Department of
Mineral and Petroleum Resources

Petroleum Prospectivity of the Eastern Canning Basin, WA

TROY·IKODA
AUSTRALASIA

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EXECUTIVE SUMMARY

The Canning Basin is one of a series of large intracratonic basins that spans northwestern and central Australia. The Canning Basin is known to be prospective, with five commercial oil fields in operation. The study area in the southeast onshore Canning Basin is prospective, but considered frontier territory.

Data available in and around the study area is generally sparse and of moderate quality. However, a number of regional geological studies have been conducted. Seismic data consists of eight 2D surveys with generally low to moderate data quality. Seismic coverage is moderate and confined mainly to the northern region of the study area. Landsat imagery, as well as magnetic and gravity data is available over the entire study area. Three exploration wells have been drilled (Point Moody-1, White Hills-1 and Lake Hevern-1), one of which (White Hills-1) displays promising hydrocarbon shows.

The Silurian to Late Carboniferous interval has been focussed on, due to data coverage and resolution. Five horizons have been seismically mapped. However, the data quality does allow for highly detailed mapping.

Wells drilled to date, in and around the area, have generally been unsuccessful in locating hydrocarbon accumulations primarily due to the lack of structural closure, originally unrecognised due to poor seismic data quality, and a misunderstanding of the timing of hydrocarbon migration.

Good reservoir, seal and source rocks can be found throughout the geological succession, many of which contain good intraformational seals.

Source rocks in the area reached maturity during three main time periods; 1) Triassic to post Triassic – Noonkanbah and Anderson Formations, 2) Carboniferous to Permian – Gogo and Luluigui Formations and Fairfield Group, and 3) Devonian – Willara and Goldwyer Formations. Trap timing versus maturity is concluded to be the critical factor in locating hydrocarbon accumulations. The presence of reservoirs, seals and adequate source is not a significant risk within the study area. However, identifying structures pre-dating source maturity is the key to successful exploration.

Stratigraphic, structural and combined stratigraphic/structural plays have been identified within the area. The combined stratigraphic/structural plays are considered the most prospective. Specifically, the Devonian to Carboniferous reservoirs sub-cropping the Base Grant Group unconformity at their pinch-out edge along the southern Gregory Sub-basin margin are deemed most prospective. Traps have been formed by erosion followed by subsequent deposition of the Grant Group in the Late Carboniferous. This has resulted in reservoirs within trap configurations, potentially charged by source rocks maturing during the Late Carboniferous, Permian and Triassic (Gogo Formation, Luluigui Formation, Fairfield Group and Anderson Formation).

A number of promising and exciting leads have been identified and several have been worked up to show volumetrics and reserves. Conceptual development planning has enabled Net Present Value (NPV) to be estimated for the development of the smallest of these prospects, which in the event of a discovery has P90 recoverable hydrocarbons of 2.17 MMbbls. The project NPV is US$4.3MM at P90 volumes, increasing to US$20.3 at the P50 level. Once risked, the Expected Monetary Value (EMV) of the project is positive at P90, and US$3.53MM at P50.

This area represents a low cost exploration opportunity to gain significant leverage from a modest investment, and will immediately add value to most junior explorers portfolio valuation.

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1. INTRODUCTION

This report presents the results of a petroleum prospectivity study over a 30,000 square kilometre area in the eastern Canning Basin, Western Australia (Figure 1.1). The area has been selected for acreage release in 2002. The study has been carried out by Troy-Ikoda Australasia Pty Ltd in conjunction with the Western Australian Department of Mineral and Petroleum Resources.

1.1. DATA

All relevant well data, submitted operator and non-operator reports, and seismic data have been made available for use in this study.

Eight wells are present within the study area (Tables 1.1 & 1.2): Stansmore Range 1-5, Point Moody-1, White Hills-1 and Lake Hevern-1. Stansmore Range 1-5 are shallow mineral exploration wells; little data is available for these wells. Well completion reports, associated data and digital log data were made available for Point Moody-1, White Hills-1 and Lake Hevern-1 as well as similar data from relevant wells in the vicinity of the study area, i.e. Ngalti-1, Kilang Kilang-1, Contention Heights-1, Wilson Cliffs-1, Patience-1 and Kidson-1 (Enclosures 1, 2 & 3).

