According to *Kopsen & McGann (1985)* the Carnarvon Basin area was initially formed during the Palaeozoic to Triassic as a complex intra cratonic basin. A series of aborted rift valley sub-basins and platforms developed later. The structural and depositional history of the basin was largely controlled by the episodic break up of Gondwana and the eventual separation of India from Australia during Valangian time *(Thomas et al, 2002)*. The generalised stratigraphy of the Dampier Sub-Basin is shown in *Figure 2.2* on page 6.

Palaeozoic

The pre-Mesozoic tectono-stratigraphic evolution of the Dampier Sub-Basin is not well understood. The oldest sedimentary rocks which have been penetrated in the basin are Permian *(Woodside Offshore Petroleum, 1988)*. The Palaeozoic sediments appear to be fluvio-deltaic clastic sediments deposited in a series of north trending half grabens *(Thomas et al, 2002)*.

Triassic

The Triassic began with a widespread marine transgression resulting in the deposition of the Basal Locker Sand unconformably on the older rocks. As the transgression proceeded most of the basin became submerged by outer shelf to bathyal waters resulting in the deposition of the Locker Shale *(Kopsen & McGann, 1985)*. The Locker Shale grades into the Mungaroo Formation representing a slow drop in relative sea levels with fluvial to marginal marine rocks found near the top of the formation *(Woodside Offshore Petroleum, 1988)*.

Jurassic

The Early Jurassic to Neocomian was a period of increased tectonism in the Dampier Sub-Basin. This is reflected by more stratigraphic variability and fault controlled depositional environments than had previously been seen *(Kopsen & McGann, 1985)*. The North Rankin Formation at the base of the Jurassic represents nearshore and shoreline facies *(Woodside Offshore Petroleum, 1988)*. There was a major marine transgression during the Pliensbachian which was related to the initial stages of rifting in the Dampier Sub-Basin *(Thomas et al, 2004)*. The Dingo Claystone was deposited in a deepening marine environment – this resulted in a widespread shale deposition across much of the Northern Carnarvon Basin. The only exception was in the north-east where a thick deltaic wedge, the Legendre Formation, was deposited *(Kopsen & McGann, 1985)*. By the end of the Middle Jurassic the regression was at its maximum extent and the only place which was under marine conditions was the rapidly subsiding Lewis Trough *(Woodside Offshore Petroleum, 1988)*. Widespread deposition of shallow marine sands (such as the Angel Formation) took place during the Tithonian *(Woodside Offshore Petroleum, 1988)*.

Cretaceous

The Jurassic succession is unconformably overlain by Berriasian Sands. In the area surrounding Rosemary 1 and Rosemary North 1 they take the form of submarine fan deposits. However, near the Legendre and Talisman Fields, marine shelf and deepwater turbidite clastics were deposited *(Woodside Offshore Petroleum, 1988).* During the upper Valanginian there was a sea level rise causing a major transgression which resulted in the deposition of the Muderong Shale. During this time there were periods of low relative sea level resulting in the deposition of sands such as the *M. Australis* sand. In some localities there was deposition of the Birdrong Sandstone and the Mardie Greensand which were time equivalent to the Muderong Shale. These were deposited in littoral to sub-littoral and mid to outer shelf environments respectively *(Woodside Offshore Petroleum, 1988).* Above the Muderong Shale lies the Windalia Sandstone Member which possibly represents a minor regressive phase *(Campbell et al, 1984),* and the Windalia Radiolarite which was deposited during a rise in the sea level *(Woodside Offshore Petroleum, 1988).* After an Albian transgression a passive margin setting prevailed with deposition of marls, claystones and calcilutites deposited in outer shelf to slope environments during the upper Cretaceous *(Thomas et al, 2004).*

Tertiary

The Tertiary succession represents a period of outbuilding and upbuilding of a continental shelf during various transgressive / regressive sea level pulses. This shelf depositional setting continued until the Early Eocene. This was followed by two periods of progradation – one during the Early Oligocene and a second during the late Middle Miocene *(Thomas et al, 2004).* During the Miocene there was a period of compressional tectonism which caused movement along the Rosemary Fault System *(Thomas et al, 2004).*

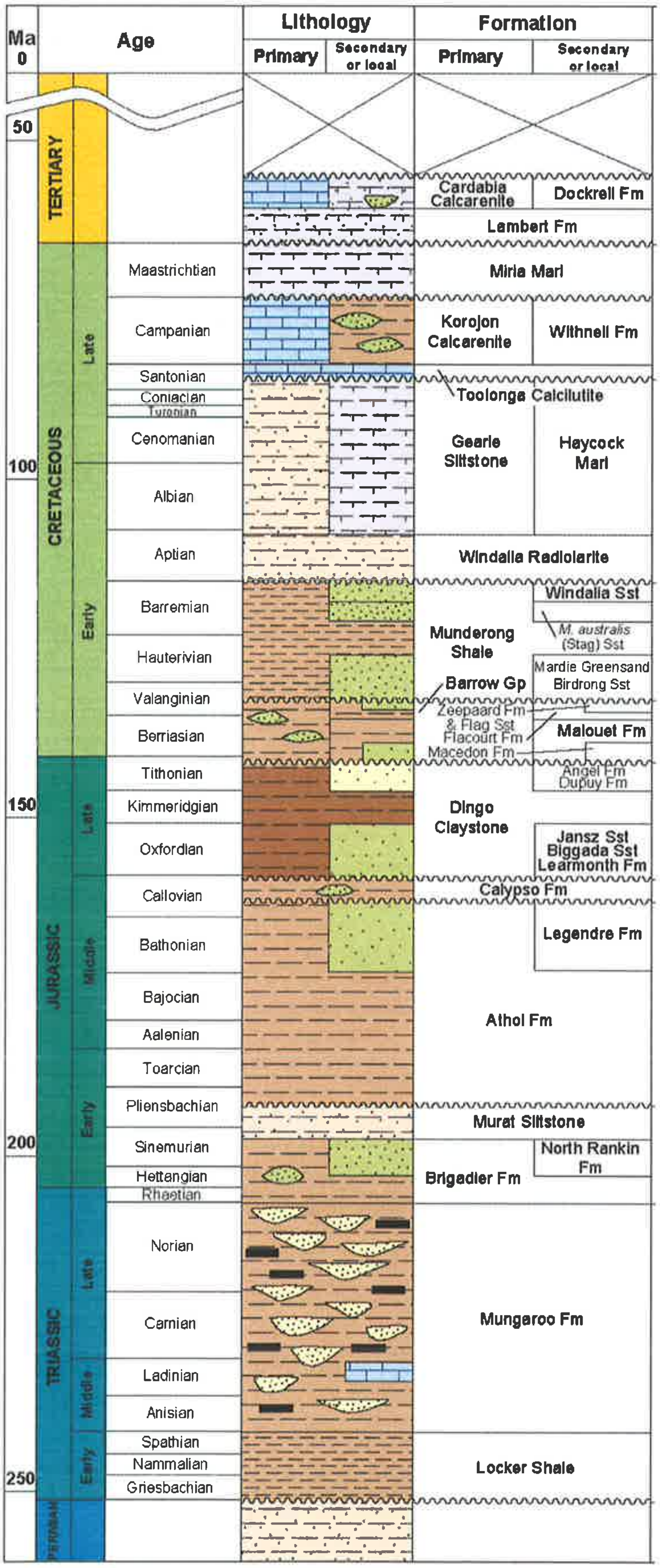

Figure 2.2: Column showing the regional stratigraphy of the Carnarvon Basin (modified from Department of Industry, Tourism and Resources, 2006)

3. Available Data & Methods

3.1 Well Data

The 98 wells used for this project are shown in *Figure 3.1*. Well completion reports were available for most and many had wireline or LWD / MWD data – the data available for each well is listed in *Appendix 1*.

3.2 Seismic Data

Figure 3.2 shows the 2D seismic data coverage. There was generally good coverage for most of the area. The base maps and seismic data used were provided by Strike Oil. A partially interpreted Base Cretaceous Unconformity horizon and several fault interpretations by Glenn Simon of Strike Oil were incorporated.

Most of the seismic lines were initially interpreted using Kingdom software. This data was later imported into GeoFrame Version 4.0.4.2 where additional interpretation was done. Maps were then produced using Petrosys Mapping Version 14.3.

Horizons were picked using formation tops from the Western Australian Petroleum Information Management System (WAPIMS) which were then checked against wireline logs and occasionally altered if necessary. These depths were input into the interpretation software and converted to two way time using time-depth curves from WAPIMS. The control wells for the various horizons are listed in the following section.

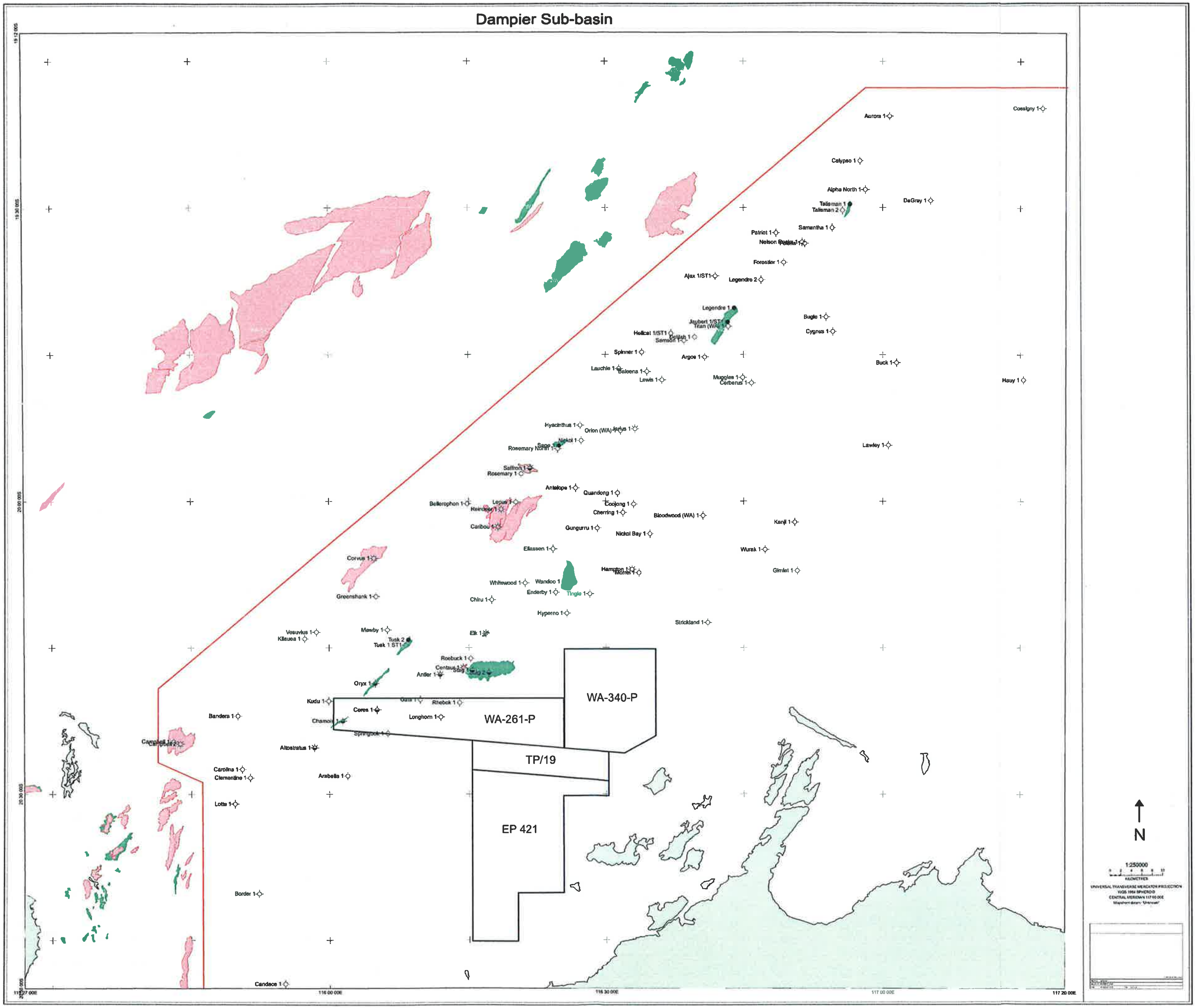

Figure 3.1: Map showing the locations of the wells used in this study and Strike Oil's relevant blocks. Red line marks the boundary of study area

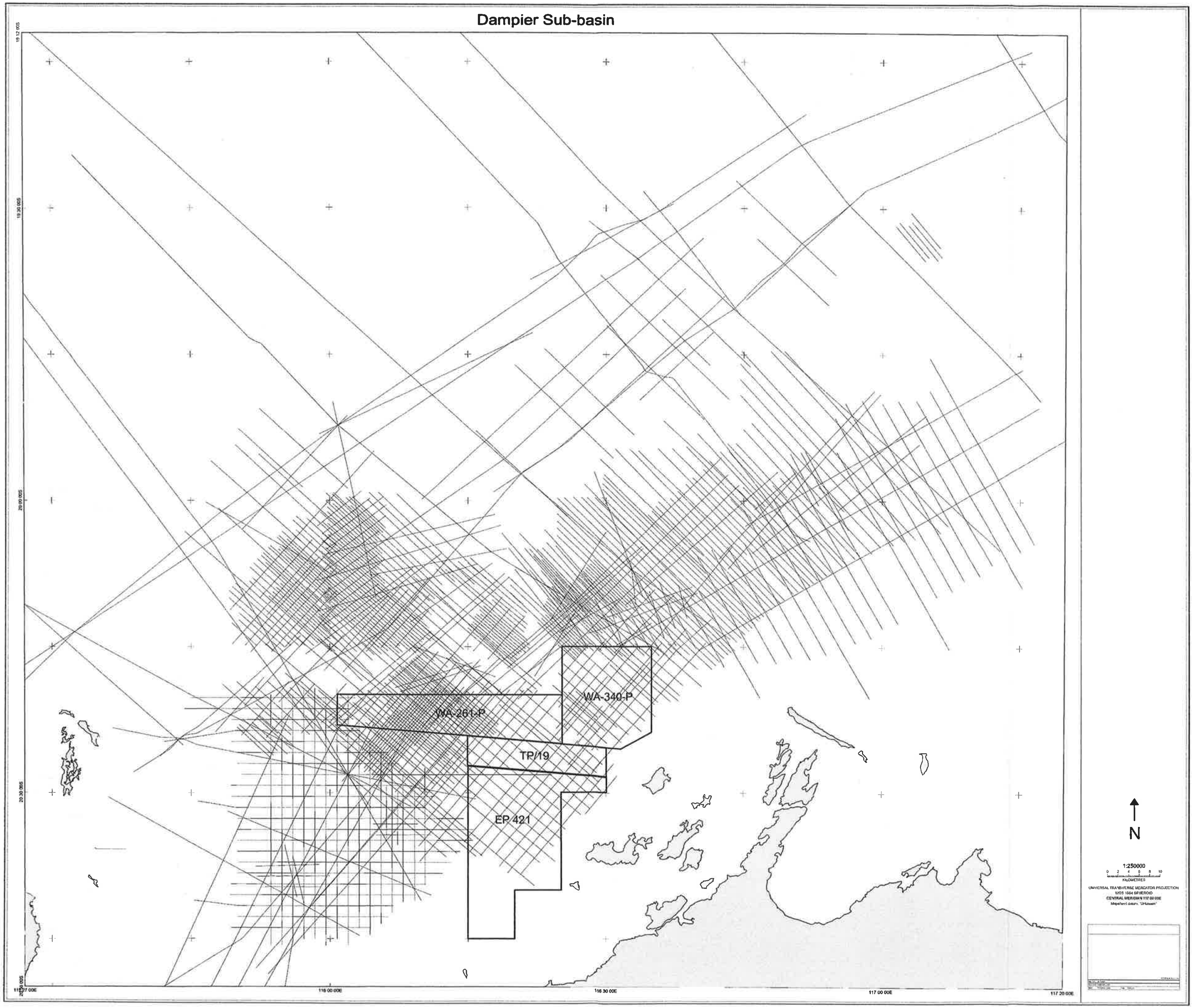

Figure 3.2: Map showing the seimic data coverage.

3.3 Horizons Interpreted

The following horizons were chosen for widespread interpretation.

Top Basement

Control well – Gimlet 1.
Red horizon on seismic cross sections.
Picked on peak (red).

This horizon was chosen for interpretation for the following reasons:

- It is relatively easy to pick on seismic due to its chaotic nature (although it gets more difficult as you go north-west.
- It is the base of the Basal Locker Sand – a potential reservoir rock.
- Units commonly onlap onto the basement at the margin of the Sub-Basin creating potential stratigraphic traps.

The TWT map for the top of the Basement is shown in *Figure 3.3.*

Top Mungaroo Formation

Control well – Rhebok 1.
Bluish grey horizon on seismic cross sections.
Picked on trough (blue).

This horizon was chosen for interpretation for the following reasons:

- It forms the top of the Mungaroo Formation - a potential reservoir.
- It forms the base of the Athol Formation – a potential seal.

Base Cretaceous Unconformity (BCU)

Control wells – All wells with WAPIMS data.
Pale green horizon on seismic.
Picked on trough (blue).

This horizon was chosen for interpretation for the following reasons:

- It is a major regional unconformity / sequence boundary.
- It is the base of the Berriasian aged sands – a potential reservoir rock.
- Can be used to identify the structure of other lower Cretaceous sands such as the M. australis sand.

The TWT map for the BCU is shown in *Figure 3.4.*

Aptian Unconformity (Top Muderong Shale)

Control wells – All wells with WAPIMS data.
Dark green horizon on seismic cross sections.
Picked on trough (blue).

This horizon was chosen for interpretation for the following reasons:

- It represents the top of the Muderong Shale which acts as the seal for many of the reservoir rocks in the study area.

The TWT map for the Aptian Unconformity is shown in *Figure 3.5.*

Additional Horizons

In addition the following horizons were picked over much smaller areas for the purpose of identifying plays:

IMH (Intra Muderong Hiatus)	Yellow
Top Locker Shale	Blue
Base Locker Sand	Pink

The extent of the interpretation varied for each horizon. The basement was limited by seismic quality – as you go outboard it becomes harder to pick. The BCU was interpreted over the widest area – stretching back towards the Lewis Trough area to enable identification of migration pathways. The Aptian was interpreted over a similar area while the Mungaroo Formation was only picked in a highly faulted area of Strike Oil's acreage which had the potential for structural traps.

3.4 TWT Maps

The TWT maps for the Top Basement, Base Cretaceous Unconformity and Aptian Unconformity are shown in *Figures 3.3* to *3.5.*

TOP BASEMENT TWT MAP

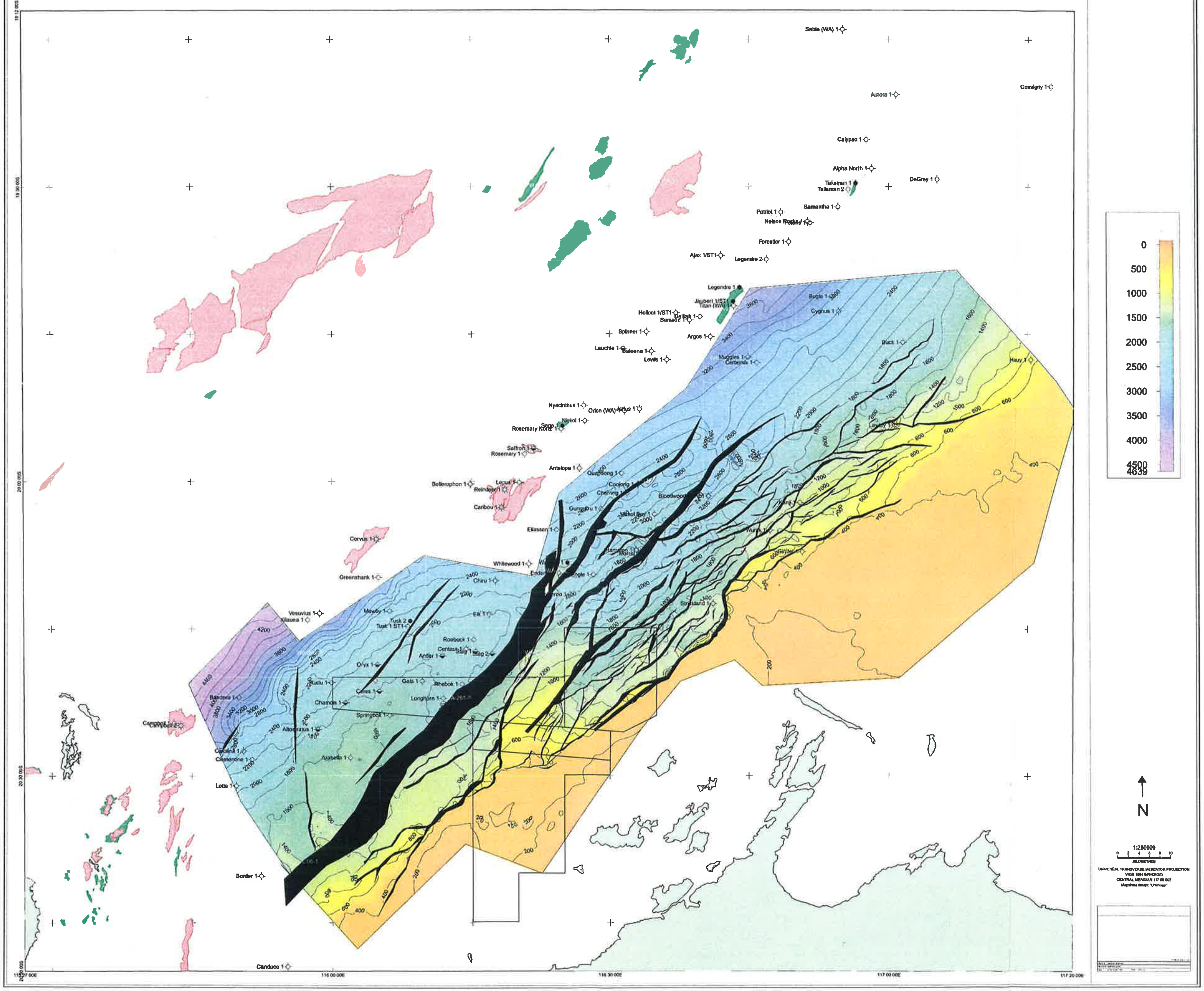

Figure 3.3: Top Basement TWT Map.