Approximately 8,000 km of re-scanned 2D seismic is available within the study area. This has been made available along with associated acquisition, processing and interpretation reports (Enclosures 4–14).

Magnetic and gravity survey data, and Landsat images were used in this report over the study area (Table 1.3).

Well Name	Latitude	Longitude	Year	TD (m)
Contention Heights-1	22 25 30.93S	127 13 35.71E	1973	1790.7
Kidson-1	22 36 54.52S	125 00 39.69E	1965	4431.5
Kilang Kilang-1	20 12 41.91S	127 07 41.64E	1984	2300.0
Lake Hevern-1	21 27 52.04S	127 34 44.20E	1998	2296.0
Ngalti-1	19 52 02.90S	127 18 50.63E	1984	2758.0
Patience-1	23 21 40.98S	125 40 11.83E	1986	1869.0
Point Moody-1	21 15 28.90S	127 48 26.66E	1965	2441.1
White Hills-1	21 09 15.26S	127 35 19.64E	1982	4148.0
Wilson Cliffs-1	22 16 33.95S	126 46 59.71E	1968	3722.2

Table 1.1 Wells reviewed in this study

WELL	SPUD DATE	TD (mKB)	Interval	Status	Shows		WCR	Digital Logs	Geochemistry	DST	Costs / Development	Geo. Interp.		TIG Petrophysics	Seismic Tie
					GAS	OIL									
Lake Hevern-1	1998	2296.0	Early Perm. - Late Dev.	Dry	Nil	Nil	Basic	Y - 23 Logs	?	?	?	Basic		Y	Y
Patience-1	1986	1869.0	Late Jur. - Early Dev.	Dry	Nil	Nil	Y	Y - 9 Logs	Y	N	N	Y		Y	?
Ngalti-1	1984	2757.8	Late Perm. - Late Dev.	Dry	Nil	Nil	Y	Y - 21 Logs	N	N	N	Y		N	?
Kilang Kilang-1	1984	2300.0	Early Perm. - Early Carb.	Dry	Nil	Nil	Y	Y - 19 Logs	Y	N	N	Y		Y	?
White Hills-1	1982	4148.0	Early Perm. - Late Dev.	Dry	Fair	Fair	Y	Y - 20 Logs	Y	Y	Y	Y		Y	Y
Contention Heights-1	1973	1790.0	Late Perm. - Early Ord.	Dry	Nil	Nil	Y	Y - 12 Logs	Y	N	N	Y		N	?
Wilson Cliffs-1	1968	3722.0	Early Perm. - Early Ord.	Dry	Nil	Poor	Y	Y - 14 Logs	N	Y	N	Y		Y	?
Point Moody-1	1965	2441.0	Early Perm. - Early Carb.	Dry	Poor	Nil	Y	Y - 8 Logs	Y	Y	N	Y		N	N
Kidson-1	1965	4431.5	Jur. - Lwr Ord.	Dry	Nil	Nil	N	Y - 7 Logs	?	?	?	?		N	?
Stansmore Range-1–5	1964	300.0-500.0	Early Perm.	Dry	Nil	Nil	Y	N	N	N	N	V. Basic		N	N

Table 1.2 Summary of wells reviewed in this study

Magnetics			
Survey	**Details**	**Coverage**	**Format**
Wilson/Webb (1998)	400m line spacing / 80 m AGL	30% south	located line data or ERMapper (.ers)
BMR Regional Data (1980-88)	compilation of 1500-2000 m line spacing		
	/100-150 m AGL surveys	70% north	ERMapper (.ers)
Gravity			
Survey	**Details**	**Coverage**	**Format**
6437 (1964)	5 km grid and 1/2 mile traverse data	50% central east	located point data
6805 (1968)	11 km grid	50% northwest and south	located point data
6744	1/2 mile traverse data		located point data
6837	1/2 mile traverse data		located point data
7044	1/2 mile traverse data		located point data
Landsat			
	Details	**Coverage**	**Format**
	Bands 7,4,1 only	100%	BIL