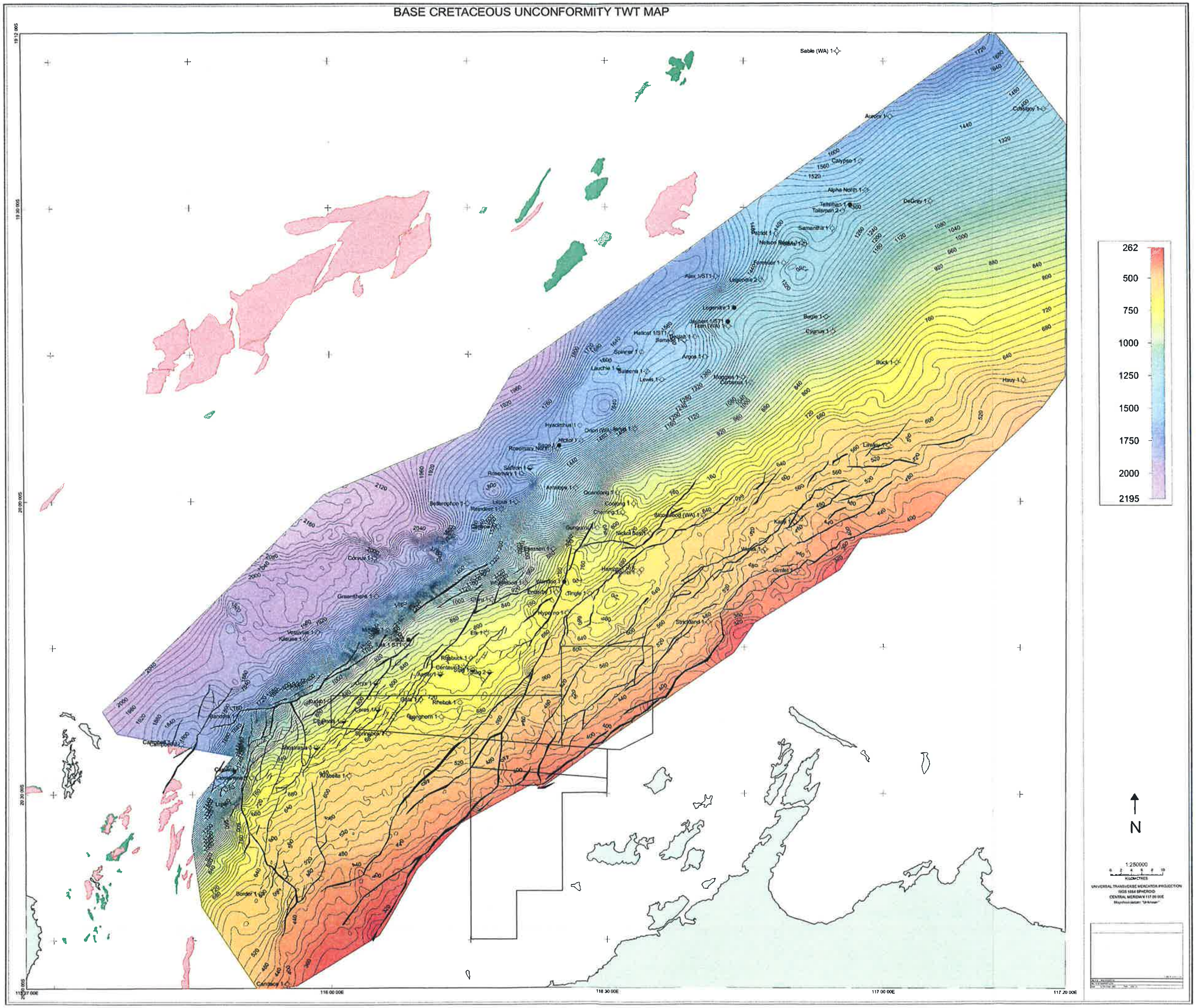

Figure 3.4: Base Cretaceous Unconformity TWT Map.

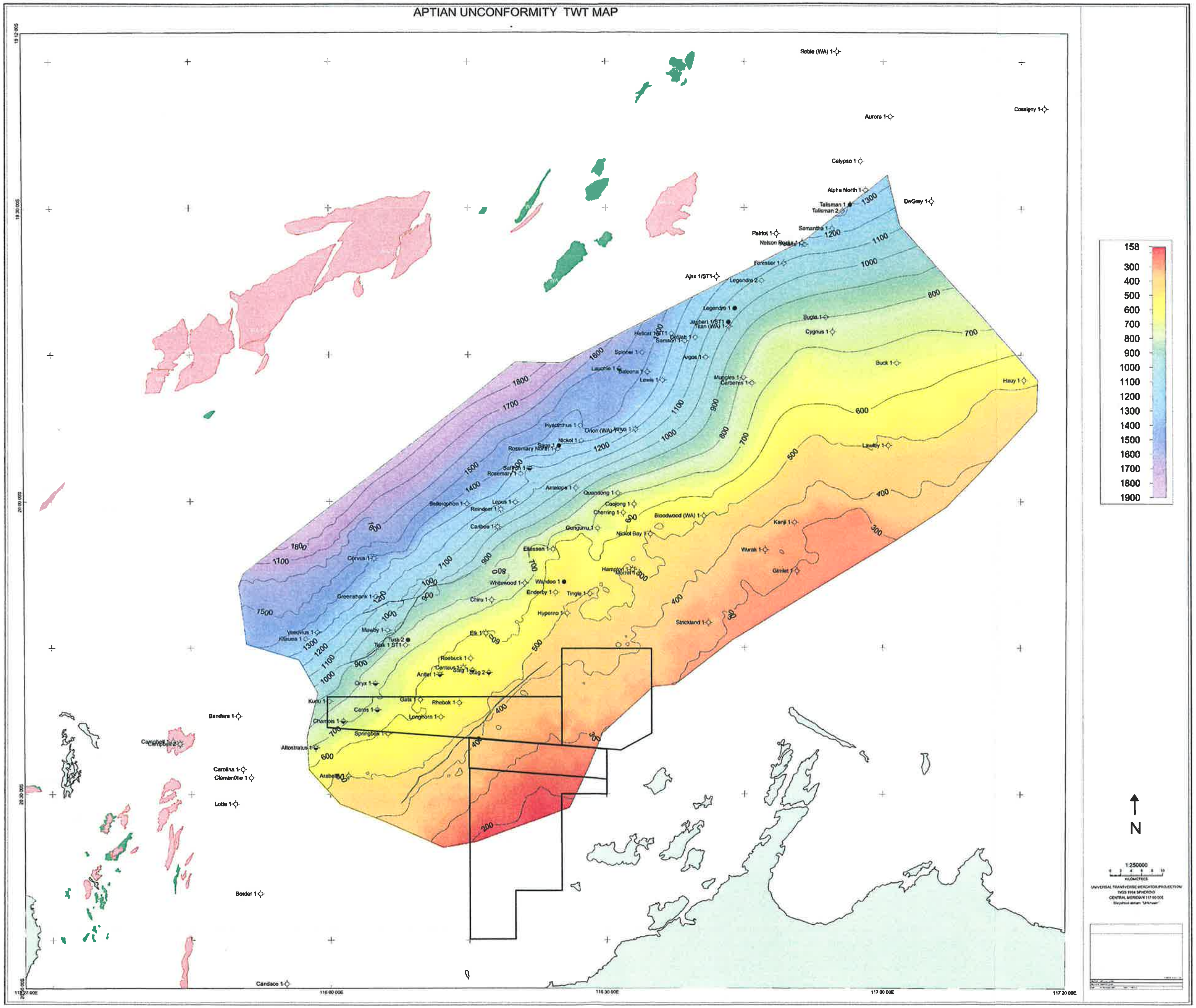

Figure 3.5: Aptian Unconformity (Top Muderong Shale) TWT Map.

3.5 Seismic Data Quality Control and Problems Encountered

Seismic data from several different surveys and acquisition years were used. Although efforts were taken during processing to ensure all data had the same phase and similar amplitudes unfortunately this was not always the case. The problems caused by this were fairly minimal. *Figure 3.6* shows several horizons at Springbok 1. Although the nature of the reflectors vary this is their most common appearance.

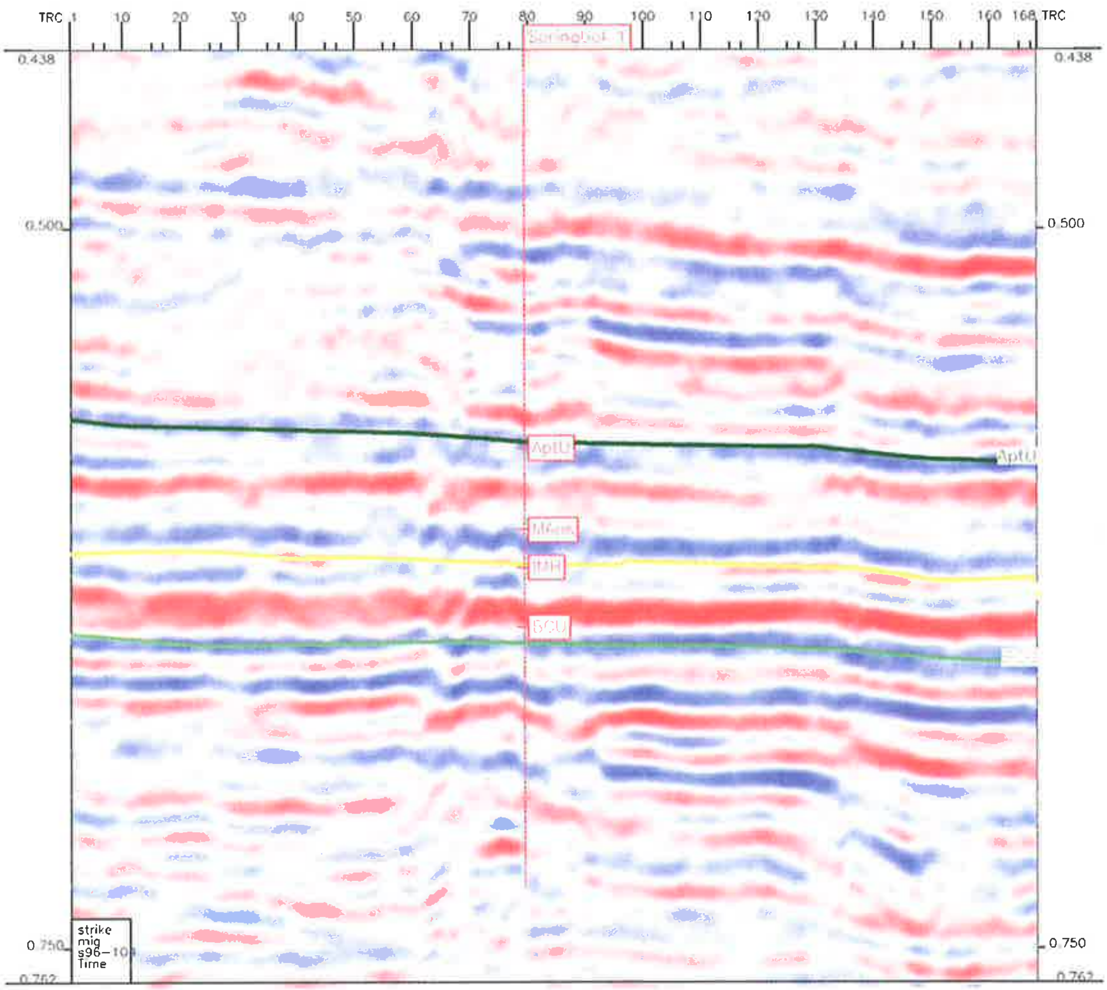

Figure 3.6: Typical seismic reflectors at Springbok 1.

The main problem encountered was the lack of control wells drilled in the area of interest (see *Figure 3.1*). Picks had to be made at nearby wells and extrapolated into the study area. Occasionally this was difficult due to the presence of faults – especially for heavily faulted horizons such as the top of the Mungaroo Formation.

The quality of the seismic interpretation was tested by doing a mistie analysis. This was conducted on four horizons - the Aptian Unconformity, the Base Cretaceous Unconformity, the Top Mungaroo Formation and the Top Basement. The general rule which was applied was that the misties must be less than half the smallest contour interval used for each horizon in order for the data to be represented accurately on a TWT map.

Aptian Unconformity – The contour interval used for this horizon was 100ms. Therefore the misties were corrected to below 50ms. The average mistie was 6.6ms. This interval is probably the least accurately interpreted. As can be seen in *Figure 3.5* there are significant problems in the area around Tingle 1, Hampton 1 and Morrel 1. Since it is not used for identification of plays or migration pathways the decision was made to spend more time on the other horizons. To reduce the effects of misties on the TWT map a moderate amount of smoothing was applied to this horizon. Four passes of a Bartlett 3 filter were used to reduce the magnitude of the anomalies.

Base Cretaceous Unconformity – The smallest contour interval used was 20ms. Unfortunately due to time constraints it was not possible to correct the misties to 10ms – instead they were corrected until they were below 25ms. To counter this problem a moderate amount of smoothing was applied to the TWT map. Four passes of a Bartlett 3 filter were used to remove any anomalies while maintaining the overall structures. The interpretation is less accurate below 1000ms and some faults in this area have not been interpreted. Therefore this section of the interpretation is only useful for giving a general idea of the structure and should not be assumed to be exact. The average mistie was 5.02ms and in general the misties become smaller the closer you get to Strike Oil's acreage.

Top Mungaroo Formation – The contour interval used for the Mungaroo Formation was 50ms. The misties were corrected to below 25ms. The average mistie value was 3.4ms.

Top Basement – The smallest contour interval used was 200ms – the misties were therefore corrected to below 100ms. However the vast majority were much lower than this with the average mistie value being 16.41ms.

4. Source Rocks

4.1 Identification of Potential Source Rocks

Before evaluating the possibility of hydrocarbons being present in the areas of interest it is important to identify the source rocks and kitchen areas for the Dampier Sub-Basin.

The source rocks are generally of poor quality and hydrocarbons from different stratigraphic levels commonly mix during migration *(Longley et al, 2002).* This makes their identification difficult. However, the presence of several oil and gas discoveries in the area means at least one valid petroleum system is in place.

It is generally agreed that there are several units which have source rock potential within the Cretaceous to Triassic interval. These are listed below.

Triassic

The Locker Shale along the eastern margin is enriched in sapropel and has oil generating potential *(Woodside Offshore Petroleum, 1988). Robertson Research (1986)* identified that the Locker Shale contains local oil prone sources at its base (within the deeper water facies). It is likely to have TOC values of 1-2.5%.
The Mungaroo Formation has predominantly inertinitic kerogen and is more gas prone. TOC values are generally 0.5-1.5% but some shales approach 10% *(Robertson Research, 1986).*

Jurassic

Jurassic beds are the most important hydrocarbon source rocks in the Dampier Sub-Basin. The Lower to Middle Jurassic Murat Siltstone, Athol and Legendre Formations are oil and gas prone with TOC values of 1-3% *(Kaiko, 1998).* The Dingo Claystone is more oil prone. It ranges from Type II/III to Type III kerogen *(Scott, 1992).*

Cretaceous

The Muderong Shale had previously been thought of as immature, however, *Kaiko (1998)* identified these rocks are locally more mature than previously thought. The Muderong has TOC values of 1-4% *(Kopsen & McGann 1985).* Post Muderong sediments are considered to be immature.

4.2 Maturity Study

Previous work had been done by *Kaiko (1998)* creating burial histories and maturity information for several wells in the Barrow and Dampier Sub Basins. This study included the wells Sable 1, DeGrey 1, Talisman 2, Legendre 1, Legendre 2, Hauy 1, Lewis 1A, Rosemary 1, Hampton 1, Enderby 1, Arabella 1 and Candace 1 as well as a couple of synthetic wells which are located within this projects area of scope. This study is looked at in more detail in *Section 4.4*. Sufficient data for 1D basin modelling was available for 4 additional wells - Aurora 1, Corvus 1, Oryx 1 and Janus 1, which had not been covered by previous studies. The decision was made to create basin models for these wells in order to expand *Kaiko's* study and to compare the results.

In order to create burial histories for these wells, information from their well completion reports was used. Vitrinite reflectance (Ro) values, formation tops, water depths and corrected bottom hole temperatures (BHTs) were input into Basin Mod 1D Version 3.15 (Platte River Associates Inc.).

Aurora 1 – *Figures 4.1 and 4.2*
Seven vitrinite reflectance values were used from the Muderong Shale to the Legendre Formation. The corrected BHT value of 104.4°C was extrapolated with a Horner Plot using temperature readings and time since circulation data from the well completion report *(Marathon Petroleum Australia Ltd., 1991).*

Corvus 1 – *Figures 4.3 and 4.4*
Twelve vitrinite reflectance values were used from the Lower Muderong Shale to the Mungaroo Formation. A value of 150.1°C was used for the BHT which had been previously corrected using a Horner Plot and was taken from the well completion report *(Apache Energy Ltd., 2000).*

Janus 1 – *Figures 4.5 and 4.6*
Four vitrinite reflectance values were used from the Dingo Claystone to the Legendre Formation. The BHT value of 99.4°C from the well completion report *(Apache Northwest PTY Ltd., 2000)* was used which had been corrected in the well completion report by adding 10% to compensate for changes in temperature since circulation stopped.

Oryx 1 – *Figures 4.7 and 4.8*
Five vitrinite reflectance values were used from the Athol Formation to the Mungaroo Formation. The BHT value of 86.6°C from the well completion report *(Apache Northwest PTY Ltd., 2004)* was used which had been corrected in the well completion report by adding 10% to compensate for changes in temperature since circulation stopped.

The Ro values used for the oil window were those as defined by Basin Mod - 0.5 to 0.7% was defined as early mature for oil generation, 0.7 to 1.0% was mid mature and 1.0 to 1.3% was late mature for oil generation.

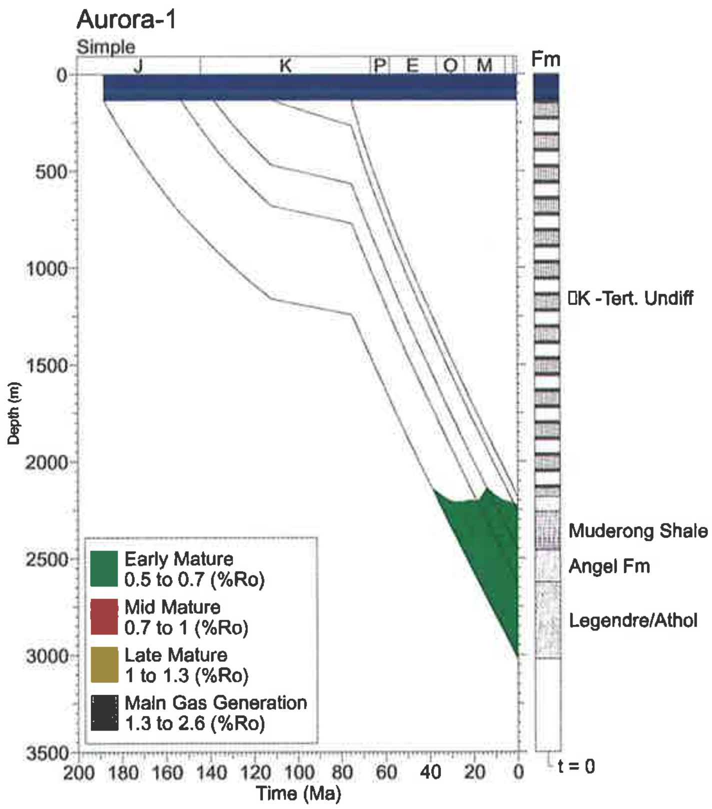

Figure 4.1: Simple burial history plot for Aurora 1

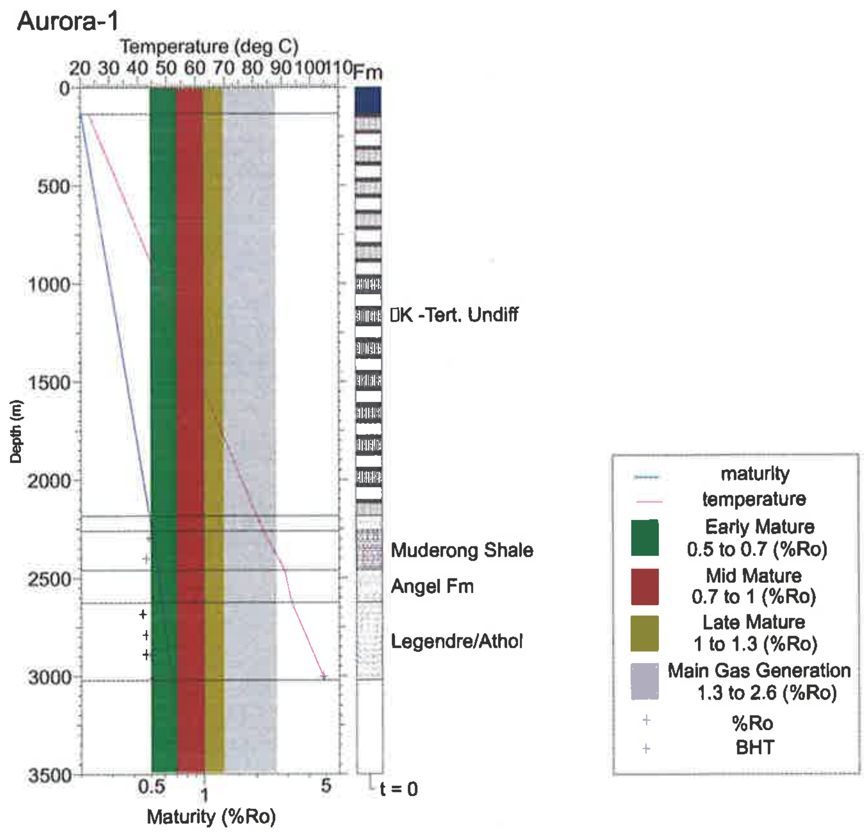

Figure 4.2: Temperature and Maturity / Depth Plot for Aurora 1

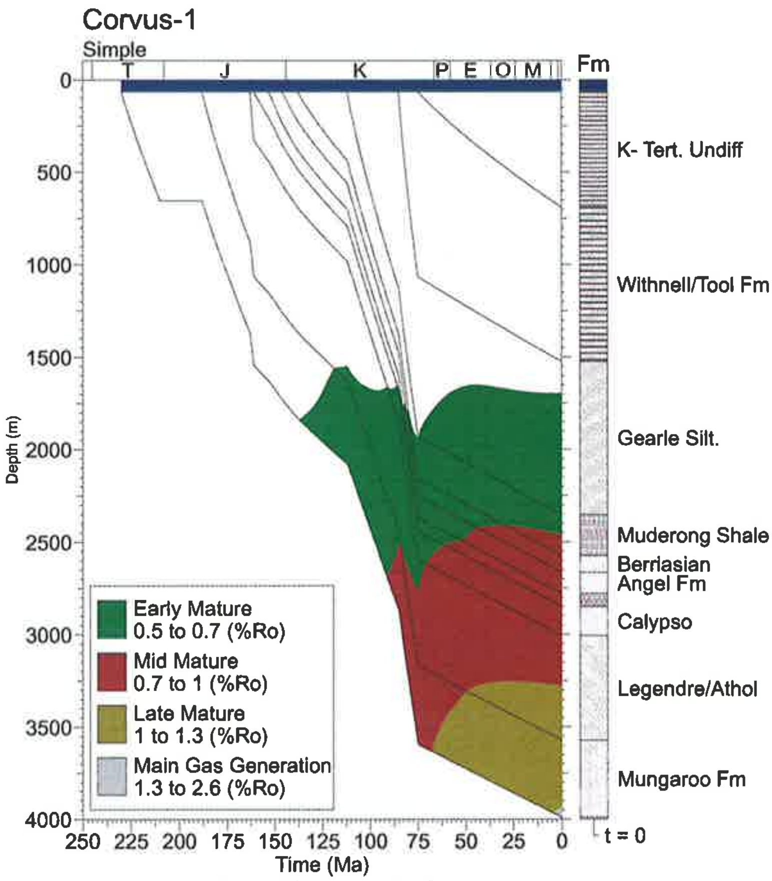

Figure 4.3: Simple burial history plot for Corvus 1

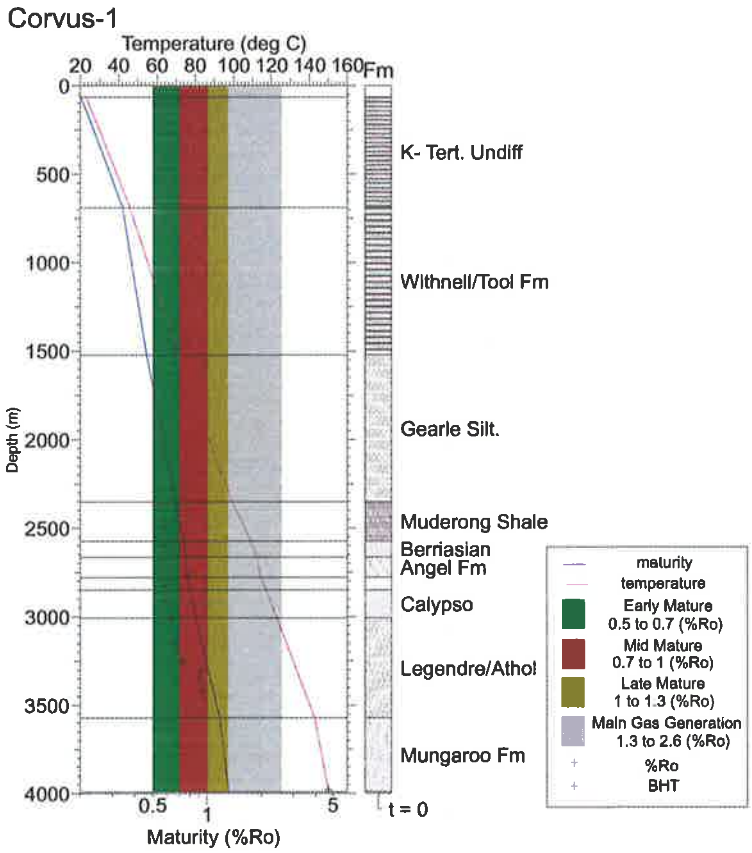

Figure 4.4: Temperature and Maturity / Depth Plot for Corvus 1

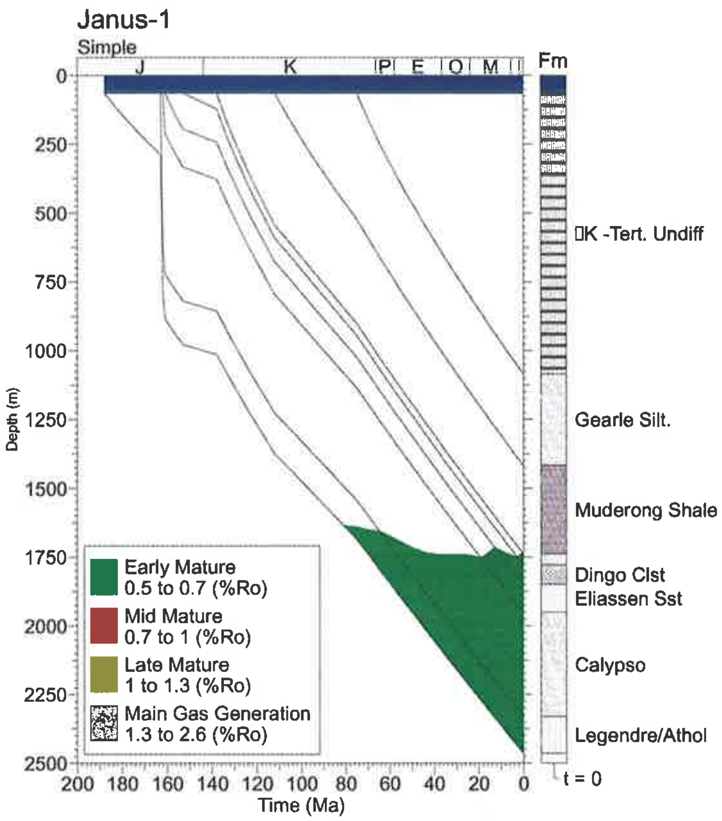

Figure 4.5: Simple burial history plot for Janus 1

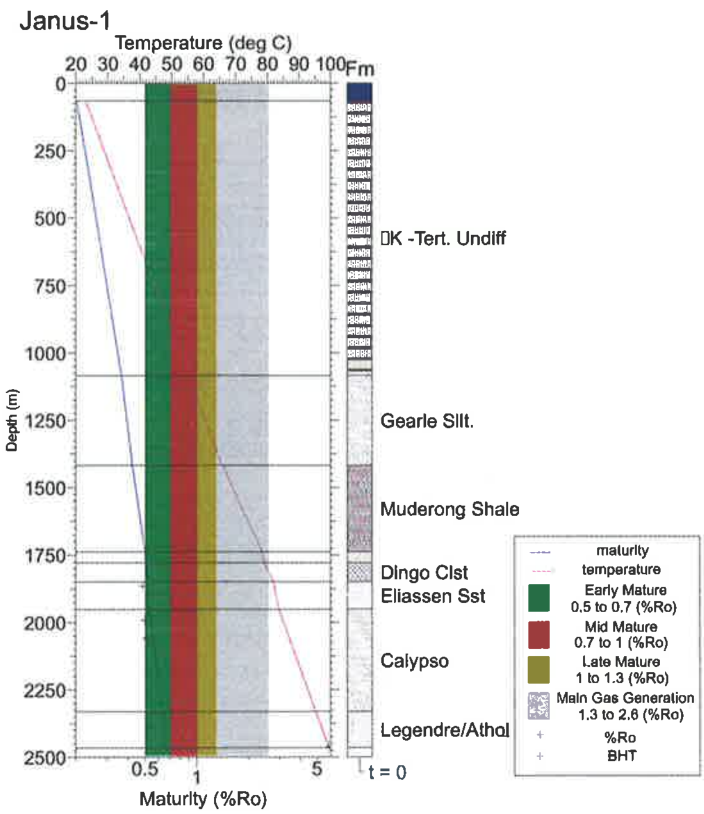

Figure 4.6: Temperature and Maturity / Depth Plot for Janus 1

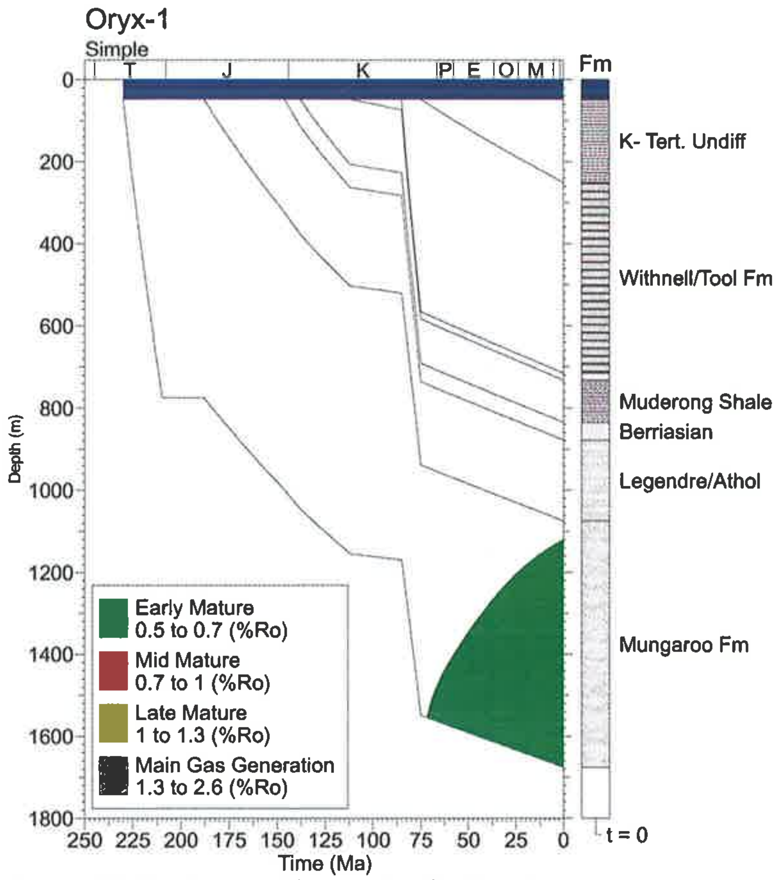

Figure 4.7: Simple burial history plot for Oryx 1

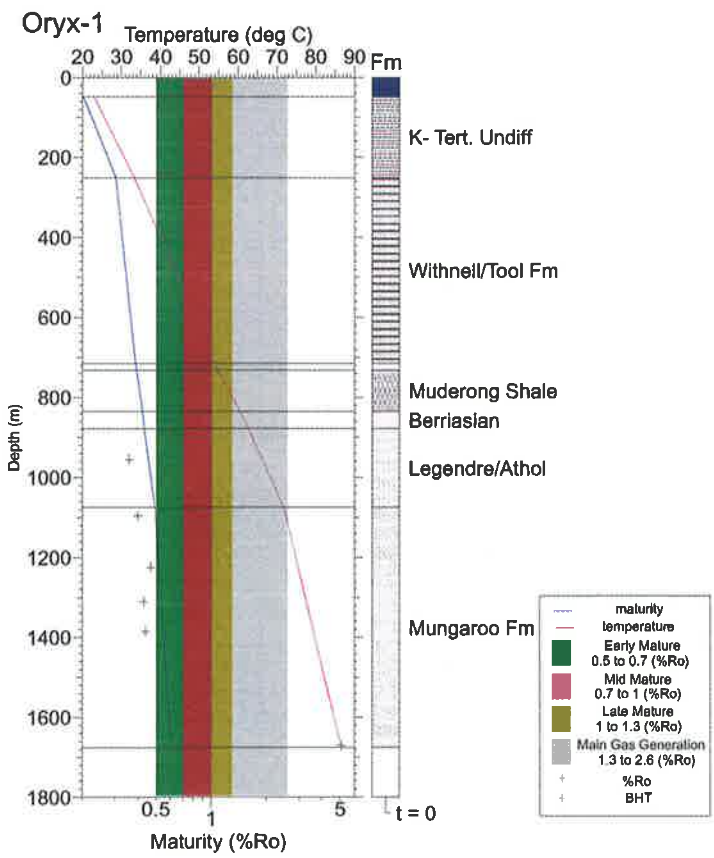

Figure 4.8: Temperature and Maturity / Depth Plot for Oryx 1

Discussion of Results

The burial history plots and temperature and maturity / depth plots for the 4 wells examined in this study are shown in *Figures 4.1 to 4.8.*

The calculated Ro for all four wells were consistently above the measured Ro. This is the same phenomenon which *Kaiko (1998)* encountered. The most likely reason for this is vitrinite suppression. This occurs in marine formations such as the Legendre Formation due to maceral misidentification and / or chemical suppression of vitrinite - something that has been widely recognised to occur in the Dampier Sub-Basin *(Kaiko, 1998).* However, the vitrinite reflectance appears to show that the rocks at these wells have undergone a simple burial history and are currently at their maximum temperature. This is consistent with the findings of *Kaiko (1998)* who determined that with the exception of Candace 1, Hauy 1 and DeGrey 1 all the wells analysed within the study area were currently at their maximum temperatures.

There appears to be some anomalies in the Ro values for the Mungaroo Formation at Oryx 1. They appear to be suppressed but the lithology is described as being fluvial which makes suppression unlikely. However because the lithologies only reach early maturity this does not have much effect on the overall results.

The results show that Janus 1, Oryx 1 and Aurora 1 only reach the early mature oil generation stage. However the lithologies at Corvus 1 have oil generation potential – becoming Mid-Mature from approximately 100Ma with the Mungaroo Formation becoming late mature at approximately 70Ma and the Legendre at 50Ma. This suggests that the wells nearest the shoreline have not produced sufficient volumes of hydrocarbons to be economically viable and that it is necessary to look at migration over a larger area. Corvus 1 sits on the edge of the Lewis Trough and has been buried to greater depths.

4.3 Source Rock Geochemistry

The eastern Dampier Sub-Basin liquids have few distinguishing biomarker features. A study by *Thomas et al (2004)* revealed that they derive from marine source rocks containing mixed Type II/III kerogen and display varying degrees of marine / terrestrial affinity. *Thomas et al (2004)* took samples of cuttings and crude oils / condensates for several wells within the study area and correlated them using GC-MS. The conclusion was that the oils and condensates from Saffron 1, Sage 1, Forestier 1 and the Legendre and Talisman Fields are probably sourced from the *W. spectabilis* interval within the Dingo Claystone. *Thomas et al (2004)* conclude that the source kitchen for these accumulations is in the Lewis Trough however it is probable that the oil from the Talisman Field may have migrated from the Angel Field after being displaced by gas.

It is therefore likely that any hydrocarbons discovered in the blocks studied for this project will be sourced from this interval.

4.4 Identification of Source Rock Kitchens and Timing of Expulsion.

Figures 4.9 to 4.12 summarise the findings of a study by *Kaiko (1998).* These maps show the maturity of the W. spectabilis interval at various time periods. In addition the two wells from this study which intersected the Dingo Claystone (Corvus 1 and Janus 1) have been added. The Ro values from these two wells appear to closely match *Kaiko's* findings. The maps show that the wells closest to Strike Oil's block do not reach sufficient maturities to produce large amounts of hydrocarbons and that it is necessary to look for long range migration pathways from the Lewis Trough where the sediments reach greater burial depths.

3D basin modelling by *Thomas et al (2004)* revealed that Oxfordian oil expulsion (including the *W. spectabilis* interval) was significantly higher during the first half of the Tertiary (65-32Ma) than the second half (32-0Ma). Any hydrocarbons generated before the Tertiary were thought by *Thomas et al (2004)* to have been lost or biodegraded.

4.5 Local Generation from Triassic Sediments?

The wells studied for this project, and those studied by *Kaiko (1998)* generally do not reach sufficient depths to evaluate the source potential of the Triassic sediments such as the Locker Shale. To investigate the possibility of local oil generation from this formation the well completion report for Arabella 1 which is about the same distance away from the source kitchen as Strike Oil's blocks was investigated. According to the well completion report *(Australian Occidental Petroleum, 1983)* the Mungaroo Formation and the Locker Shale had fair organic richness with TOC values ranging from 0.57 to 0.90%. The Mungaroo Formation was classed as immature and the Locker Shale was classed as immature from 1480 to 1510m and moderately immature between 1530 and 1850m. This means that extensive local hydrocarbon generation is unlikely.

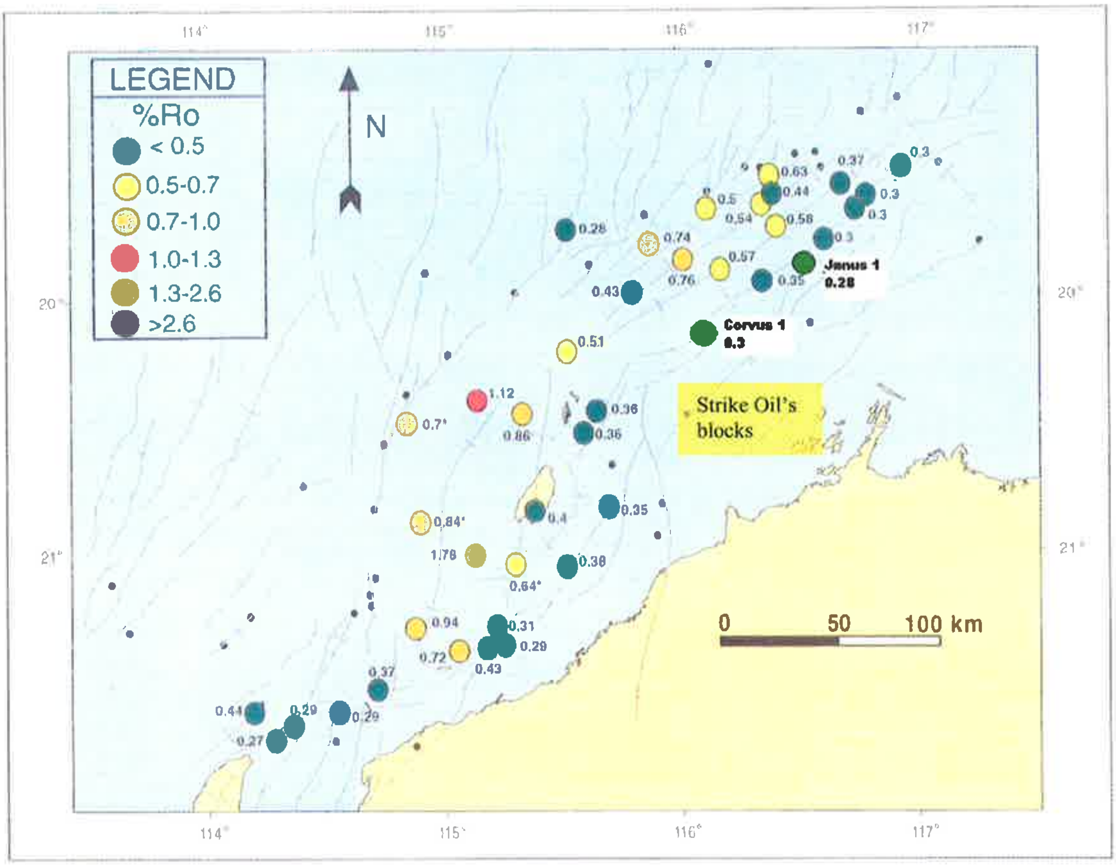

Figure 4.9: %Ro for the W. spectabilis dinoflagellate zone at 135 Ma (modified from Kaiko 1998).

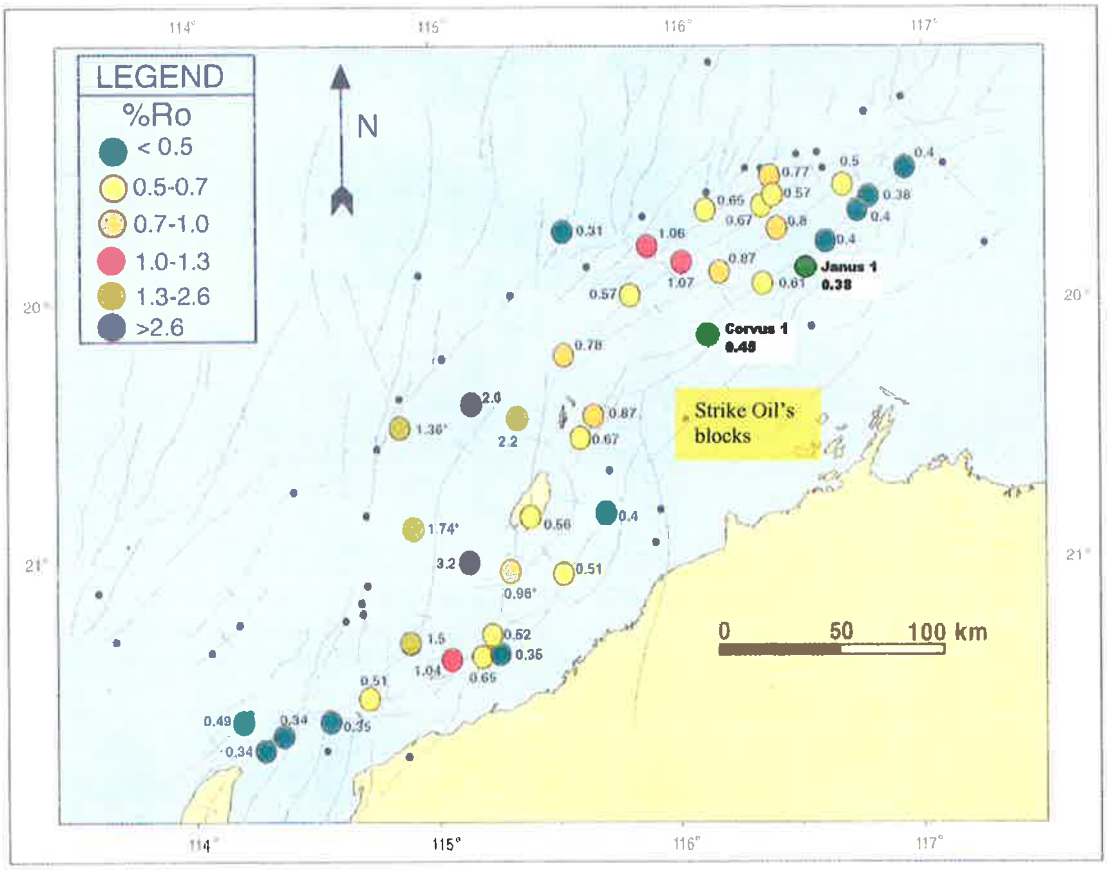

Figure 4.10: %Ro for the W. spectabilis dinoflagellate zone at 87 Ma (modified from Kaiko 1998).

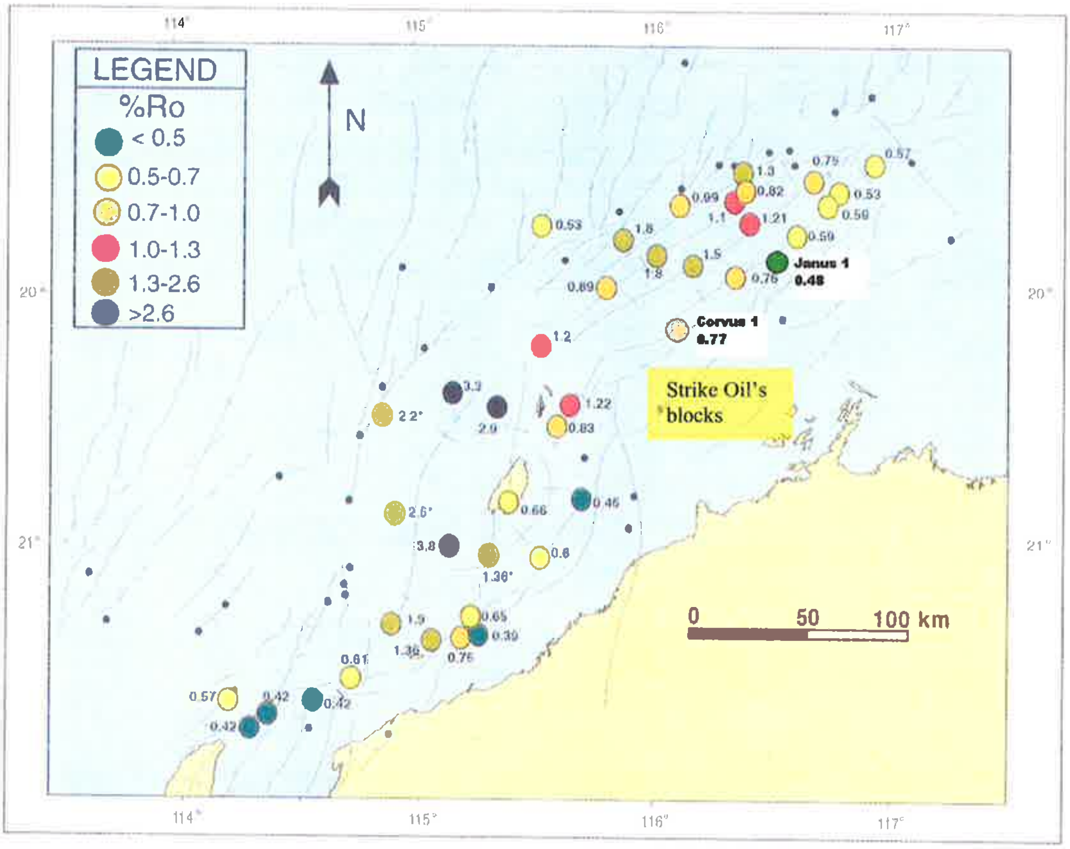

Figure 4.11: %Ro for the W. spectabilis dinoflagellate zone at 15Ma (modified from Kaiko 1998).