Table 1.3 Magnetic, gravity and Landsat data made available for this study

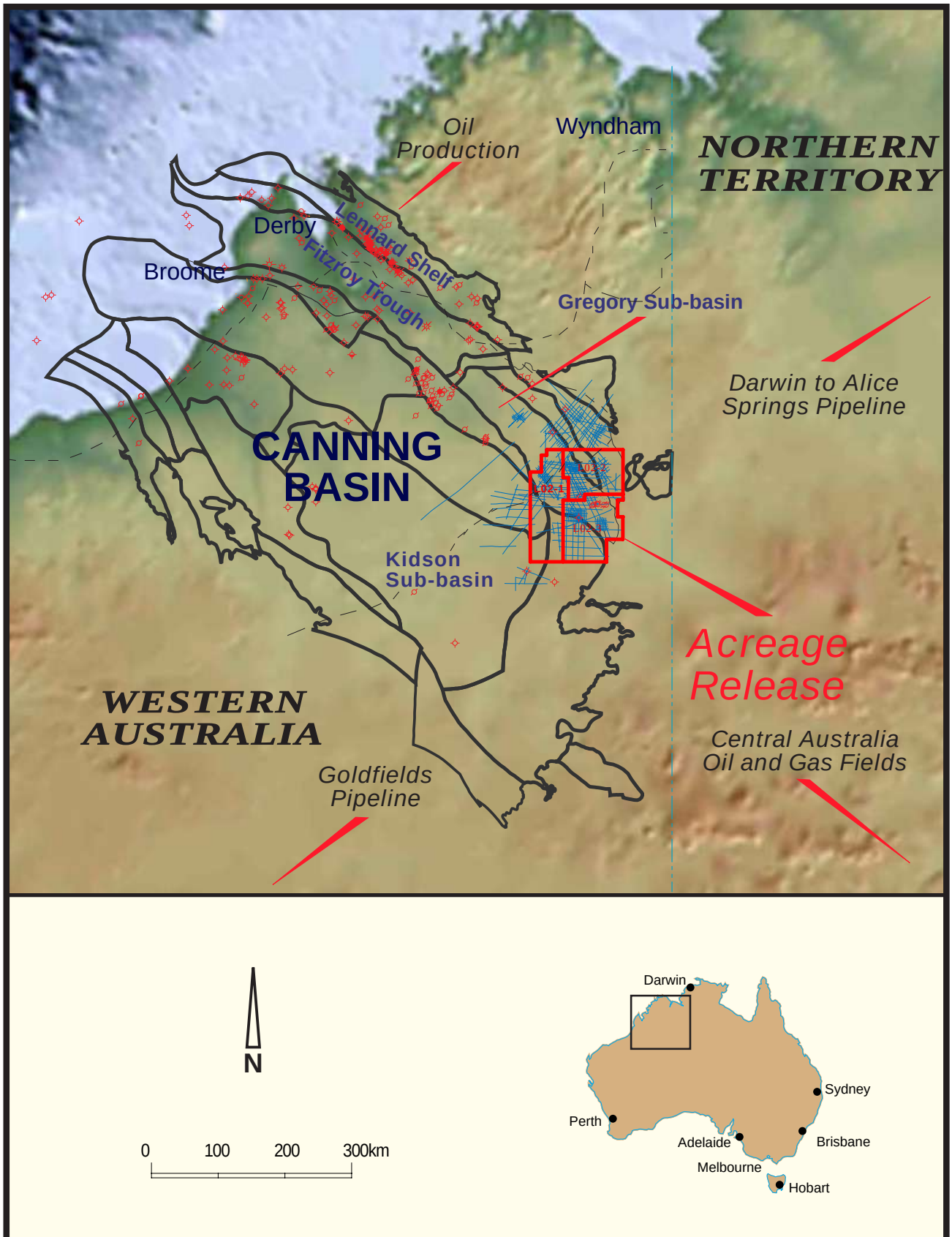

Figure 1.1. Study Area Location

2. EXPLORATION HISTORY

Exploration interest in the Canning Basin began in 1919 after water bores showed traces of oil at Prices Creek in the Pillara Range. Three of the four Prices Creek wells yielded traces of oil in massive limestone, which was regarded as Early Carboniferous in age. From 1923 to 1925, three more wells were completed in the Fitzroy River Valley on structures around Mt Wynne. In Mt Wynne-3, traces of oil and bitumen were reported from sandstones, deposited unconformably over Early Carboniferous limestones (Reynolds and Flavelle, 1984). Encouraging hydrocarbon shows were reported from Poole Range-3 and 5 and Nerrima-1 (Reynolds and Flavelle, 1984).

Since these first shows of oil, over 100 exploration wells have been drilled and 30,000 km of variable quality seismic has been recorded. Petroleum exploration interest was rekindled in the Canning Basin with the 1952 Bureau of Mineral Resources (BMR) Reconnaissance Gravity Program. Between 1952 and 1962, reconnaissance gravity, aeromagnetic and surface mapping was carried out by Western Australian Petroleum Pty Ltd (WAPET) and the BMR.

Steady exploration by WAPET and others in the period up to 1975 failed to locate commercial hydrocarbons. However, renewed exploration in the late 1970s, generated by favourable government policies, resulted in the first significant oil flow at the Blina-1 well on the Lennard Shelf in 1981. The Blina field development became the first commercial oilfield in the Canning Basin. This successful discovery prompted more interest in the local area and the company that operated Blina-1, Home Energy Company Ltd, also discovered oil in clastic sediments of the Grant Group and Anderson Formation in the Sundown-1 well in 1982.