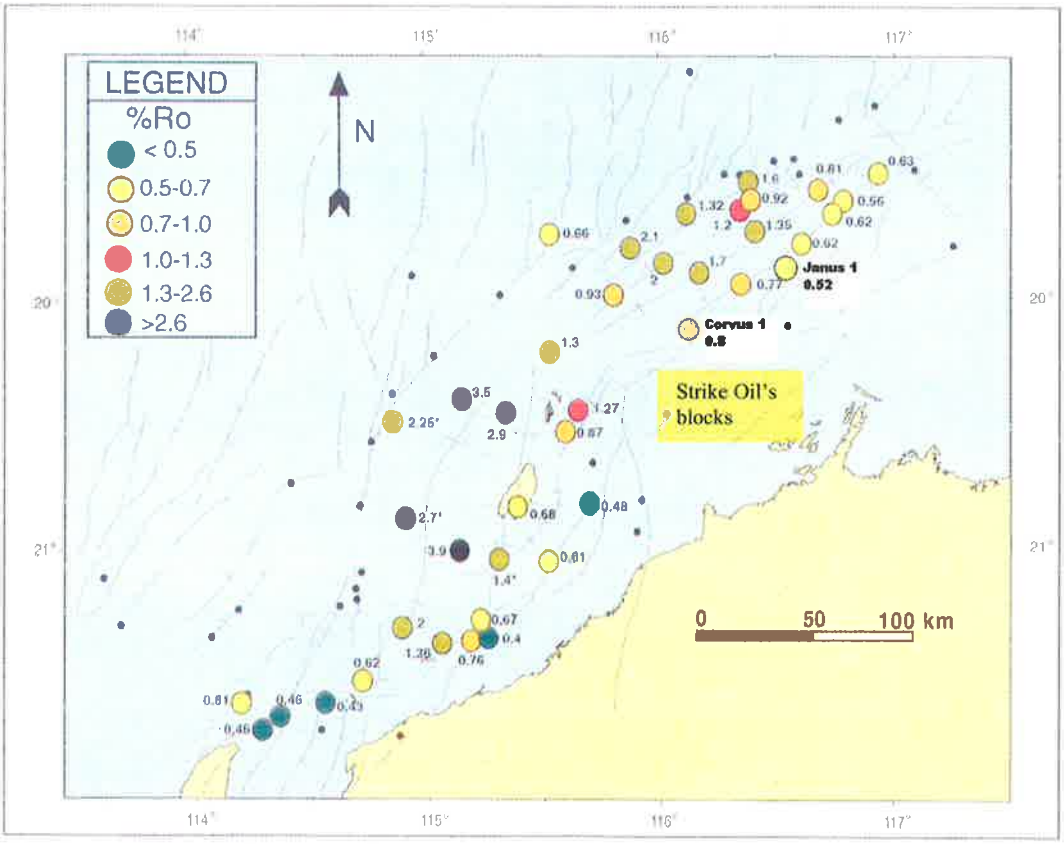

Figure 4.12: %Ro for the W. spectabilis dinoflagellate zone at 0 Ma (modified from Kaiko 1998).

5. Reservoirs and Seals

5.1 Overview & Methodology

In order to identify possible reservoir and seal pairs, well completion reports (as listed in *Appendix 1*) were examined. Reservoir targets and hydrocarbon accumulations were noted and the findings were summarised in *Table 1* along with the trap types at each well. This indicates that there are complete, working petroleum systems at these locations including valid reservoirs. These discoveries are discussed in more detail in *Sections 7.4* to *7.6* along with shows and fluorescence which are not listed in this table.

Well	Hydrocarbons Present	Formation / Age	Trap Type
Altostratus 1	Residual oil, strong gas peak	M. australis	Downthrown, terraced fault bound structural trap.
	3m gas column	Mungaroo	Upthrown fault bound closure with an element of 4 way dip closure.
Antler 1	2.4m of gas overlying 1.4m of oil	M. australis	Small four way dip closed anticline with potential stratigraphic component.
Campbell 2	Gas and minor oil	Dingo (Dupuy Member)	Broad, low relief anticline.
Caribou 1	Gas. Oil shows	North Rankin / Brigadier / Mungaroo	Large N-S trending tilted fault block and horst complex.
	21.6m gas column, poor oil shows	Legendre	
Centaur 1	4.5m gas column over 1m oil leg	M. australis	Fault dependent closure.
Chamois 1	Gas	M. australis	Closure from M. australis to Mungaroo Fm by dip to N, W & S and fault dependent closure to SE
	Residual oil (live oil column identified)	Athol (C. Halosa)	
Cherring 1	Dry Gas	M. australis	4 way dip closure.
Corvus 1	Gas column	North Rankin / Mungaroo	Complexly faulted structure. Dip closure to N and W, fault dependent closure to E and S.
Elk 1	2.2m dry gas column	M. australis	Small 4 way dip closure with stratigraphic enhancement.
Jaubert 1	Oil	Berriasian	Low relief dip closed anticline.
Janus 1	4.2m oil column	Eliassen	Large N-S trending tilted fault block structure at Legendre Fm primary target level.
Lauchie 1	Minor oil	Middle Jurassic to Early Cretaceous	Stratigraphic pinchout plays.
Legendre Field	Oil	Lower Neocomian	Anticlinal structure.

Morrel 1	Column of dry gas	M. australis	Low relief anticline formed by rollover into the downthrown side of the Hampton fault.
Oryx 1	Minor oil and gas	Athol / Mungaroo	Tilted fault block.
Reindeer 1	Significant gas show	Legendre	NE-SW trending 4 way dip closed anticline at top of Legendre Fm.
	Good show but immovable	Calypso	
Saffron 1	Small amount of oil and gas	Angel	Faulted anticlinal structure.
	Small amount of oil and gas	M. australis	
Sage 1	7m oil column	Angel	4 way dip closed structure formed by rollover on downthrown side of Rosemary fault.
	4.7m oil column	P. burgeri	
	Movable oil present	Saffron	
Samson 1	Minor gas	Lower to Middle Jurassic	Broad low relief high on upthrown side of an antithetic fault associated with and parallel to the Rosemary Fault system.
Stag field	Oil	M. australis	Structural with stratigraphic component.
Talisman field	Minor oil and gas	Neocomian to Tithonian	Anticlinal closure.
Tusk 1	Oil	Athol	Tilted fault block with closure formed by dip to N, W & S and by fault closure to SE.
	12.7m oil column	Mungaroo	
Wandoo 1	22.1m oil column	M. australis	3 way dip closure bounded on W by Enderby Fault which is downthrown to W.
	3.4m gas column	Early to Middle Jurassic	

Table 1: Hydrocarbon occurrences in the Dampier Sub-Basin. Data from Well Completion Reports and Geoscience Australia Petroleum Wells Database.

Wireline logs for several wells *(see Appendix 1)* were also studied in detail using Geolog software to view, edit and print the logs.

Formation tops were taken from the well completion reports where available. The quality of these picks is variable. For example the first wells drilled in the area during the 1970s were often interpreted using poor biostratigraphy as the palynological subdivision at this time was not well defined. In addition the stratigraphy was also often vague – for example simply referred to as undifferentiated Jurassic. The formation tops were therefore all reviewed using correlation and biostratigraphic data. Biostratigraphy data in the form of dinoflagellate and spore / pollen microfossils and the Updated Jurassic – Early Cretaceous Dinocyst Zonation for the NWS Australia by *Helby et al (2004)* was used.

The common reservoirs identified in *Table 1* are looked at in more detail in this chapter. For each of these an overview is given as well as a typical lithological description (usually from a well where the lithology acts as a proven reservoir). A typical gamma trace is also given for each potential reservoir. The likelihood of these reservoirs being present within Strike Oil's blocks is then discussed using evidence from the closest wells.

5.2 M. australis Sand

Sands of *M. australis* age are the most economically productive in the Dampier Sub-Basin. It is sometimes referred to as the Stag Sand. The *M. australis* sandstone is thought to be a deep water basin floor fan sequence unconformably deposited upon the argillaceous outer shelf sediments of the Lower Muderong Shale following the Intra-Muderong Hiatus *(Apache Energy Ltd., 2005)*. The *M. australis* sand is not continuous throughout the basin – it is diachronous making it difficult to pick on seismic. The seal for this potential reservoir is provided by the Upper Muderong Shale.

Oil or gas has been discovered *in M. australis* aged sediments at many localities including the Stag Field, Wandoo Field, Antler 1, Centaur 1, Chamois 1 and Elk 1.

Reservoir Quality

Chamois 1 *(Apache Energy Ltd., 2003)*
The *M. australis* interval at this locality consists of silty to sandy claystone with interbeds of very fine to fine-grained, moderately well to well sorted sands. The sandstone beds have average porosity of 29% and permeabilities up to 1435.5 mD.

Wandoo 1 *(Delfos, 1992)*
The *M. australis* sand is predominantly glauconitic sandstone with up to 50% greensand. The gamma trace is shown in *Figure 5.1*. The glauconitic sandstone is fine to medium grained (but predominantly fine), well sorted, sub-angular to sub-rounded with moderate sphericity. It contains 5-40% glauconite which decreases with depth.

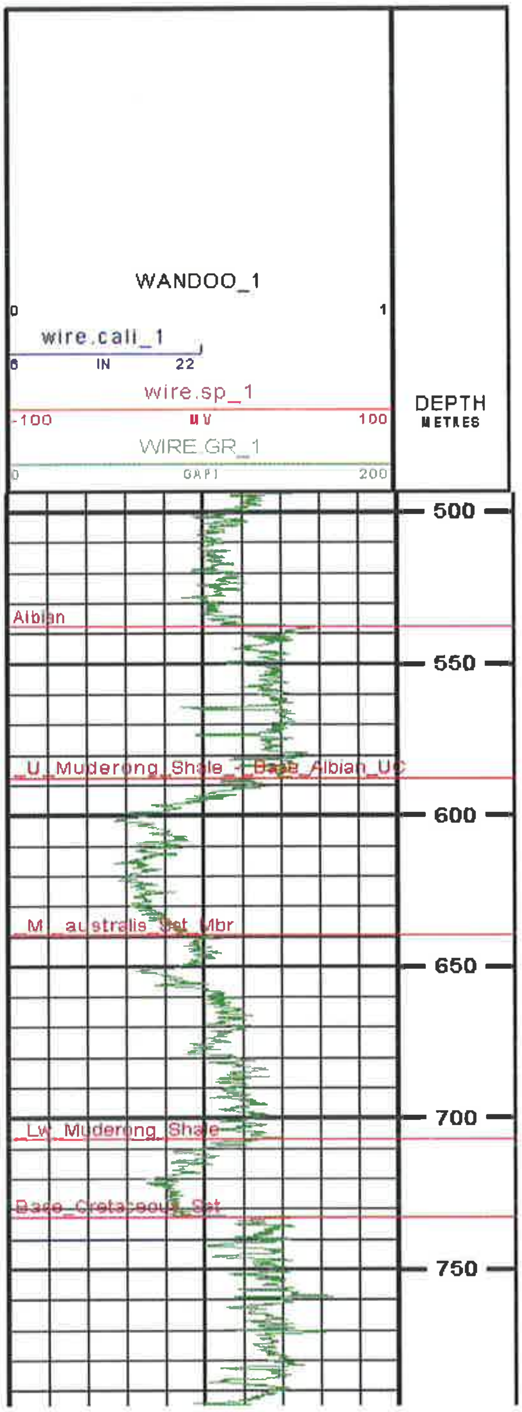

Figure 5.1: Gamma trace for the Lower Cretaceous at Wandoo 1 showing M. australis sand (labels indicate the base of formations).

Blocks WA-261-P, WA-340-P, TP/19 and EP 421

It has been recognised that there is a pinchout of the *M. australis* sand to the north-west of Strike Oil's blocks *(Apache Northwest PTY Ltd. , 2003).* This pinchout forms a stratigraphic trap which along with a structural component forms the trap at the Stag Field. The wells Rhebok 1 and Longhorn 1 have been recognised as being outside this pinchout. The *M. australis* interval in this area is interpreted as being deposited in a very near-shore or shelfal marine environment *(Apache Northwest PTY Ltd. , 2003). Figure 5.2* shows the distribution of the *M. australis* sand.

The closest well along strike to the acreage of interest is Strickland 1. The well completion report does not have an accurate description of this interval – it is simply described as dominantly claystone with interbedded fine to granular sandstone. The sandstone is described as unconsolidated and becomes increasingly glauconitic with depth *(Hudbay Oil Australia Ltd., 1982).* At Gimlet 1 the M. australis was encountered. It was described as being predominantly medium grained, moderately well sorted with zero to good visible porosity. Analysis showed that the M. australis had an estimated average porosity of 21.6% between the depths of 374-385m and 29.9% between 386m and 392m giving the impression of an excellent reservoir rock. However, although well developed the high glaucony content (up to 74%) and clay content (up to 13.5%) and the lack of quartz reduces the permeability and reservoir quality to below what has been encountered in nearby wells *(Mobil Exploration & Producing Australia, 2000).*

It therefore appears there is a fairly large risk associated with the presence of the M. australis reservoir in Strike Oil's blocks. However it should not be ruled out. There is some irregularity in the distribution of the sand – e.g. it is absent at Mawby 1 and Nickol Bay 1 making it difficult to accurately predict its distribution *(Figure 5.2).*

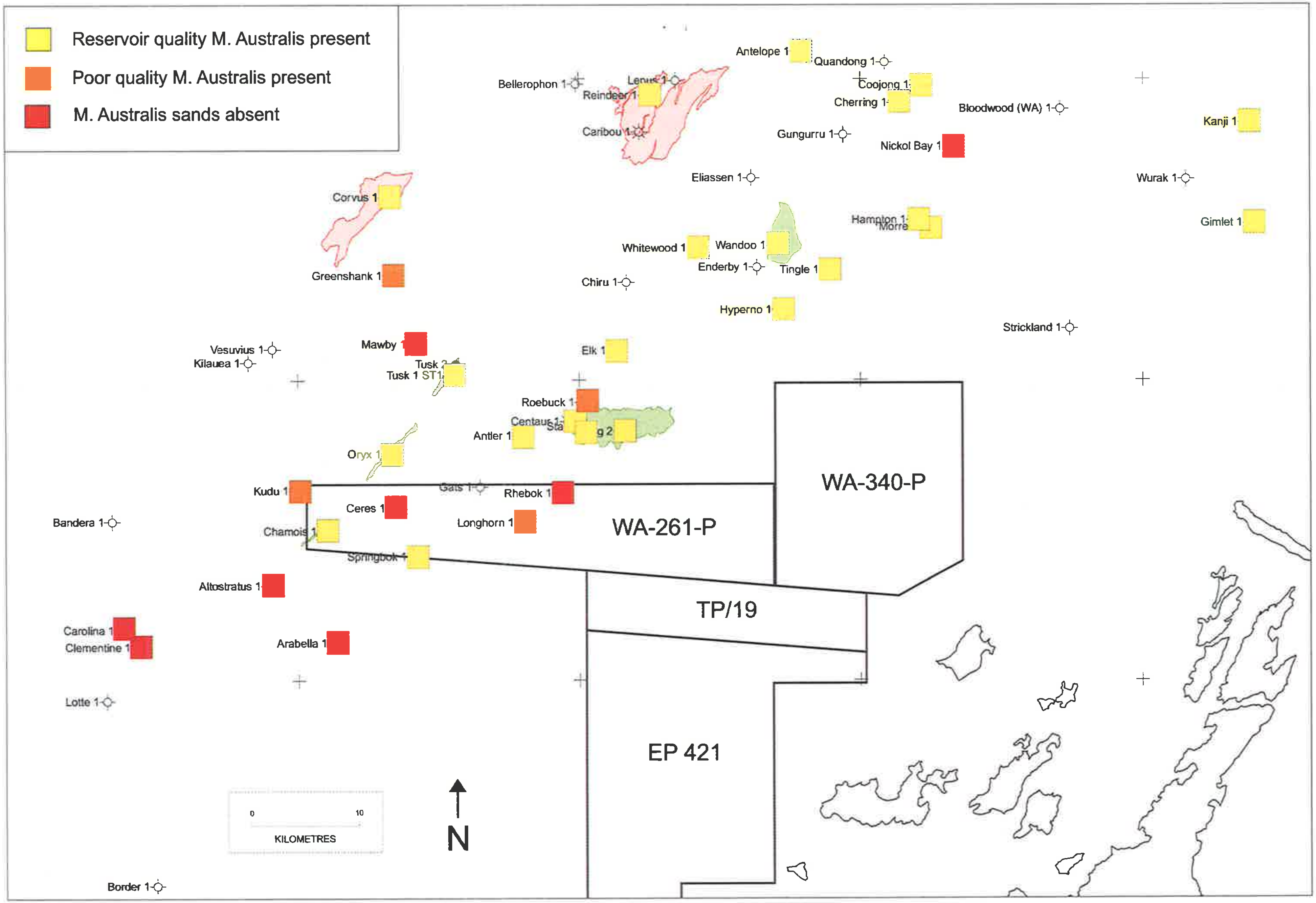

Figure 5.2: Distribution of M. Australis sand

5.3 Neocomian Sands

The Neocomian sands include the Hauterivian to Valanginian age Mardie Greensand and Birdrong Sandstone and the Berriasian age sands within the Barrow Group. The Berriasian sands are transgressive and lie on top of the Base Cretaceous Unconformity. The seal for these potential reservoirs is provided by the Muderong Shale.

Berriasian aged sands form the reservoir for the Legendre Field *(B.O.C. of Australia Ltd., 1968).*

Reservoir Quality

Legendre 1 *(B.O.C. of Australia Ltd., 1968)*
The sands here are divided into three separate units of sandstone interbedded with siltstone and claystone. The sands are predominantly fine to coarse grained, sub-rounded to sub angular and poorly to moderately sorted.

Carolina 1 *(Apache Northwest PTY Ltd., 2000)*
Figure 5.3 shows a sand lying above the Base Cretaceous Unconformity. It has been dated as *B. reticulatum* – Berriasian aged sand.

Blocks WA-261-P, WA-340-P, TP/19 and EP 421

Seventy-five metres of predominantly medium to coarse grained, poorly sorted argillaceous sandstone is present along strike at Strickland 1. The Berriasian to Valanginian sandstones at Gimlet 1 are interpreted to have been deposited in a nearshore to intermediate marine environment. They are described as being moderately well to well sorted, sub-angular to sub-rounded with moderate sphericity and poor to excellent visible porosity *(Mobil Exploration & Producing Ltd., 2000).* Berriasian sands appear to be more widespread than those of M. australis age. To the north-west Neocomian sands are also present in most wells including Rhebok 1 and Longhorn 1 (although thin) where reservoir quality *M. australis* was absent.

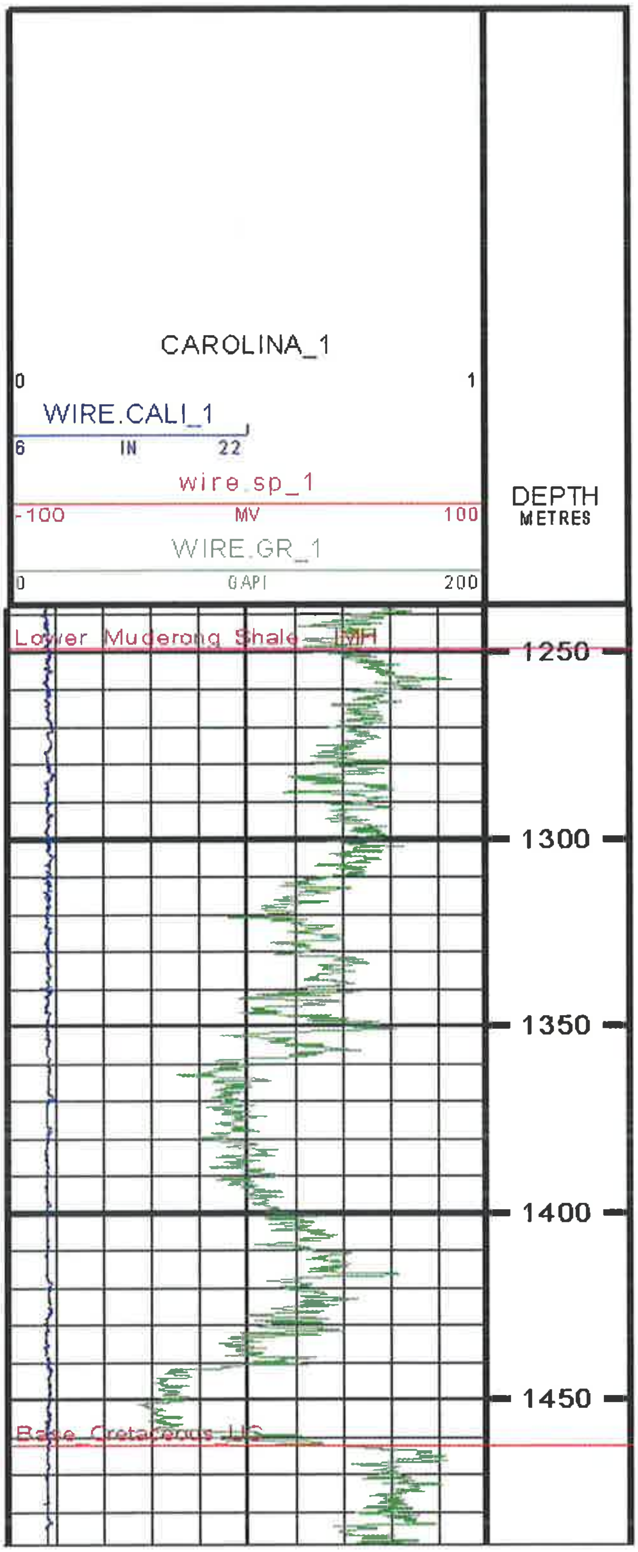

Figure 5.3: Gamma log showing Berriasian aged sand at Carolina 1 (labels indicate the base of formations).

5.4 Legendre Formation

The Legendre Formation acts as the reservoir for the Caribou and Reindeer Fields and has minor hydrocarbon shows in several other wells.

Reservoir Quality

Caribou 1 *(Kenny, 2001)*
The Legendre Formation at this locality is a thick sequence of sandstone with minor interbedded claystone and siltstone. The thickest sandstone bed is 107m while most of the claystones and sandstones are less than 5m thick. The sandstone is quartzose and predominantly fine to medium grained with poor to moderate sorting.