The original oil shows in the 1920s resulted in the Devonian limestones becoming a prime exploration target. It was this target, in particular Late Devonian to Early Carboniferous carbonates, that became the focus of greater attention due to the Blina-1 discovery and the play type associated with it became the centre of further exploration projects. Up until the late 1980s, exploration focused on the northern basin/shelf and mid basement arch areas where thousands of kilometres of seismic data were acquired. Although many exploration wells had oil shows, only five discoveries resulted in commercial oil fields (Cartright, 1999). These were the Blina, Boundary, Lloyd, Sundown and West Terrace oilfields.

Within the eastern Canning Basin, exploration has been fairly limited. From 1962 to 1975, 1800 line-km of reflection seismic data were recorded and four exploration wells were drilled. Of these wells, only two (Lake Betty-1 and Point Moody-1) were drilled in the Gregory Sub-basin (Jacobson, 1984). Point Moody-1, drilled in 1965 - 1966 was located on a surface anticline. No shows were recorded from either of these wells and later seismic show that it is doubtful the wells were on a closed structure (Warris, 1991). Stansmore Range-1 to 5 are shallow stratigraphic wells drilled in 1964 and only showed water.

Between 1980 and 1982, exploration resumed in the area and almost 8,000 line-km of seismic data was acquired. White Hills-1, drilled by Mobil Exploration and Production Services in 1982, encountered over 1000 m of hydrocarbon shows through the Anderson Formation and Fairfield Group.

Ngalti-1 and Kilang Kilang-1 were drilled in 1984. Ngalti-1 was drilled on a tilted fault block, while Kilang Kilang-1 was drilled on an anticlinal structure and both failed to encounter any significant hydrocarbon shows (Warris, 1991). The most recent well,

Lake Hevern-1, drilled in 1998 by Amity Oil, evaluated the potential of the Ordovician Nita and Goldwyer Formations. Secondary targets were prognosed within the sandstones of the Carribuddy Group and the Devonian age Tandalgoo Formation. No oil shows were noted, although minor gas shows were recorded in tight sandstones.