Mawby 1 *(Woodside Offshore Petroleum, 1992)*
Figure 5.4 shows the Legendre Formation at Mawby 1. The Legendre Formation here is more clay rich than at Caribou 1 however several thin beds of sand can be seen.

Blocks WA-261-P, WA-340-P, TP/19 and EP 421

The Legendre Formation is absent from the wells closest to the study area. Therefore it is not considered to be a potential reservoir in this project area.

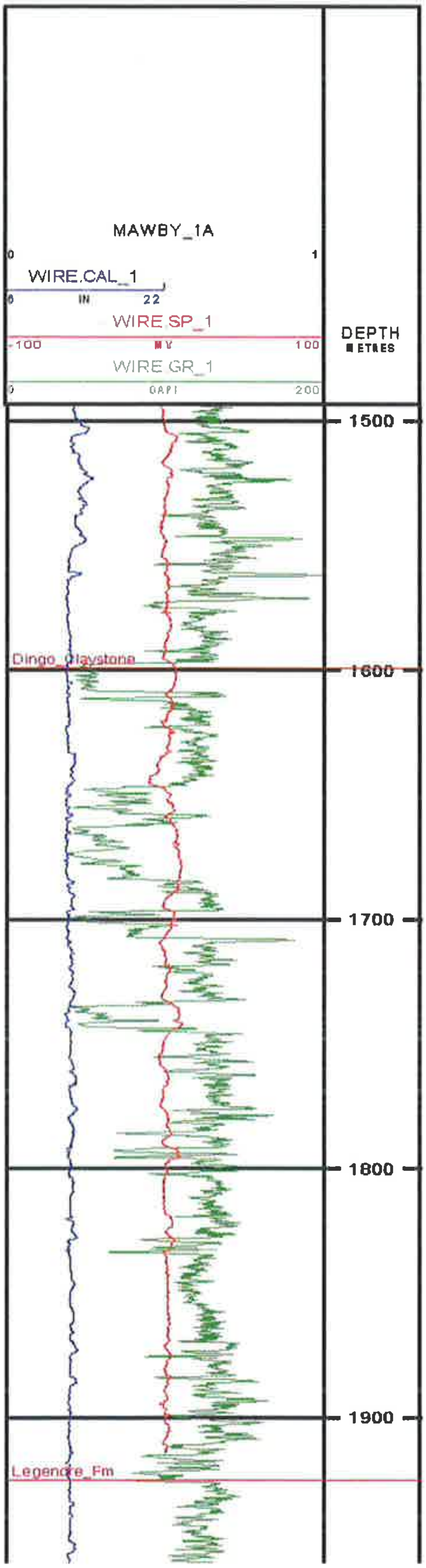

Figure 5.4: Gamma trace showing Legendre Formation at Mawby 1 (labels indicate the base of formations).

5.5 Intra Athol Sands

The Athol Formation is predominantly shale however it contains several beds of potentially reservoir quality sands. These sands include the *N. gracilis* Member, the *C. halosa* Member, the Hot Sand Member and the *D. caddaense* Member. The potential seal is provided by the shale of the Athol Formation.

Ceres 1 and Chamois 1 both have good oil shows within the *C. halosa* Member.

Reservoir Quality

Ceres 1 *(Apache Energy Ltd., 2003)*
The *C. halosa* sand at this locality is composed of sandstone which is fine to coarse grained, poorly sorted and sub angular to sub rounded. Core analysis revealed porosities of up to 31.6% and permeabilities of up to 1430mD. The *N. gracilis* sand member comprises siltstone with interbedded very fine to fine grained sandstone. It is moderately well sorted, sub-angular to sub-rounded with poor visible porosity.

Chamois 1 *(Apache Energy Ltd., 2003)*
Three Intra Athol sands were intercepted by this well. The gamma ray curve for these sands is shown in *Figure 5.5.* The *C. halosa* Sand Member is 5m thick and comprises very fine to coarse sandstone. It has a net to gross of 86.3%, a net pay of 82.4%, an average porosity of 29% and permeabilities ranging from 7.4 to 4440.6mD.
The "Hot" Sand Member is 10m of silty claystone, calcareous siltstone and claystone, interbedded with very fine to silt sized, well sorted silty sandstone, very fine grained, well sorted, calcareous sandstone and very fine to fine grained, well sorted, sandstone. The unit has a net to gross of 78.2%, a net pay of 8.9%, an average porosity of 26% with permeabilities ranging from 0.8 to 127.3mD.
The *N. gracilis* Sand Member is 11m thick. It is very fine to medium grained, predominantly fine grained, moderately well sorted, sandstone interbedded with very fine grained, well sorted, silty sandstone and minor silty claystone, siltstone claystone and calcareous sandy siltstone. The unit has a net to gross of 79.3%, no net pay, an average porosity of 23% and permeabilities ranging from 0.3 to 146.6mD.

Blocks WA-261-P, WA-340-P, TP/19 and EP 421

The Athol Formation is absent along strike at Gimlet 1. However it can be seen in most wells to the north-east. At the Longhorn 1 location, the uppermost 19 m comprises a predominantly sandstone sequence which forms a subcrop to the base Cretaceous Unconformity. This sandstone unit is correlatable to the north and north-east in the Stag wells and Centaur 1 *(Apache Energy Ltd, 1998).* At Rhebok 1 the *C. halosa, N. gracilis* and *D. caddaense* sand members were encountered. These beds were 13.0 to 13.5m thick but were not considered to be of reservoir quality.

It appears from the seismic data that the Athol Formation is present in at least WA-340P and probably also in Strike Oil's blocks to the south-west. Therefore there is potential for intra Athol Formation sands to be present in Strike Oil's blocks however they may not be of reservoir quality.

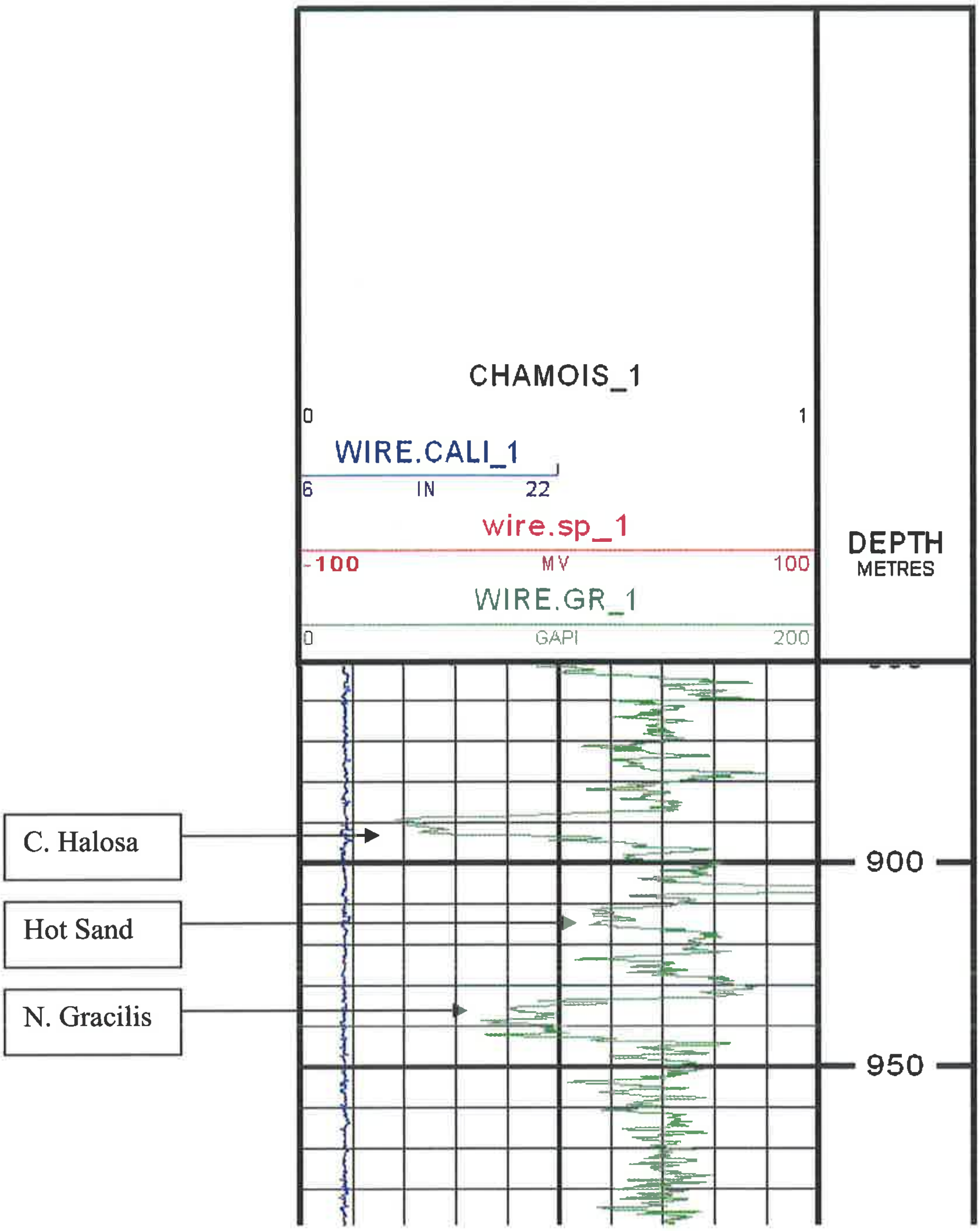

Figure 5.5: Gamma trace for Chamois 1 showing Athol sands.

5.6 Mungaroo Formation

The fluvial sandstones of the Mungaroo Formation make excellent reservoirs due to their high quartz content and almost complete lack of primary clay matrix. The maximum porosities recorded are 30% with maximum permeabilities of 4 Darcies *(Crostella & Barter, 1980).*

Although the Mungaroo Formation is the main reservoir for the North Rankin and Goodwyn Fields the only evidence of hydrocarbons discovered within the Mungaroo Formation in the study area is a gas column at Altostratus 1.

Reservoir Quality

Altostraus 1 *(Strike Oil, 2006)*
The Mungaroo Formation consists of predominantly unconsolidated, very fine to conglomeratic, moderately to well sorted sand with minor to trace kaolinite, trace glauconite and pyrite.

Springbok 1 *(Santos, 1998)*
Present as interbedded sandstone and siltstone. The sandstone is present in 20 to 30m thick units of very fine to coarse grained sands with fair inferred porosity.

Arabella 1 *(Australian Occidental Petroleum, 1983)*
The Mungaroo is predominantly fine to very coarse sandstones interbedded with beds of carbonaceous claystone and limestone up to 5m thick. This can be seen as variations in the gamma trace in *Figure 5.6.* Analysis of sonic data shows that the Mungaroo has an average porosity of 39% between the depths of 652 and 801m and 36.5% between 801 and 1225m.

Blocks WA-261-P, WA-340-P, TP/19 and EP 421

Like the Athol Formation the Mungaroo Formation is absent at Gimlet 1 but can be seen at wells down dip. At Rhebok 1 the Mungaroo Formation comprised fine to coarse grained, moderately well sorted, good inferred porosity sandstones with minor interbeds of silty claystone and siltstone. It was interpreted as being deposited in a floodplain or fluvial environment *(Apache Northwest, 2003).* It appears from the seismic data that the Mungaroo Formation is present in block WA-340P (see *Section 6.2*).

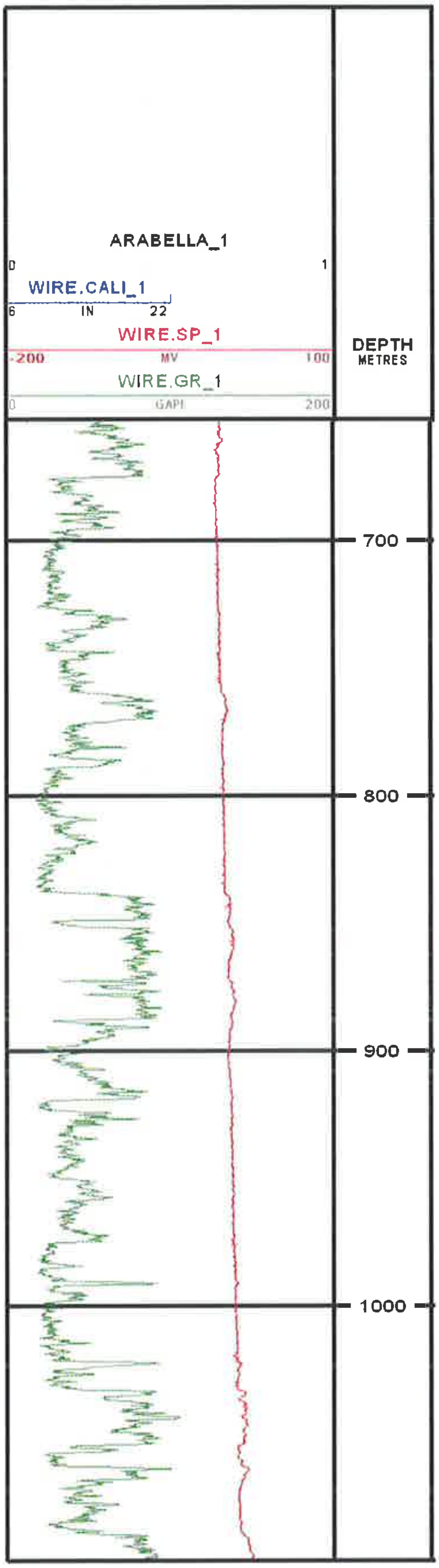

Figure 5.6: Gamma trace for the Mungaroo Formation at Arabella 1

5.7 Base Locker Sand

The Base Locker Sand is a transgressive sand which lies above the basement in this area. It is thought to be the weathering product of basement rock. The Locker Shale would provide the seal for this potential reservoir.

There has not been a significant show or fluorescence at Base Locker Sand depth for any wells to date.

Reservoir Quality

Kanji 1 *(Ampol Exploration Ltd., 1994)*
The sandstone here displays good to excellent reservoir characteristics. There are 21m of chemically immature (high feldspar and mica content), lithic, fine to medium grained, moderately well to well sorted sandstones with poor to fair visible intergranular porosity.

Arabella 1 *(Australian Occidental Petroleum, 1983)*
The basal sand at this locality is thought to be 40.5m thick. This is much thicker than at any other locality in the study area. The sand is also a lot cleaner than elsewhere and is medium to coarse and moderately well sorted. The cylindrical gamma profile and the lack of marine indicators suggest that it is a beach sand which was deposited near the start of the transgression. It is thought that the absence of a limestone marker bed may suggest the sand is younger here than in other parts of the basin.

Gimlet 1 *(Mobil Exploration & Production Ltd., 2000)*
At this location the basal Triassic sandstone is not well developed and is considered to be poor reservoir. It is 45m thick and consists of sandstone, claystone and minor siltstone. The gamma curve for this well is shown in *Figure 5.7*. The sandstone is described as being lithic, fine to coarse, angular, mineralogically immature and very poorly sorted. There is no visible porosity and no shows were recorded for this unit. There is a good seal at this locality with the Locker Shale above the sands consisting of 100% claystone.

Blocks WA-261-P, WA-340-P, TP/19 and EP 421

The Base Locker Sand can only be seen in wells Arabella 1, Hampton 1, Gimlet 1, Kanji 1, Lawley 1, and Hauy 1 (and possibly Enderby 1). However this is only because all the other wells fail to reach a depth sufficient to encounter it - it is therefore present in every well which reaches sufficient depth. The presence of good sands at Arabella 1 means there is potential for reservoir quality in Strike Oil's acreage. However the poorer sands at Gimlet 1 may suggest that it becomes poor reservoir closer to the basin margins.

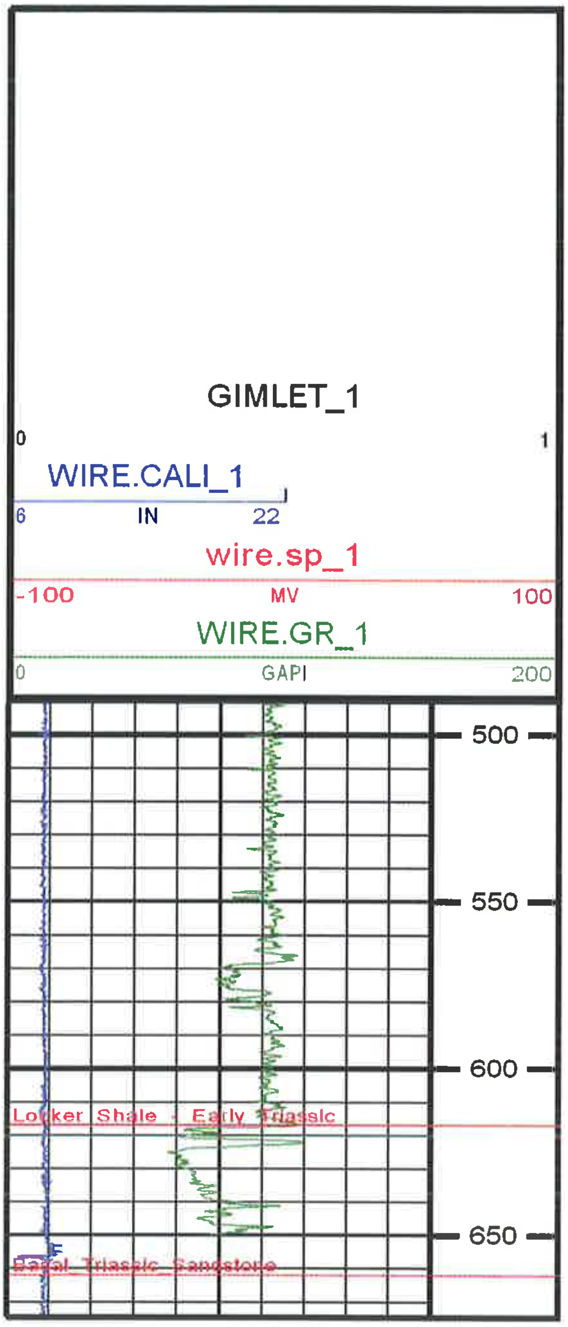

Figure 5.7: Gamma trace at Gimlet 1 showing Base Locker Sand (labels indicate the base of formations).

5.8 Seals

Three potential seals were identified:

Muderong Shale

The Muderong shale acts as the regional seal for the Dampier Sub-Basin. The TWT for the top of the Muderong Shale (Aptian Unconformity) is shown in *Figure 3.5*. This shows the Muderong Shale is present over the whole study area and can provide a seal for older reservoirs.

The maximum hydrocarbon column height which the Muderong Shale can support varies from 166m to 606m across the basin. Observed hydrocarbon column heights generally range from 7 to 37m (with the exception of the 510m gas column at North Rankin 1) *(Ryan, 2000)*. The Muderong Shale could potentially provide a seal for any Cretaceous aged reservoirs such as the M. australis or Berriasian aged sands.

Athol Formation

This is a potential seal for Mungaroo Formation and Intra Athol sand reservoirs. It has acted as a proven seal holding back a 3m hydrocarbon column at Altostratus 1 *(Strike Oil, 2006)*.

Locker Shale

This could potentially provide a seal for a Base Locker Sand reservoir. It is unproven within the Dampier Sub-Basin. At Gimlet 1 the Locker Shale is described as being predominantly claystone with a 15m interval of claystone with minor siltstone *(Mobil Exploration & Producing Australia, 2000)*.

6. Identification of Traps & Plays

The colour code for horizons on seismic cross sections is as follows:

Dark Green	Aptian Unconformity
Yellow	Intra Muderong Hiatus
Pale Green	Base Cretaceous Unconformity
Pink	Top Mungaroo Formation
Red	Top Basement

Faults are in **blue**

6.1 Play 1

The location of the seismic lines referred to in this section are shown in *Figure 6.1* below. The red arrows highlight the potential plays.

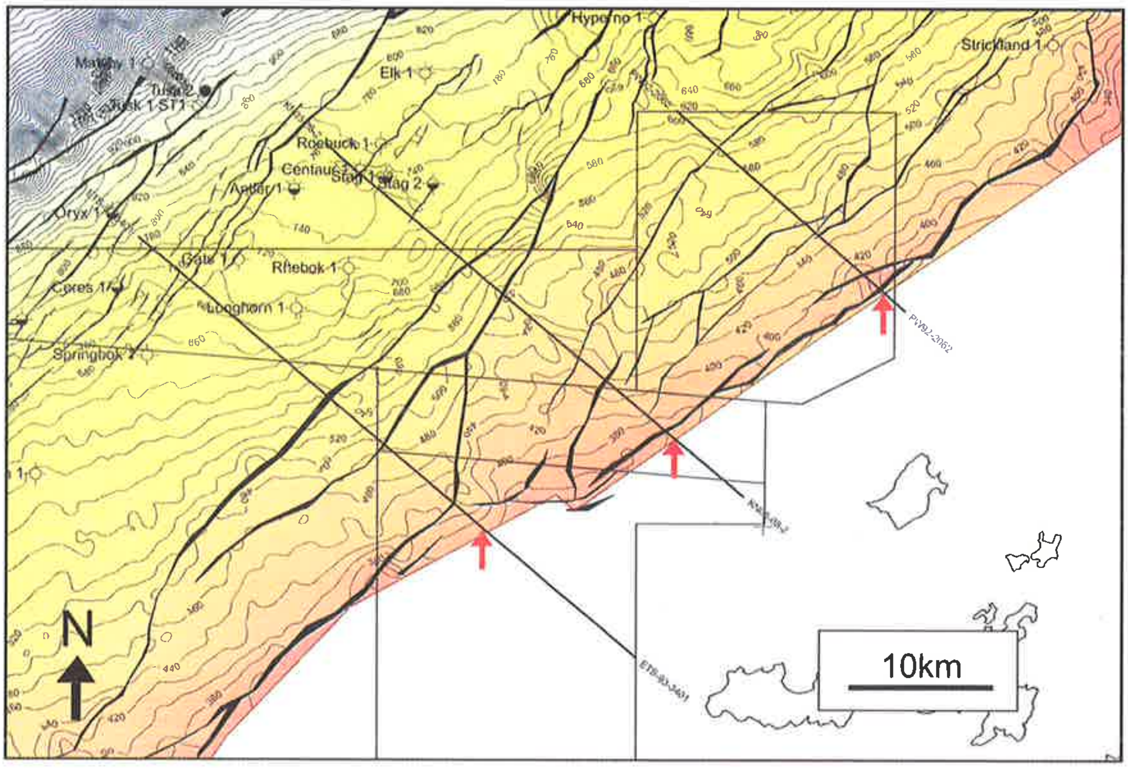

Figure 6.1: BCU TWT map showing the location of plays and seismic lines.

Lower Cretaceous Play

This play is formed by the Lower Cretaceous sands onlapping and pinching out onto the basement at the margins of the Dampier Sub-Basin as shown in *Figures 6.2 and 6.3*. This trap has been previously identified by Strike Oil as the "Sharp Peak Prospect". Seismic mapping undertaken for this project has confirmed its possible existence within Strike Oil's blocks.

The reservoir here is provided by the lower Cretaceous aged sands. As described in *Section 5.2* there is some uncertainty about the presence of M. australis sands at this locality. The M. australis aged sandstone in this area is interpreted as being deposited in a very nearshore to shelfal marine environment and a pinchout has been recognised to the north-west. There is also some uncertainty about the presence of the Neocomian sands however Berriasian sands have been found at most nearby wells making it more likely to be present than the M. australis.