WAPET drilled the first exploration wells in the Kidson Sub-basin, Kidson-1 and Sahara-1. They were located on poorly controlled seismic and no hydrocarbon shows were evident. Between 1968 and 1973, Wilson Cliffs-1 and Contention Heights-1 were drilled in the eastern part of the sub-basin. These wells were not drilled on valid structures (Howell, 1984), but encountered fluorescence and gas shows from Ordovician shales. The most recent well drilled in the Kidson Sub-basin was Patience-1 in 1986 (Patience-2 is currently being drilled and thus no data is available). Patience-1 was drilled to test a structural high in the southeast of the basin but recorded no hydrocarbon shows. Reservoir potential within the Grant Group is considered excellent although structural closure is not present.

The Lennard Shelf has been the most prospective in terms of petroleum exploration. Currently, exploration activity is concentrated on the Lennard Shelf, Broome Platform and Fitzroy Trough. The southeastern Canning Basin remains largely unexplored with less than a dozen exploration wells drilled and only a few thousand kilometres of seismic data acquired in an area of 200,000 sq km (Purcell, 1984).

3. REGIONAL GEOLOGICAL SETTING

The Canning Basin is one of a series of large intracratonic basins that spans northwestern and central Australia. Throughout its 500 million year history, the basin has undergone a complex structural evolution and has been controlled by several major tectonic events that have resulted in the development of several basin phases.

Sedimentation in the region began as early as the Late Proterozoic (Officer and Amadeus Basins) and continued through to the Permian (Canning and Bonaparte Basins). These four basins are separated by large Precambrian metamorphic blocks and shallow basement arches of Archaean granitoids and metasediments (Brown et al., 1984).

The Canning Basin is bounded to the northeast and southwest by crystalline basement of the Kimberley and Pilbara Blocks, respectively, and to the south and east by the Officer and Amadeus Basins along with the Musgrave Block. An arch of Late Proterozoic sediments defines its separation to the east from the Amadeus Basin and an area of shallow basement, recognised as the Warri Arch, defines its boundary with the Officer Basin.

Thick Mesozoic sediments and Cainozoic rifted margin sequences, similar to those evident along the rest of Australia's northwest margin characterise the offshore Canning Basin. Within the onshore Canning Basin, the sedimentary sequence comprises up to 15 km of Palaeozoic sediments that are overlain by Mesozoic and Cainozoic units.

The northwesterly Palaeozoic structural trend, which defines major tectonic units in the onshore Canning Basin, continues offshore onto the continental shelf. On the shelf in the southern offshore Canning, a northeasterly structural trend has been superimposed on the older Palaeozoic trend associated with rifting and breakup of Gondwana during the Mesozoic (Cadman et al., 1993).

3.1. STRUCTURAL SUBDIVISION

The Canning Basin contains two major depocentres, trending in a northwesterly direction, separated by a mid-basin arch. To the north of this arch, lie the Gregory and Fitzroy Sub-basins and to the south lie the Kidson and Willara Sub-basins (Enclosure 1 and Figure 3.1).

The northern depocentres (Gregory and Fitzroy Sub-basins) contain Devonian and younger sediments, while the southern depocentre (Kidson and Willara Sub-basins) contain far thinner successions of dominantly Ordovician to Silurian age rocks. The Gregory and Fitzroy Sub-basins are constrained by the Lennard and Billiluna Shelves, and Balgo and Betty Terraces. Their southern margin is marked by the mid-basin arch, consisting of the Broome and Crossland Platforms, which contain thin Ordovician to Permian age strata.

The study area in the southeastern onshore Canning Basin covers four major structural provinces, 1) the Billiluna Shelf and Balgo Terrace on the basin margin to the north, 2) the Gregory Sub-basin, 3) the mid-basin arch Barbwire Terrace and Crossland Platform, and 4) the Kidson Sub-basin (Enclosure 1).

3.2. STRATIGRAPHIC EVOLUTION

Deposition in the Canning Basin began in the Early Ordovician (Figure 3.2), an initial transgression from the northwest resulted in approximately 1,000 m of sediment being laid down on a Precambrian erosional surface. Paralic and shallow marine mixed clastics and carbonates of the Nambeet Formation and platform carbonates on basement highs of the Willara Formation represent this early phase.