The top seal is provided at this locality by the Muderong Shale with the basement acting as a base seal. Igneous crystalline basement was encountered at Gimlet 1 *(Mobil Exploration & Producing Australia, 2000)*. There is potentially closure down to 400ms.

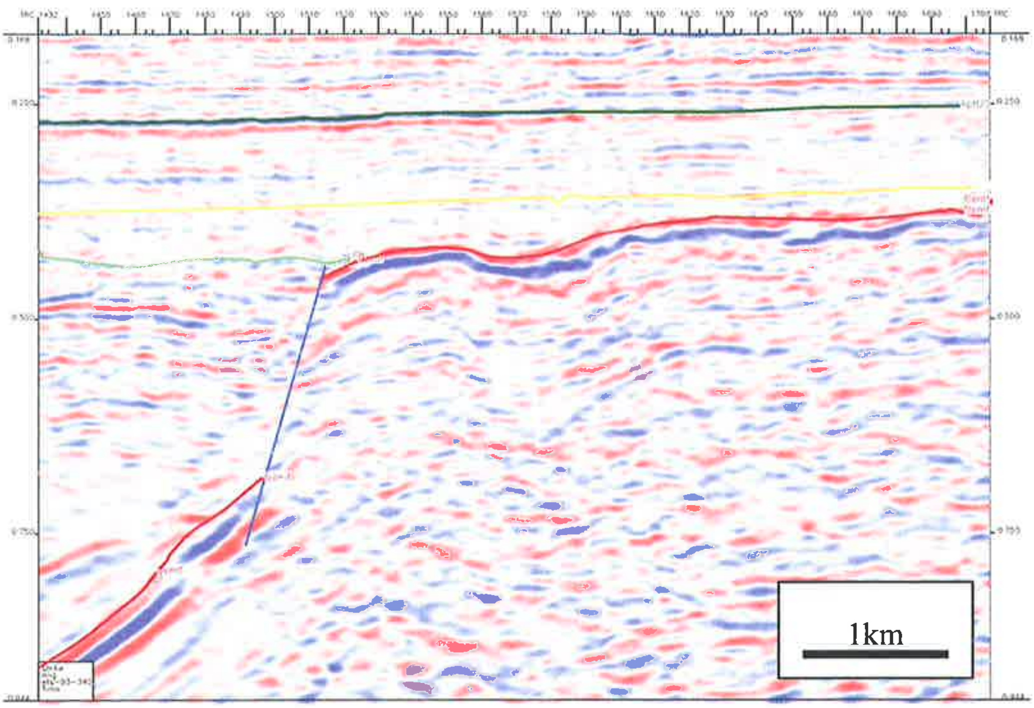

Figure 6.2: Seismic line ETS-93-3401

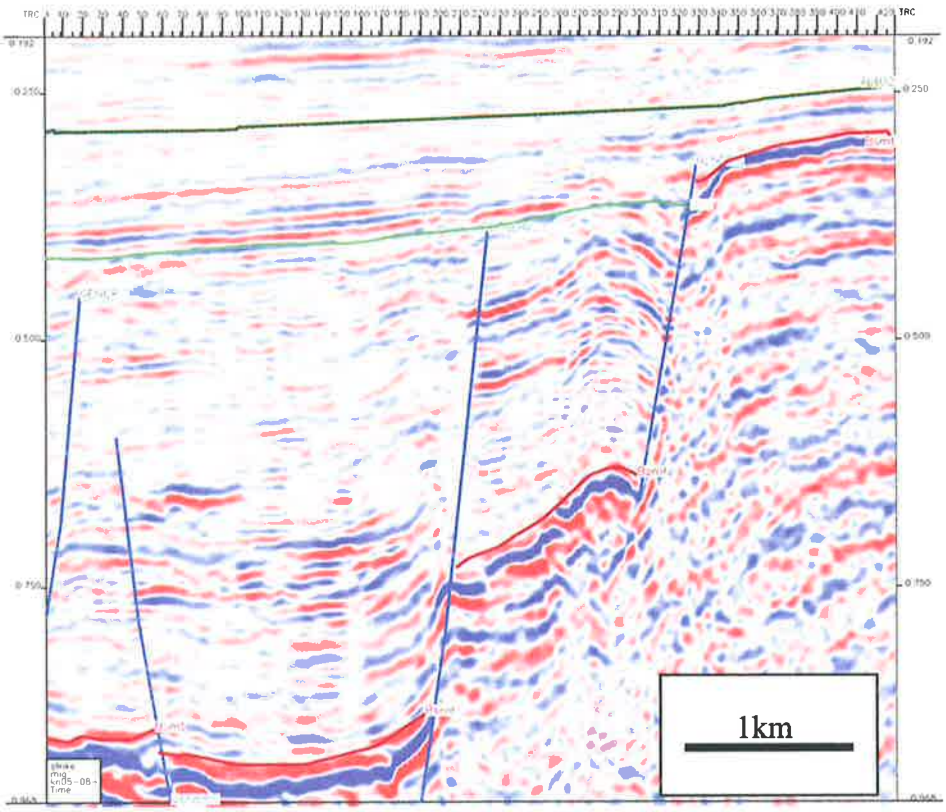

Figure 6.3: Seismic line KN05-08-2

Similar structure to that seen in *Figure 6.2* and *Figure 6.3* can be seen in block WA-340-P as shown in *Figure 6.4* however the TWT map of the BCU does not appear to show closure at this location.

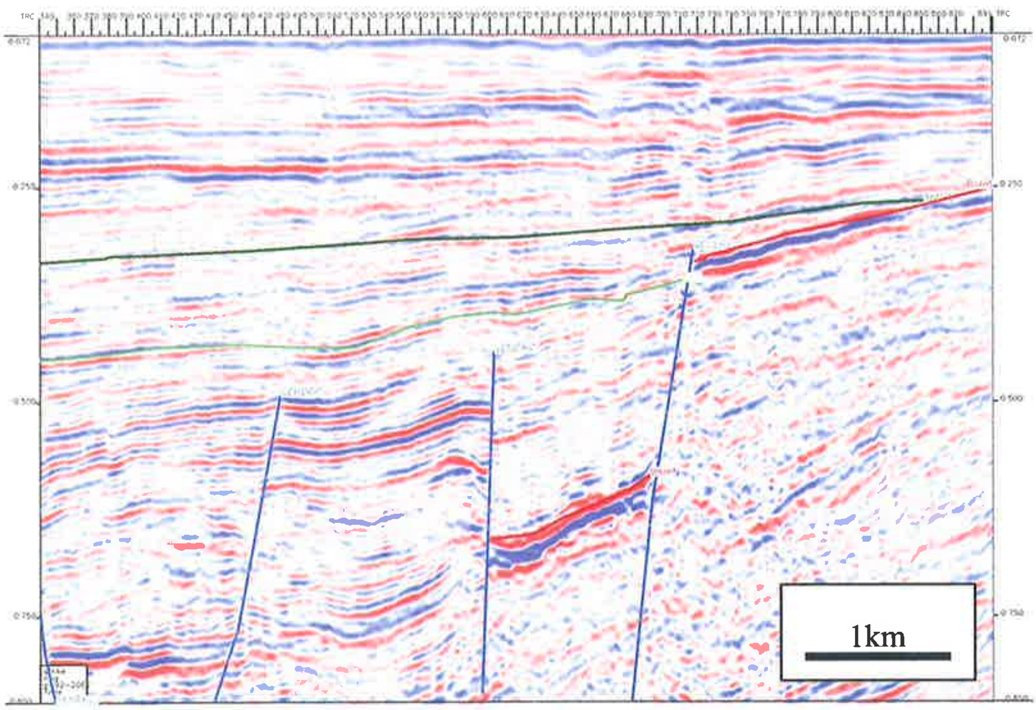

Figure 6.4: Seismic line PW92-2062

Triassic Play

There is also some potential for a Base Locker Sand structural play at these localities. This would have a Locker Shale top seal and a basement base / lateral seal. The biggest issue would be the presence of the reservoir – due to the fact most wells in the area do not drill to sufficient depths to encounter the Base Locker Sand, its extent is unknown. Gimlet 1, which is along strike, encountered a basal sand but had poor reservoir quality. However at Arabella 1 excellent reservoir quality sands were found.

Analogous Play

A similar play was tested to the north–east by the well Gimlet 1. It was plugged and abandoned as a dry hole. The location of Gimlet 1 and the seismic line HL80-15 is shown in *Figure 6.5*. An interpreted version of HL80-15 is shown in *Figure 6.6*.

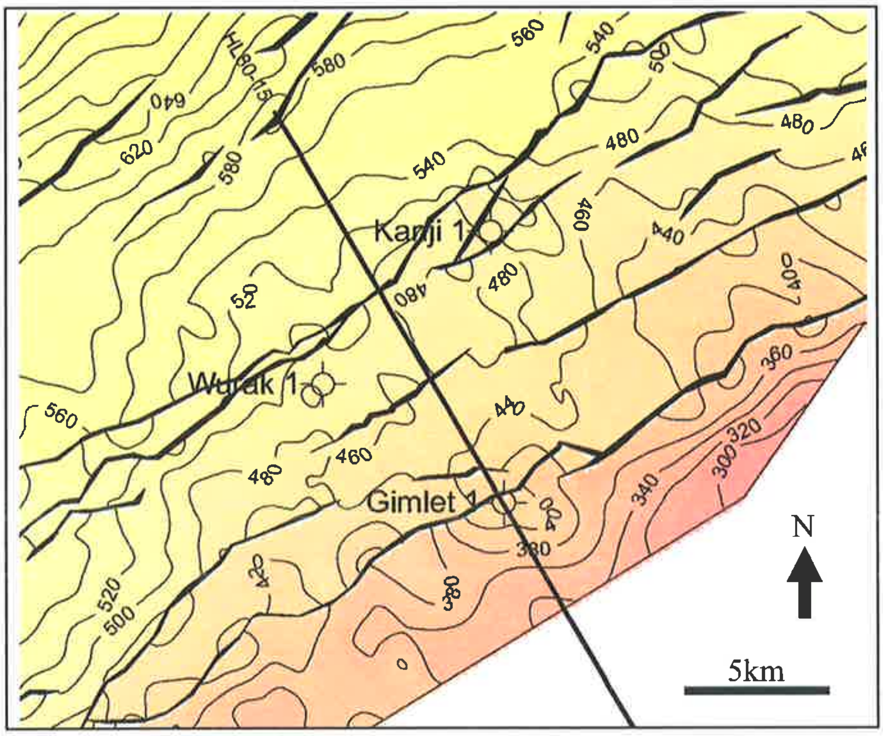

Figure 6.5: BCU TWT map showing location of seismic line HL80-15 and the well Gimlet 1.

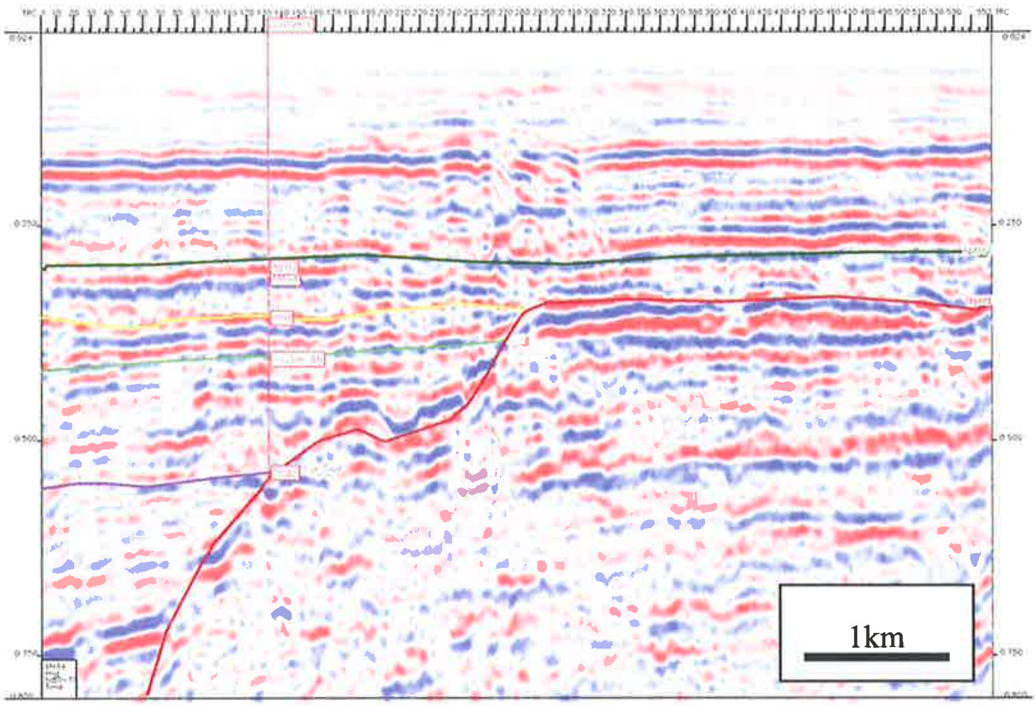

Figure 6.6: Cross section showing structure on line HL80-15 at Gimlet 1.

The main target of this well was the M. australis sand with other lower Cretaceous and Triassic sands acting as secondary targets. The target M. australis sands were intercepted however the presence of up to 74% glaucony and up to 13.5% clay and the lack of quartz grains meant that the reservoir quality was worse than anticipated. The well completion report *(Mobil Exploration & Producing, 2000)* lists three possible explanations for the lack of hydrocarbons at this locality:

- The lack of an effective seal due to erosion of the Muderong Shale by an Eocene aged channel.
- Invalid trap due to failure of the pinchout closure at the interface between the Muderong Shale and the basement.
- Lack of an effective migration pathway into the structure.

This will be discussed in more detail in *Chapter 7.*

6.2 Play 2

The location of this play is shown on the TWT map of top Mungaroo Formation in *Figure 6.7*. The structure is shown in *Figures 6.8 and 6.9.*

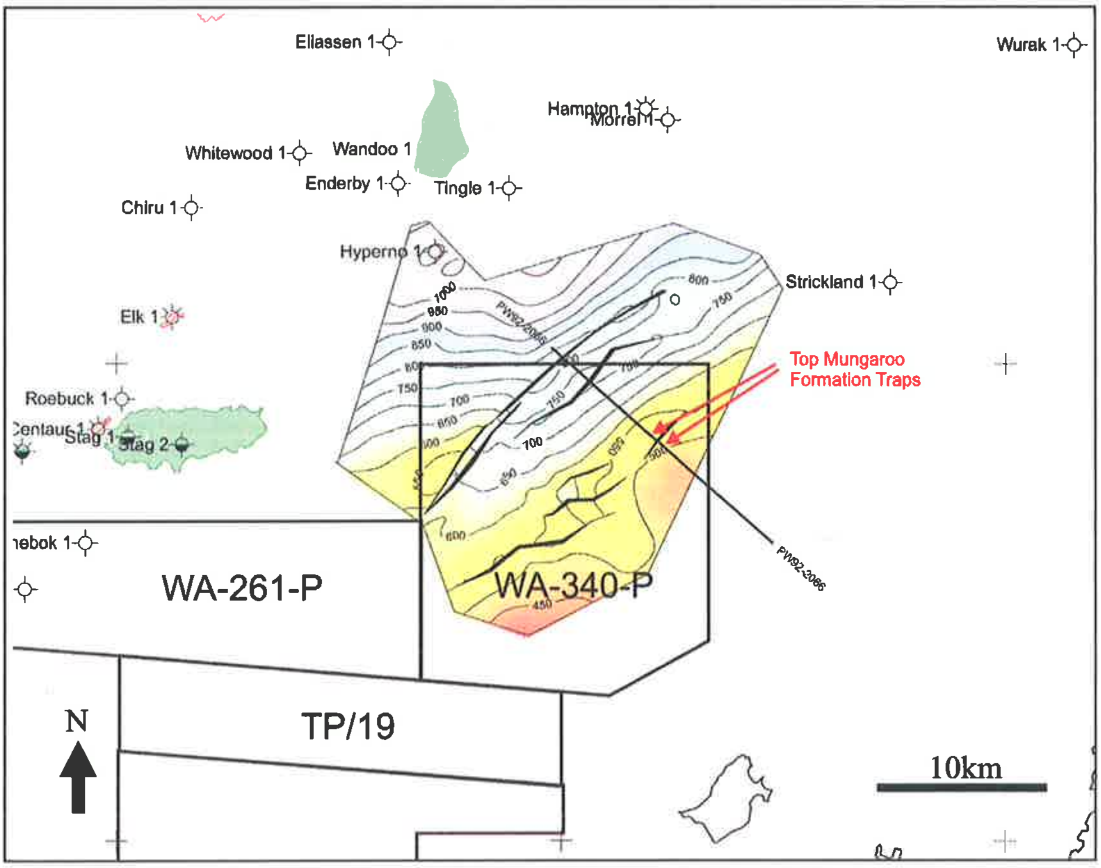

Figure 6.7: TWT map of top Mungaroo Formation showing location of seismic lines.

As can be seen in *Figure 6.7* the pre-Cretaceous sediments in block WA-340-P are highly faulted, giving the potential for the presence of structural traps. A potential play is described in the following section.

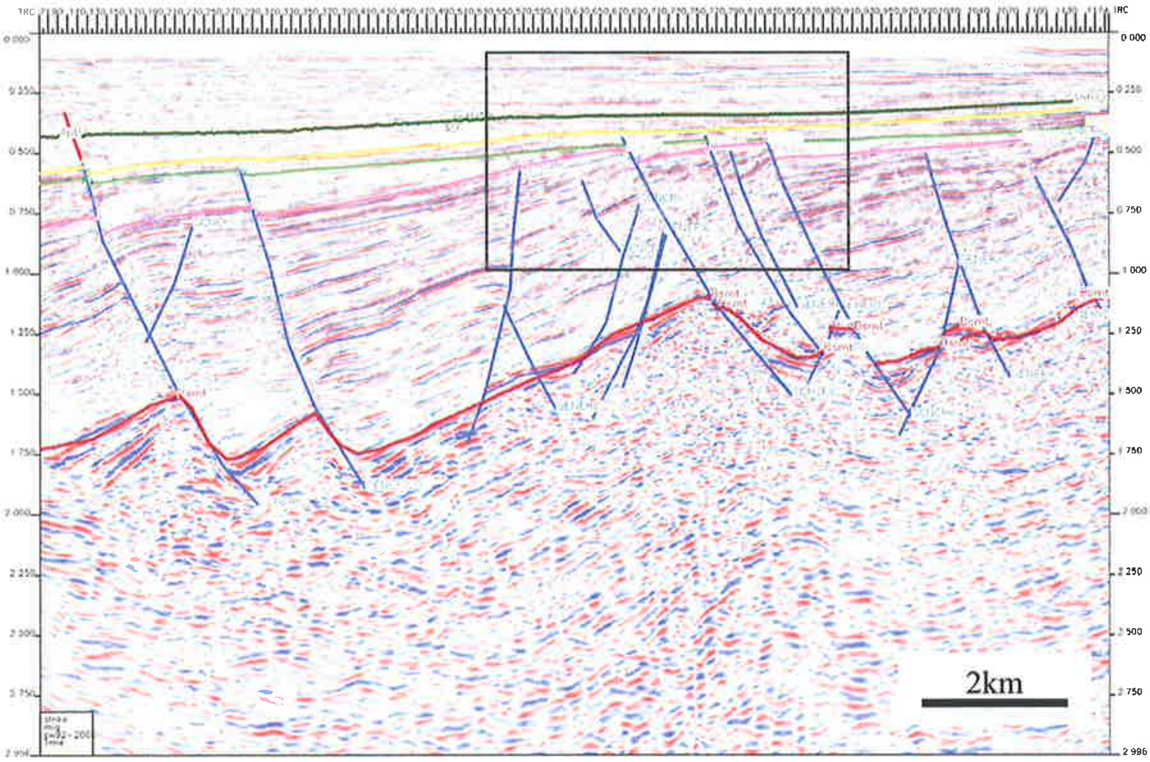

Figure 6.8: Seismic Line PW92-2066 showing Play 2

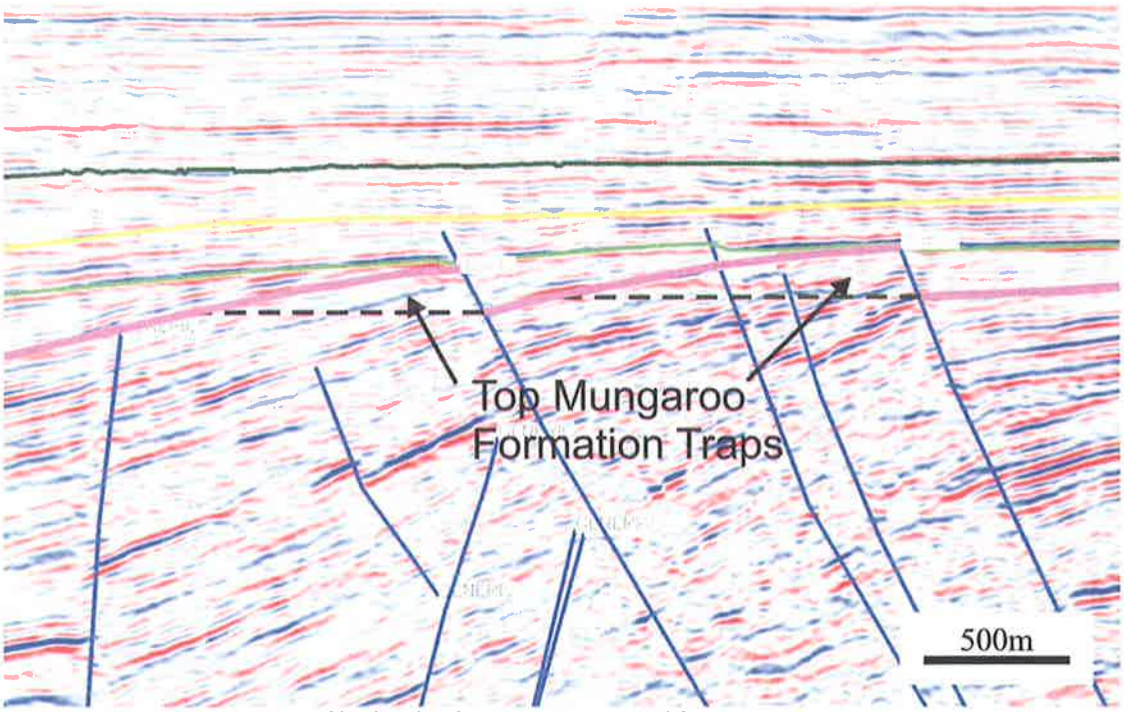

Figure 6.9: Magnified view of highlighted section in Figure 6.8.

Athol / Mungaroo Formation Play

This play is shown in *Figures 6.8* and *6.9.* It has been identified by Strike Oil and is known as the "Sherlock Lead". Mapping undertaken for this project confirms its possible existence.

The first potential reservoir / seal pair here is the Mungaroo Formation / Athol Formation. The Intra Athol Sands including the C. halosa and N. graclis beds represent another potential reservoir with the shale of the Athol acting as a top and lateral seal where displacement by faults has occurred.

The top seal may be provided by the Athol Formation although it appears to be very thin in this interpretation *(Figure 6.9).* If Berriasian sands are absent the Lower Muderong Shale may also act as a seal. Lateral seals are provided by the displacement of the Athol Formation by the faults.

Base Locker Play

The presence of the Base Locker Sand and Locker Shale is uncertain. It is present at Gimlet 1 to the north-east but is regarded as poor and non reservoir *(see Section 5).* However, at Arabella 1 to the south-west 40.5m of good clean reservoir sands were intersected. *Figure 6.10* shows the TWT map for the top Basement in block WA-340-P. It is highly faulted meaning there is potential for a Base Locker Sand reservoir sealed by Locker Shale in a structural trap. However, the Basement has not been accurately enough mapped to identify traps.

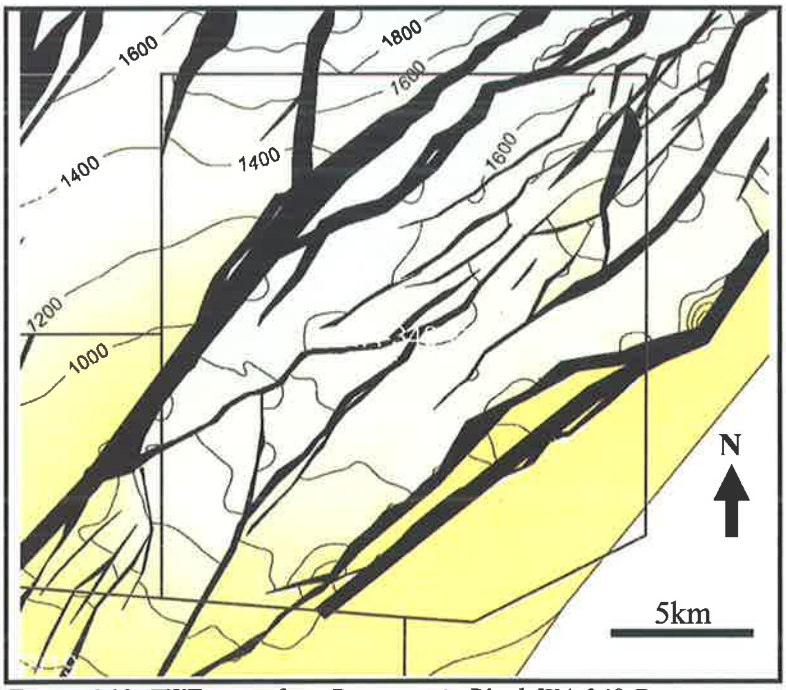

Figure 6.10: TWT map of top Basement in Block WA-340-P.

Analogous Play

A similar play at Altostratus 1 (see *Figure 3.1*) outside the permit area was moderately successful with a 3m gas column discovered *(Strike Oil, 2006)*. The reservoir was the Mungaroo Formation and the play was an upthrown fault bound structure with an element of four way dip closure. The top seal was provided by the shale of the Athol Formation.

7. Migration Pathways

7.1 Overview

As discussed in *Section 5* the most likely source for any hydrocarbons found within Strike Oil's acreage is the Lewis Trough. It is the aim of this chapter to list any evidence for long distance migration and attempt to determine viable migration paths from the source kitchen to Strike Oil's blocks.

7.2 Evidence for Migration

In order to understand the movement of hydrocarbons within the Dampier Sub-Basin it useful to look at the distribution of wells which have exhibited hydrocarbon shows and fluorescence. *Figure 7.1* shows a map of the study area and highlights wells at which hydrocarbons have been found and also where fluorescence or shows (taken as evidence of migration through the area) were present. These are described in more detail in *Tables 2 to 6*. *Figure 7.1* also shows the edge of the source kitchen – approximately where Ro is greater than 0.75% for the Oxfordian aged sediments at 0Ma (taken from *Kaiko, 1998 and Thomas et al, 2004*).

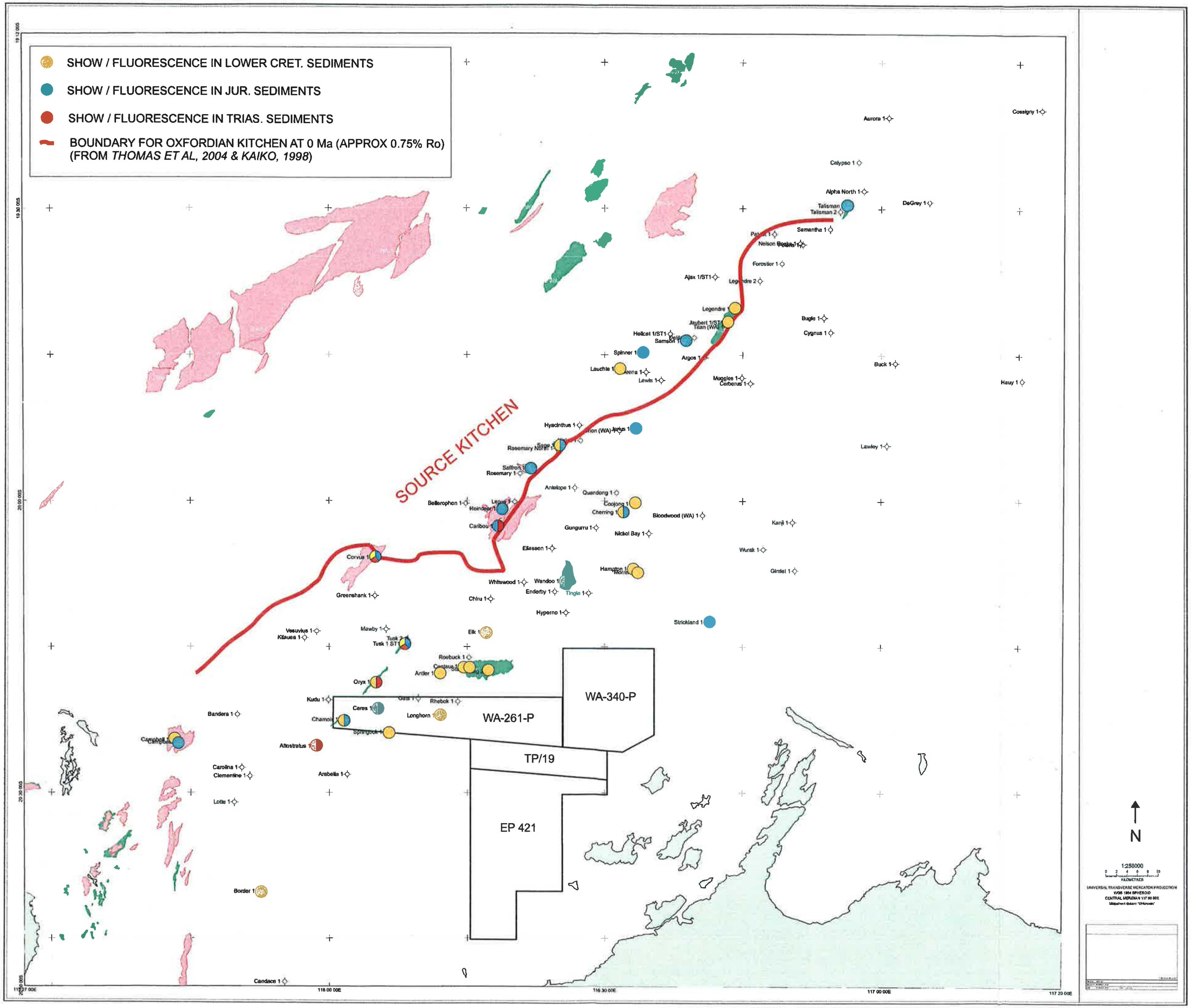

Figure 7.1: Map showing distribution of fluorescence or shows and location of source kitchen.

Figure 7.2 shows the location of SAR (Synthetic Aperture Radar) slicks *(O'Brien et al, 2003)*. This technique uses satellites to identify slicks on the surface of the ocean. The slicks are not limited to known accumulations and therefore probably indicate that petroleum generation and migration is currently active. Clusters of SAR slicks were observed around the Lambert Shelf in the south-western offshore Canning Basin, near and along the approximate location of the regional edge of seal. No slicks were detected in Strike Oil's acreage.

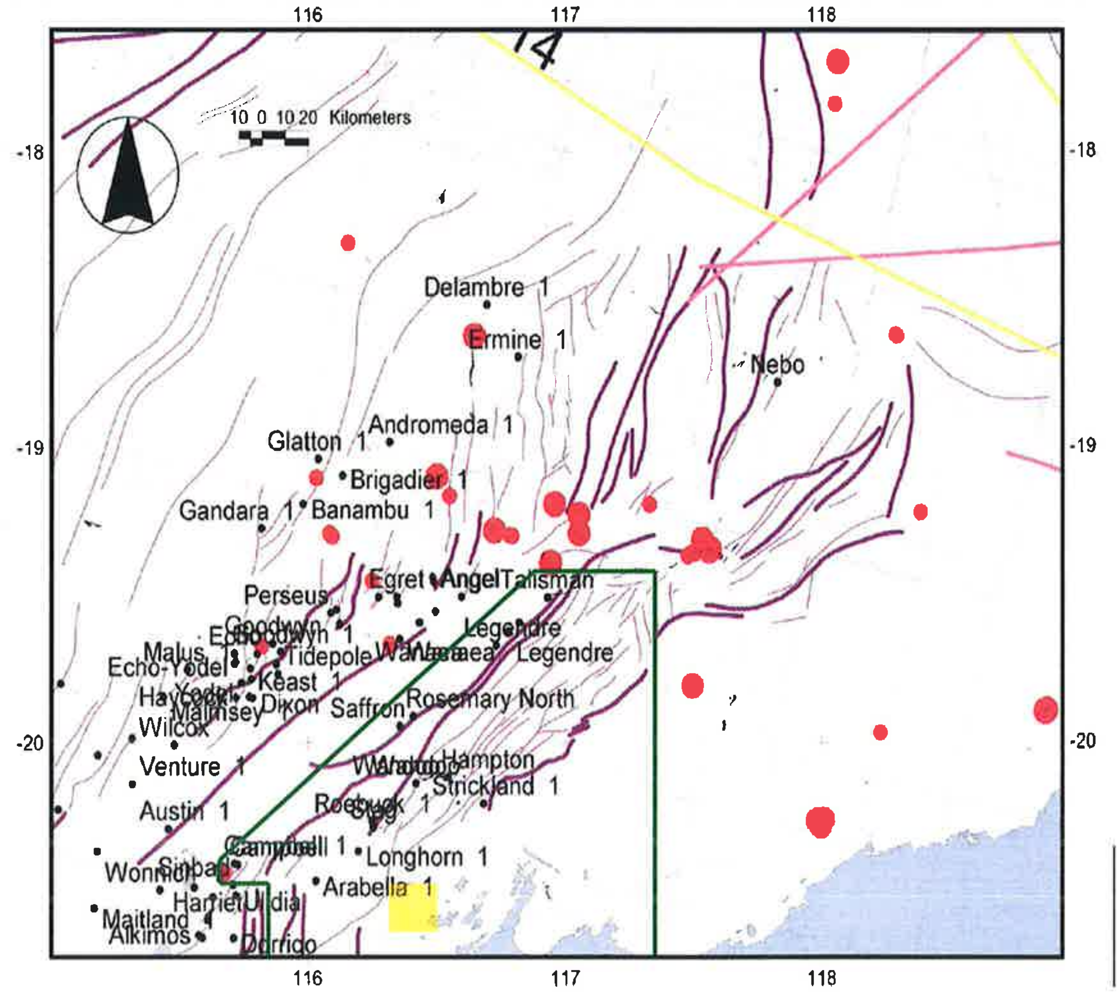

Figure 7.2: Location of SAR slicks – shown as red circles, study area is marked in green (modified from O'Brien et al, 2003). The location of Strike Oil's acreage is shown by yellow square.

This data suggests that long-range migration is happening in the Dampier Sub-Basin as hydrocarbons appear to be travelling from the depocentre in the Lewis Trough to the edge of the seal. The lack of any slicks in the study area could suggest that all the hydrocarbons are being trapped before reaching the edge of the seal supporting the idea of undiscovered traps around the Enderby Terrace.

7.3 Faults – Sealing or Non-Sealing?

Due to the fact that many faults lie between the source kitchen and Strike Oil's acreage it is important to consider whether these faults are sealing or non-sealing. Sealing faults could act as barriers preventing long-range migration.

Migration of hydrocarbons through a fault is determined by the orientation of the maximum stresses with respect to the orientation of the faults (*Mildren, 1997*). A fault perpendicular to the maximum horizontal stress (σ_{Hmax}) is much more likely to be sealing than a fault parallel to σ_{Hmax}.

A study was done on the regional contemporary stress field using borehole breakout data by *Mildren, 1997*. He calculated the σ_{Hmax} as shown in *Figure 8.3*. This shows that the σ_{Hmax} at Wandoo is oriented approximately NE-SW. The majority of the major faults in the study area including those associated with the Rosemary Fault system have similar orientations. This suggests there is some possibility of up-fault migration in the study area because the faults have low sealing potential.

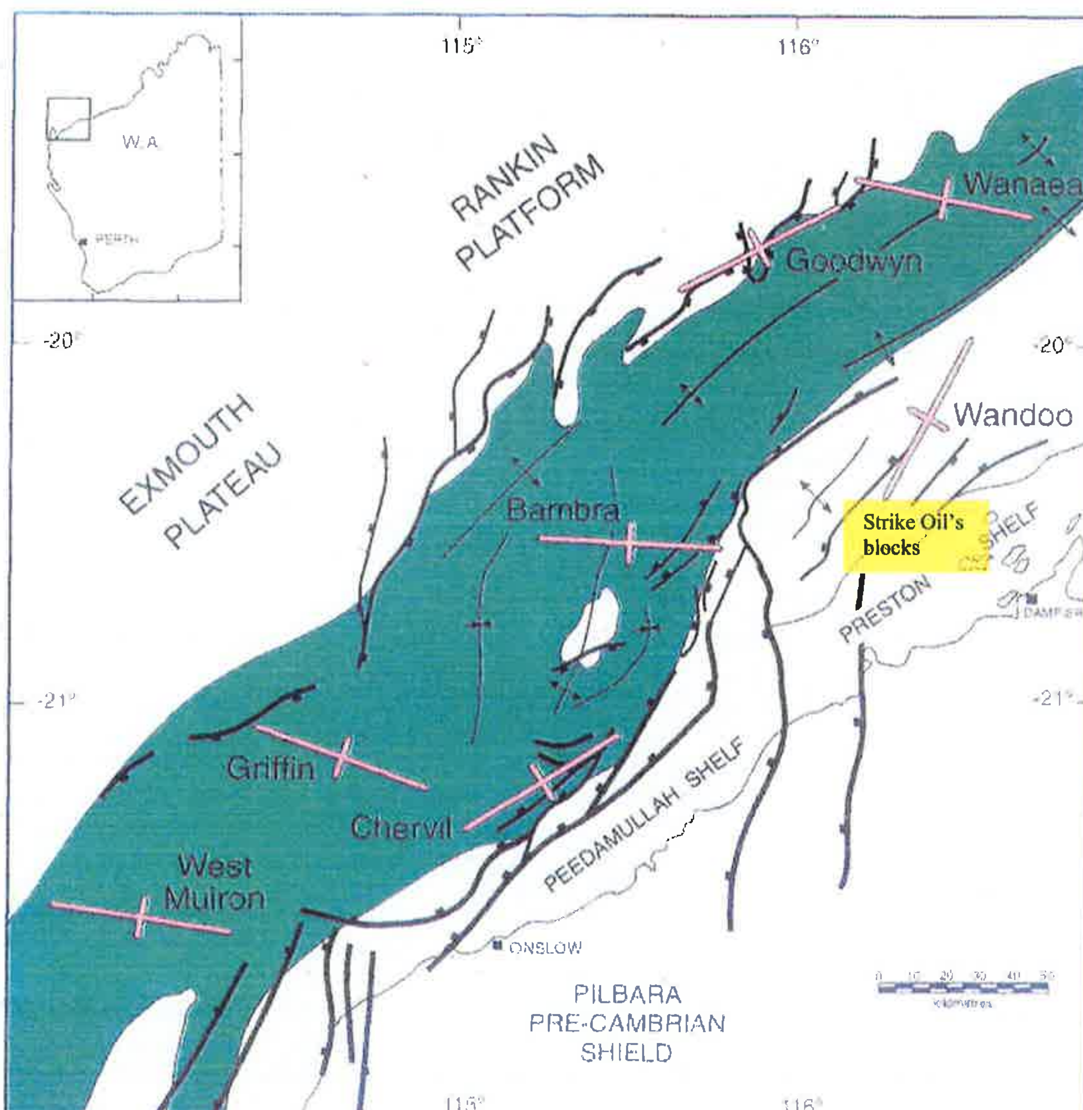

Figure 7.3: Map showing σHmax directions (from Mildren, 1997).

From the distribution of hydrocarbons throughout the basin it is clear that many of the faults permit migration. Although simplistic, for the purpose of this project, faults running north-east to south-west are assumed to be non sealing. Faults at different angles are more likely to be sealing. As shown in *Table 1* there are many instances where faults have been proven to be sealing. One example is the Wandoo Field which is bounded to the west by a fault which runs approximately north to south. This fault has been proven to be sealing due to the large hydrocarbon accumulations present there.

7.4 Migration at Lower Cretaceous Level

It is useful to look at the two largest fields which are close to Strike Oil's blocks and sit between the source kitchen and the traps – the Stag and Wandoo Fields. The reservoirs for these are M. australis aged sands. It is important to know if these fields have been filled to spill point. If they have it suggests any further migration will bypass these traps. If the structures have not been filled to spill point it suggests there has been insufficient charge and that they will continue being filled by any further migration.

Stag Oil Field
The Stag oil field contains less structurally mapped closure than the height of the hydrocarbon column. This cannot be explained by lateral variations in velocity. Therefore the Stag Oil Field is thought to have a significant component of stratigraphic trapping due to lateral variations in the M. australis aged sand. *(Crowley and Collins, 1996).* This has some implications for reservoir presence in Strike Oil's blocks however it does mean that any hydrocarbons migrating through the area will bypass this trap and continue onwards.

Wandoo Oil Field
The maximum closure at Wandoo 1 is approximately 33m with a 22.1m oil column spread over 15km^2 *(Delfos, 1994).* This means the structure has not been filled to spill point and rules out any further migration. This will result in a migration shadow effect to the south of the field.

Table 2 reviews the information available on petroleum system components present at the lower Cretaceous level for several wells.

The wells closest to Strike Oil's blocks which exhibit evidence of hydrocarbons at the Lower Cretaceous level are those of the Stag Field and Morrel 1. Those wells which are along strike such as Strickland 1, Gimlet 1, Wurak 1, Kanji 1, Lawley 1 and Hauy 1 have no shows or fluorescence. It should be noted however that partial lost circulation prevented accurate lithological determinations of the Lower Cretaceous to Recent interval at Strickland 1 *(Hudbay Oil Australia Ltd., 1982).*

Well	Hydrocarbons	Formation / Age	Reservoir Present?	Seal Present?	Valid Structure?
Altostratus 1	Residual oil, small gas column	M. australis	No	Yes	Yes
Antelope 1	No	Hauterivian	Yes	No	?
Antler 1	Gas and oil columns	M. australis	Yes	Yes	Yes
Border 1	Slight fluorescence, gas	M. australis	Yes	Yes	Yes
Campbell 1	Very minor gas	-	?	?	No
Candace 1	No	Birdrong / Mardie	Yes / Poor	?	?
Carolina 1	No	Mardie / Barrow	Poor	Yes	Maybe
Centaur 1	Gas and oil	M. australis	Yes	?	?
Ceres 1	Poor shows	M. australis	No	?	?
Chamois 1	Gas	M. australis	Yes	Yes	Yes
Cherring 1	Dry gas	M. australis	Yes	Yes	Yes
Coojong 1	Residual oil show	M. australis	Yes	Yes	No
Corvus 1	Minor oil show (residual)	-	Yes	?	?
Elk 1	Dry gas column	M. australis	Yes	Yes	Yes
Eliassen	No	Mardie	Yes	?	No
Enderby 1	No	-	Yes	Yes	No
Gimlet 1	No	M. australis	Yes	Maybe	Maybe
Hampton 1	Minor	-	Yes	Yes	Yes
Hauy 1	No	-	Yes	Maybe	No
Hyacinthus 1	No	-	Yes	?	No?
Hyperno 1	No	M. australis	Yes	No	Yes
Jaubert 1	Oil	Berriasian	Yes	Yes	Yes
Kanji 1	No	M. australis	Yes	No	No?
Lawley 1	No	-	Yes	Maybe	Yes
Lauchie 1	Minor oil	Early Cret.	Yes	No	?
Legendre 1	Oil	Lower Neocomian	Yes	Yes	Yes
Longhorn 1	No	M. australis	No	Yes	No
	Minor shows	Greensands	?	?	No
Morrel 1	Column of dry gas	Windalia sst / M. australis	Yes	Yes	Yes
Nickol Bay 1	No	-	Yes	Yes	Yes
Oryx 1	Oil shows	M. australis	Poor	?	No
Reindeer 1	No movable	M. australis	Poor	?	?
Rhebok 1	No	M. australis	No	Yes	No
Saffron 1	Minor gas and oil	M. australis	?	?	?
Sage 1	Oil column	Valangian - Hauterivian	Yes	Yes	Yes
Springbok 1	Poor shows	M. australis	Yes	?	Yes
Stag 1	Oil and gas	M. australis	Yes	Yes	Yes
Tingle 1	No	M. australis	Yes	Yes	Yes
Tusk 1	Minor oil shows (residual)	M. australis	Yes	?	?
Wandoo 1	Gas and oil	M. australis	Yes	Yes	Yes
Whitewood 1	No	M. australis	Yes	No	No

Table 2: Petroleum system components at the Lower Cretaceous level (from well completion reports, Geoscience Australia Petroleum Wells Database and SPCPL (2002)).

Although it appears that the wells highlighted in red in *Table 2* have the necessary reservoir, seal and trap in place they do not have any evidence of hydrocarbons. These will be examined in more detail:

Nickol Bay 1: The lack of hydrocarbons at this location is unusual. Cherring 1 and Coojong 1 which are located down dip have dry gas and a residual oil show respectively.

Gimlet 1 and Lawley 1: As mentioned in *Section 6.1* there is some uncertainty about the integrity of the seal and the structure at Gimlet 1. However, the lack of hydrocarbons or fluorescence at this level in any well in this part of the study area seems to suggest the lack of effective migration pathways to these two wells.

Tingle 1: This well appears to be in the migration shadow of the Wandoo Field.

Basin Modelling

3D basin modelling by *Thomas et al (2004)* was used to track migration pathways from the Lewis Trough at base Cretaceous level. It showed that at 65Ma and at 0Ma there is migration along several narrow pathways into the study area. Unfortunately the study did not extend to the Enderby Terrace however it is possible to show the entry points of these pathways on the BCU TWT map *(Figure 7.4)*. Five entry points were identified: 1 and 2 were active at both 0 and 65Ma, 3 and 5 were only active at 0Ma, while 4 was only active at 65Ma. As mentioned previously in *Section 4* expulsion was much greater between 65-32Ma than it was during 32-0Ma *(Thomas et al, 2004)*. Potential migration pathways to Strike Oil's blocks can be drawn on *Figure 7.4*. Evidence for faults being sealing / leaking from *Section 7.3* is incorporated into these pathways. Although these migration pathways are not particularly accurate they can be used as evidence for the potential charging of plays of Berriasian and to a lesser extent M. australis aged sands.

Pathway 1 - This appears to be charging the Stag Field. Assuming that the faults are not sealing and that there is sufficient charge and carrier beds it is likely that this pathway would reach Strike Oil's acreage.

Pathways 2 - This appears to be heading towards the Wandoo Field. Assuming they can reach the Wandoo Field onwards migration is unlikely due the fact the Wandoo Field has not been filled to spill point (as recognised by the migration shadow effect observed at Tingle 1). Assuming the fault to the east of Wandoo 1 is sealing at the BCU level - as it would appear to be due to the large volume of hydrocarbons in the Wandoo Field, then the hydrocarbons may be deflected to the south-west along the fault. This would mean it is possible that it reaches the blocks of interest.

Pathways 3, 4 and 5 – None of these pathways are capable of reaching Strike Oil's blocks. The lack of any fluorescence in the wells of this part of the study area at lower Cretaceous level suggests that there is either a possible barrier to migration between the entry point and the edge of the Sub-Basin such as a fault or that the charge was insufficient to reach very far. It is therefore possible that there is an undiscovered accumulation of hydrocarbons in this area of the basin between the kitchen and the edge of the seal.

A further pathway? – It seems likely that there is at least one other pathway entering to the east of Corvus 1. This area is not covered by *Thomas et al (2004)* but it would explain the accumulations seen at wells such as Chamois 1 and Oryx 1. As far west as Altostratus 1 it appears that migration has occurred at M. australis level. Although the reservoir quality here is poor, fluorescence and the presence of gas is a strong indicator of migration through the area *(Strike Oil, 2006).* A possible pathway is shown by a black arrow continuing from Chamois 1 which shows that any hydrocarbons travelling through the area of these wells will be diverted to the south away from Strike Oil's blocks.

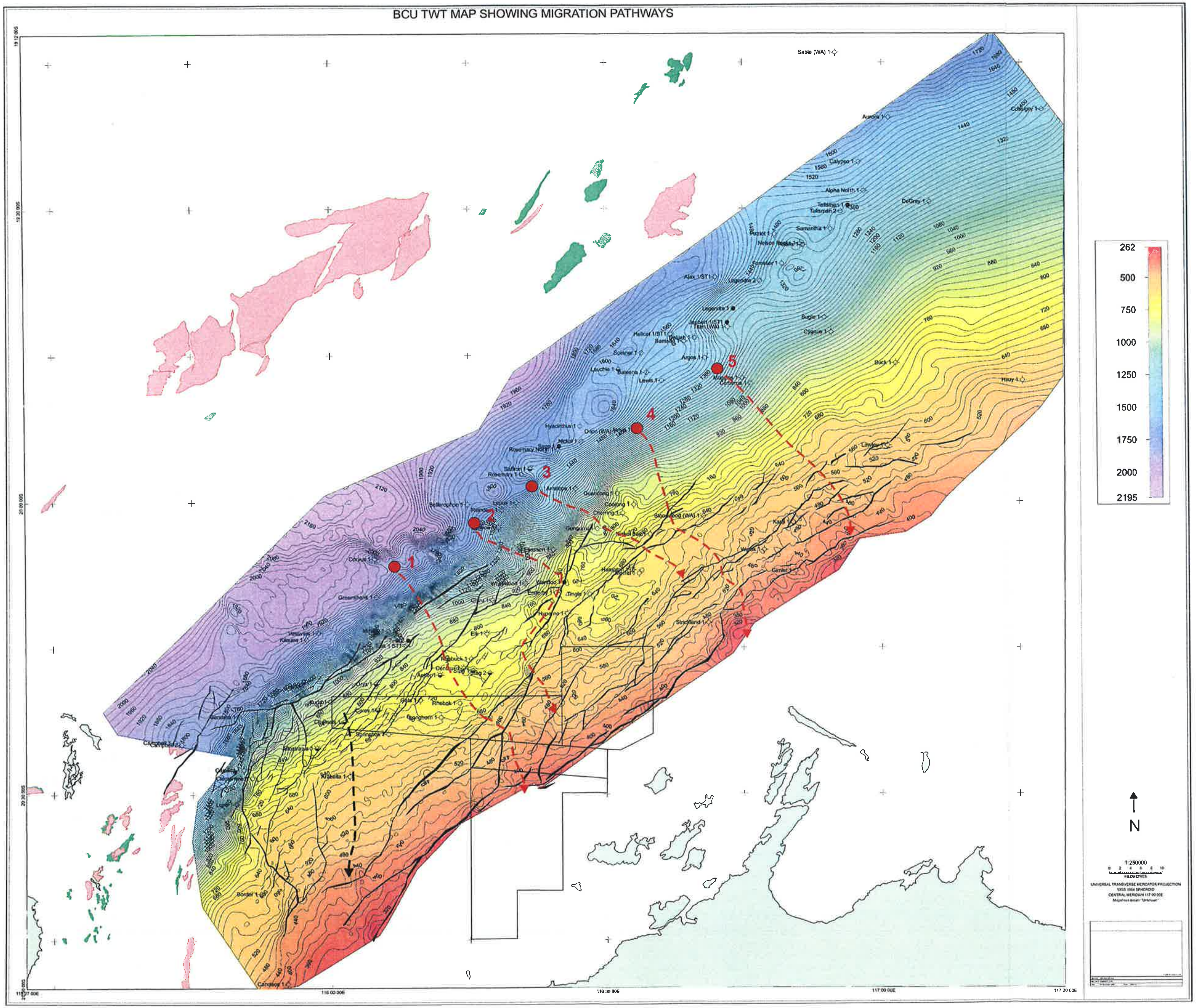

Figure 7.4: TWT Map showing migration pathways at BCU level at 65Ma and 0Ma.

7.5 Migration at Jurassic Level

Table 3 reviews the information available on petroleum system components present at the Jurassic level for several wells.

Well	Hydrocarbons	Formation / Age	Reservoir Present?	Seal Present?	Valid Structure?
Altostratus 1	No	Athol	Yes	Maybe	Yes
Baleena 1	No	Oxfordian	No	No?	?
Campbell 1	No	-	Yes	?	No
Caribou 1	Gas column	Legendre	Yes	Yes	Yes
Carloina 1	No	Dingo / Athol	No	?	?
Ceres 1	Oil shows	Athol	Yes	?	?
Chamois 1	Residual oil	Bajocian / Athol	?	No	?
Cherring 1	Minor oil shows	Pliensbachian	Yes	Maybe	Yes
Clementine 1	No	Athol	Poor	Yes	Maybe
Coojong 1	No	North Rankin	Yes	Poor	No
Corvus 1	Gas column	North Rankin	Poor	Yes	Yes
Cygnus 1	No	North Rankin	Yes	No	Yes
Eliassen	No	Oxfordian	Yes	No	Yes
Hyacinthus 1	No	Angel	Yes	Yes	No?
Janus 1	Immovable oil column	Eliassen / Angel	Yes	Yes	Yes
Lepus 1	No	Legendre	Yes	No	No
Oryx 1	Oil	Athol	Yes	Yes	Yes
Reindeer 1	Gas	Legendre	Yes	Yes	Yes
Saffron 1	Minor gas and oil	Angel	?	?	?
Sage 1	Oil column	Angel	Yes	Yes	Yes
Samson 1	Minor gas	Lower – Mid Jurassic	Poor	?	?
Spinner 1	Weak fluorescence	Oxfordian	No	?	?
Strickland 1	Fluorescence	Bajocian	Yes	No	No
Talisman 1	Minor oil and gas	-	Yes	Yes	Yes
Tusk 1	Oil column	Athol	Yes	Yes	Yes
Wandoo 1	Gas column	Aaleian	Yes	?	?

Table 3: Petroleum system components at the Jurassic level (from well completion reports and Geoscience Australia Petroleum Wells Database).

The wells closest to Strike Oil's acreage which exhibit fluorescence within Jurassic aged sediments are Chamois 1, Ceres 1, Wandoo 1 and Strickland 1. Fluorescence is notably absent in Longhorn 1 and Rhebok 1 and wells surrounding the Stag Field. If we look at Strickland 1 which is located just to north east of the blocks of interest we can see sample fluorescence within the Bajocian aged rocks (between 590 and 540m) probably representing minor residual liquid hydrocarbons *(Hudbay Oil Australia Ltd., 1982)*. It is therefore likely liquid hydrocarbons have migrated through structure and continued up-dip to the south-east. This means that there is a migration pathway existing from the Dingo Trough kitchen area to the edge of the basin and it suggests that there is migration up faults. Strickland 1 is the well furthest from the source kitchen where fluorescence has been observed. It is just over 10km north-east of the edge of WA-340P and therefore is important evidence that migration could also occur at similar levels into this and Strike Oil's other blocks.

7.6 Migration at Triassic Level

Table 4 reviews the information available on petroleum system components present at the Triassic level for several wells.

Well	Hydrocarbons	Formation / Age	Reservoir Present?	Seal Present?	Valid Structure?
Altostratus 1	Gas column	Mungaroo	Yes	Yes	Yes
Arabella 1	No	Mungaroo / Locker	Yes	Yes	Yes
Candace 1	No	Mungaroo / Basal Trias.	Yes	?	No
Caribou 1	Gas and oil shows	Mungaroo	Yes	Yes	No
Clementine 1	No	Mungaroo	Yes	Yes	Maybe
Coojong 1	No	Mungaroo	Yes	Yes	Yes
Corvus 1	Gas column	Mungaroo	Yes	Yes	Yes
Kudu 1	No	Mungaroo	Yes	Yes	Maybe
Nickol Bay 1	No	Mungaroo	Yes	No	?
Oryx 1	Residual oil column	Mungaroo	Yes	Yes	Yes
Tusk 1	Oil column	Mungaroo	Yes	Yes	Yes
Wandoo 1	No	Mungaroo	Yes	No	Yes

Table 4: Petroleum system components at the Triassic level (from well completion reports and Geoscience Australia Petroleum Wells Database).

The table shows that there is some migration occurring at the Triassic level. However the highlighted wells appear to have the relevant components in place but do not have any shows or fluorescence which is probably due to a lack of a valid migration pathway. There appears to be some migration to the west of the study area as far as Altostratus 1 but there is no evidence of a migration pathway capable of filling Triassic plays within Strike Oil's blocks. However, this may be due in part to the lack of wells which reach sufficient depths.

Too few wells reach Triassic sediments to trace an accurate migration pathway from the source kitchen. *Figure 7.5* shows that in order for any Base Locker Sand traps within block WA-340-P to be charged there must be up-fault migration. This appears to be happening at faults of similar orientations at different levels. A ramp like structure can also be seen which would enable migration into blocks WA-261-P, TP/19 and EP 421.

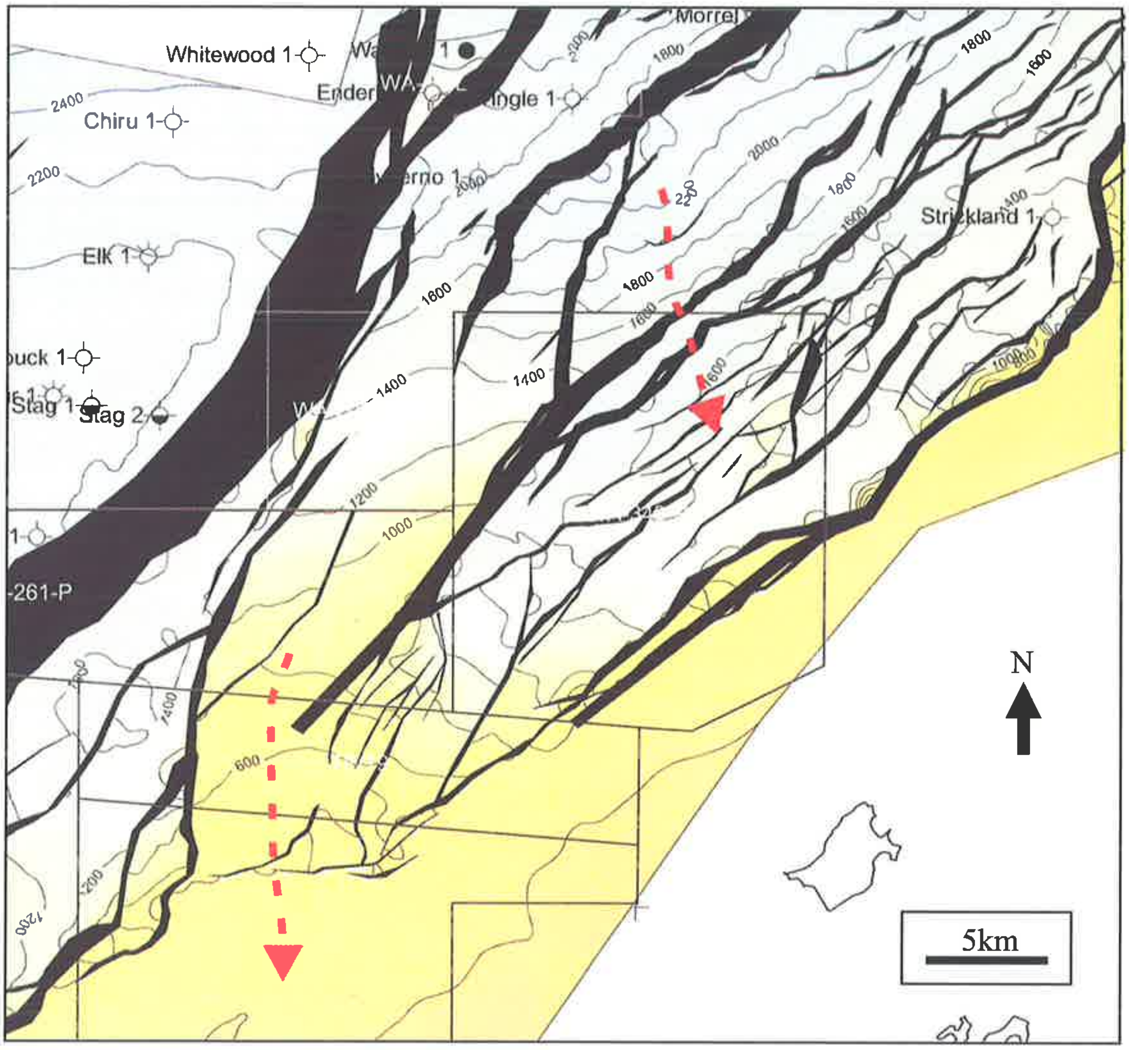

Figure 7.5: TWT map of top Basement showing possible migration pathways as red arrows.

7.8 Oil or Gas?

The general trend for the study area and the North West Shelf as a whole is that oil is found inboard and gas outboard – nearer the source kitchen. Following this logic it would seem probable that any discoveries within Strike Oil's acreage will be oil. However it is not that simple – for instance gas has been found at Border 1 and Altostratus which are just down dip from Strike Oil's blocks suggesting that (to the SE of the study area at least) discoveries may be gas or a combination of oil and gas.

8. Conclusions

Source

Geochemical analysis has proven that many of the large hydrocarbon accumulations within the study area have been sourced from the W. spectabilis interval within the Dingo Claystone. Basin modelling has shown that wells closer to the shore do not reach sufficient maturity to generate large quantities of hydrocarbons. It is therefore necessary to look further a field for the source kitchen to the Lewis Trough area where sediments have been buried to greater depths. It has been shown that there is a valid source kitchen potentially within reach of Strike Oil's acreage. However, it will require long range migration for the hydrocarbons to reach the acreage.

Reservoir

Several potential reservoirs have been identified – several lower Cretaceous sands including those of M. australis and Berriasian ages, Intra Athol sands, the Mungaroo Formation and the Base Locker Sand. The Legendre Formation is unlikely to be present in Strike Oil's blocks. There is some uncertainty about the presence of the M. australis sand in the acreage due to its pinch-out to the north but its presence cannot be ruled out. Well logs and seismic mapping show that the Athol and Mungaroo Formations seem to be present in at least block WA-340-P. It is unknown if the Base Locker Sand is present – it can be seen along strike at Gimlet 1 however it has poor reservoir quality.

Seal

The Muderong Shale is a proven seal in the Dampier Sub-Basin and is laterally extensive throughout the whole of the study area including blocks WA-261-P, WA-340-P, TP/19 and EP 421. The Athol Formation has been proven to act as a seal at Altostratus 1 to the west of the acreage, holding back a 3m hydrocarbon column. The Locker Shale is an unproven seal throughout the study area.

Traps

Potential traps within the lower Cretaceous and Athol to Mungaroo Formations exist within Strike Oil's blocks. Seismic mapping done for this study supports the possible existence of Strike Oil's "Sherlock Lead" and "Sharp Peak Prospect". There is however some uncertainty concerning the effectiveness of the seal at Play 2. There is also a possibility of a Base Locker trap.

Migration Pathways

Studies of the distribution of hydrocarbon accumulations, shows and fluorescence have shown that there has been migration at lower Cretaceous, Jurassic and Triassic levels from the source kitchen towards the south-east. It also appears that there has been up-fault migration along faults oriented north-east to south-west within the study area. At the lower Cretaceous level hydrocarbons have migrated at least as far as the Stag Field to the north east and Longhorn 1 and Springbok 1 to the east of the acreage. It seems possible that further migration may have occurred into Strike Oil's blocks at this level. The presence of fluorescence within Bajocian aged sediments at Strickland 1 proves that long range migration can occur at this level and increases the chances of hydrocarbons migrating into WA-340-P. There also appears to have been some migration to the west of the study area at Triassic (Mungaroo Formation) levels at least as far as Altostratus 1 but this seems unlikely to be able to charge Strike Oil's acreage. The lack of any Triassic fluorescence further west makes it uncertain if any Base Locker Sand plays would be charged.

It appears that any well drilled within blocks WA-261-P, WA-340-P, TP/19 and EP 421 is going to be of a reasonably high risk. There is a level of uncertainty for the presence of all the components of the petroleum system with the exception of source rocks. The greatest uncertainty is probably associated with the large distance hydrocarbons are required to travel. There is a proven source kitchen in the area however further the migration from this kitchen the more uncertainty associated with them. Even if migration does occur into the acreage there is no guarantee it will be in economic volumes. As recommended below the best way to investigate this further is the creation of a 2D or 3D basin model. This would allow the user to play out several different scenarios such as changing faults properties from sealing to non-sealing to see how this affected migration within the study area.

Recommended Further Work

- Depth conversion of the seismic data to allow the construction of a 2D or 3D basin model for investigation of migration pathways.
- Improved seismic interpretation.
- An in depth study of fault seals within the study area using stress data.
- More work could be done to completely rule out the generation of hydrocarbons locally from Triassic beds.

References

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APACHE ENERGY LTD., 2000 – Corvus 1 & Corvus 1 ST1 well completion report.

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APACHE ENERGY LTD., 2005 – Reindeer 1 well completion report – interpretive data.

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Appendix 1

The following table summarises the data available for the wells in study area.

Well	Well Completion Report (with geological data)	Log Data	WAPIMS Formation Tops
Ajax 1/ST1	No	No	No
Alpha North 1	Yes	Yes	Yes
Altostratus 1	Yes	No	No
Antelope 1	Yes	Yes	No
Antler 1	Yes	Yes	No
Arabella 1	Yes	Yes	Yes
Argos 1	Yes	No	No
Aurora 1	Yes	Yes	Yes
Baleena 1	Yes	No	Yes
Bandera 1	No	No	No
Bellerophon 1	No	Yes	Yes
Bloodwood 1	No	No	No
Buck 1	Yes	Yes	No
Bugle 1	Yes	Yes	No
Border 1	No	No	No
Calypso 1	Yes	Yes	Yes
Campbell 1	No	No	Yes
Campbell 2	No	No	Yes
Candace 1	Yes	No	Yes
Caribou 1	Yes	No	No
Carolina 1	Yes	Yes	No
Centaur 1	No	Yes	Yes
Cerberus 1	Yes	No	No
Ceres 1	Yes	Yes	No
Chamois 1	Yes	Yes	No
Cherring 1	Yes	No	No
Chiru 1	Yes	No	No
Clementine 1	Yes	Yes	No
Coojong 1	Yes	Yes	Yes
Corvus 1	Yes	Yes	No
Cossigny 1	Yes	Yes	Yes
Cygnus 1	Yes	No	Yes
DeGrey 1	Yes	Yes	Yes
Delilah 1	Yes	No	No
Elk 1	Yes	Yes	No
Eliassen 1	Yes	Yes	Yes
Enderby 1	No	Yes	Yes
Forestier 1	No	Yes	Yes
Gats 1	Yes	No	No
Gimlet 1	Yes	Yes	No
Greenshank 1	No	Yes	No
Gungurru 1	No	No	No
Hampton 1	Yes	Yes	Yes
Hauy 1	Yes	Yes	Yes
Helicon 1	Yes	Yes	No
Hellcat 1/ST1	Yes	Yes	No
Hyacinthus 1	Yes	Yes	No
Hyperno 1	No	Yes	Yes

Janus 1	Yes	No	No
Jaubert 1	Yes	No	No
Kanji 1	Yes	No	Yes
Kilauea 1	No	No	No
Kudu 1	Yes	Yes	No
Lawley 1	No	Yes	Yes
Lauchie 1	No	No	Yes
Legendre 1	Yes	Yes	Yes
Legendre 2	No	No	Yes
Lepus 1	Yes	No	No
Lewis 1	No	No	No
Longhorn 1	Yes	Yes	No
Lotte 1	No	No	No
Lynx 1	No	No	No
Mawby 1A	Yes	Yes	Yes
Montebello 1	No	Yes	Yes
Morrel 1	Yes	Yes	No
Muggles 1	No	No	No
Nelson Rocks 1	No	No	Yes
Nickol 1	Yes	Yes	No
Nickol Bay 1	No	Yes	Yes
Orion 1	No	Yes	Yes
Oryx 1	Yes	Yes	No
Patriot 1	Yes	Yes	No
Polaris 1	Yes	Yes	No
Quandong 1	Yes	Yes	No
Reindeer 1	Yes	No	No
Rhebok 1	Yes	Yes	No
Roebuck 1	Yes	No	No
Rosemary 1	No	Yes	Yes
Rosemary North 1	No	Yes	Yes
Saffron 1	No	Yes	No
Sage 1	Yes	No	No
Samantha 1	No	No	No
Samson 1	No	No	Yes
Spinner 1	No	No	No
Springbok 1	Yes	Yes	No
Stag 1	Yes	Yes	Yes
Stag 2	No	No	Yes
Strickland 1	Yes	Yes	Yes
Talisman 1	No	Yes	Yes
Talisman 2	No	No	Yes
Tingle 1	Yes	Yes	Yes
Titan 1	Yes	No	No
Tusk 1	Yes	Yes	No
Tusk 2	No	No	No
Vesuvius 1	Yes	Yes	No
Wandoo 1	Yes	Yes	Yes
Whitewood 1	Yes	Yes	No
Wurak 1	No	No	No