By the Middle Ordovician, deposition had slowed, shallow epeiric seas had formed and were restricted by this regressive phase. This regression initiated deposition of mixed clastics and carbonates of the Goldwyer Formation and dolomitised carbonates of the Nita Formation. Subaerial exposure and basin wide non-deposition in the Late Ordovician to Early Silurian marked the end of this first depositional megasequence (Warris, 1993).

A pre-rift phase followed this period. The Broome Platform and Fitzroy Trough became significant tectonic features (Cadman et al., 1993), transgression from the west produced restricted marine conditions and the evaporitic succession of the Carribuddy Formation was deposited in the Kidson Sub-basin and probably in the Fitzroy Sub-basin (Apak and Carlsen, 1996). Partial emergence in the Early Devonian resulted in aeolian sandstone deposition of the Tandalgoo Formation mainly in the southern basin depocentre, while marginal marine clastics of the Poulton Formation were deposited in the non-emergent northern depocentres.

Rifting during the Late Devonian established the Fitzroy Sub-basin (and related Gregory Sub-basin) as the major depocentres in the basin. This fault-bounded trough, flanked by shallow marine terraces was connected to a shallow epeiric sea in the south (Cadman et al., 1993). Carbonate deposition of the Pillara Limestone and Mellinjerie Formation dominated the shelves and terraces, while the depocentres underwent fine-grained clastic deposition of the Gogo Formation. A decline in subsidence rate or a fall in eustatic sea level in the earliest Famennian exposed the southern basin margin (Brown et al., 1984) and led to a cessation of deposition in the Kidson Sub-basin until Late Carboniferous times.

Increased transgression in the northern Canning Basin caused eventual drowning of the carbonate complexes in the Fitzroy and Gregory Sub-basins. A brief regressive phase and subsequent erosion of the northern margin produced carbonate and clastic breccias of the Napier and Virgin Hills Formations.

During the Late Devonian, the major northern depocentres saw prolific deep to shallow marine deposition of mixed clastics and carbonates of the Clanmeyer and Luluigui Formations, coupled with the minor reef deposits of the Nullara Limestone. Continued shallow marine conditions on the northern margin resulted in the deposition of clastic sediments of the Fairfield Group. A major subsequent regression accompanied by subsidence and rapid infill (thick Anderson Formation deltaic sediments) of the northern trough followed. A major transgression in the Late Carboniferous and accompanying basin wide erosion ended this period of deposition, known as megasequence 2 (Warris, 1993).

Subsidence commenced in the Latest Carboniferous and continued into the Triassic. This subsidence initially resulted in basin wide deposition of the Late Carboniferous to Early Permian marine to non-marine Grant Formation. Deposition of the Poole Sandstone followed, raising relative sea level and giving way to the marine shales and siltstones of the Noonkanbah Formation. The subsequent regression resulted in the

deposition of marine and deltaic sediments of the Liveringa Group. Late Permian rifting associated with Gondwanaland breakup may have resulted in an unconformity at the top of the Liveringa Group and subsequent transgression, resulting in the deposition of the Blina Shale. Minor marine regression prior to major basin rifting initiated deposition of the Erskine Sandstone. This rifting marked the end of megasequence 3 (Warris, 1993) and resulted in a basin wide erosional event.

Dextral movement along major faults of the Fitzroy and Gregory Trough during the Late Triassic to Early Jurassic, known as the Fitzroy movement, formed en echelon anticlinal structures and may have initiated a period of salt diapirism (Brown et al., 1984). Deposition recommenced in the Jurassic, with simultaneous continental breakup and marine transgression from the northwest. This transgression resulted in the deposition of the Wallal Sandstone and Alexander Formation. Conformable deposition of the Jarlemai Formation over these units represents maximum transgression. The last phase of Canning Basin deposition is marked by a regression, which deposited the shallow marine Broome Sandstone.

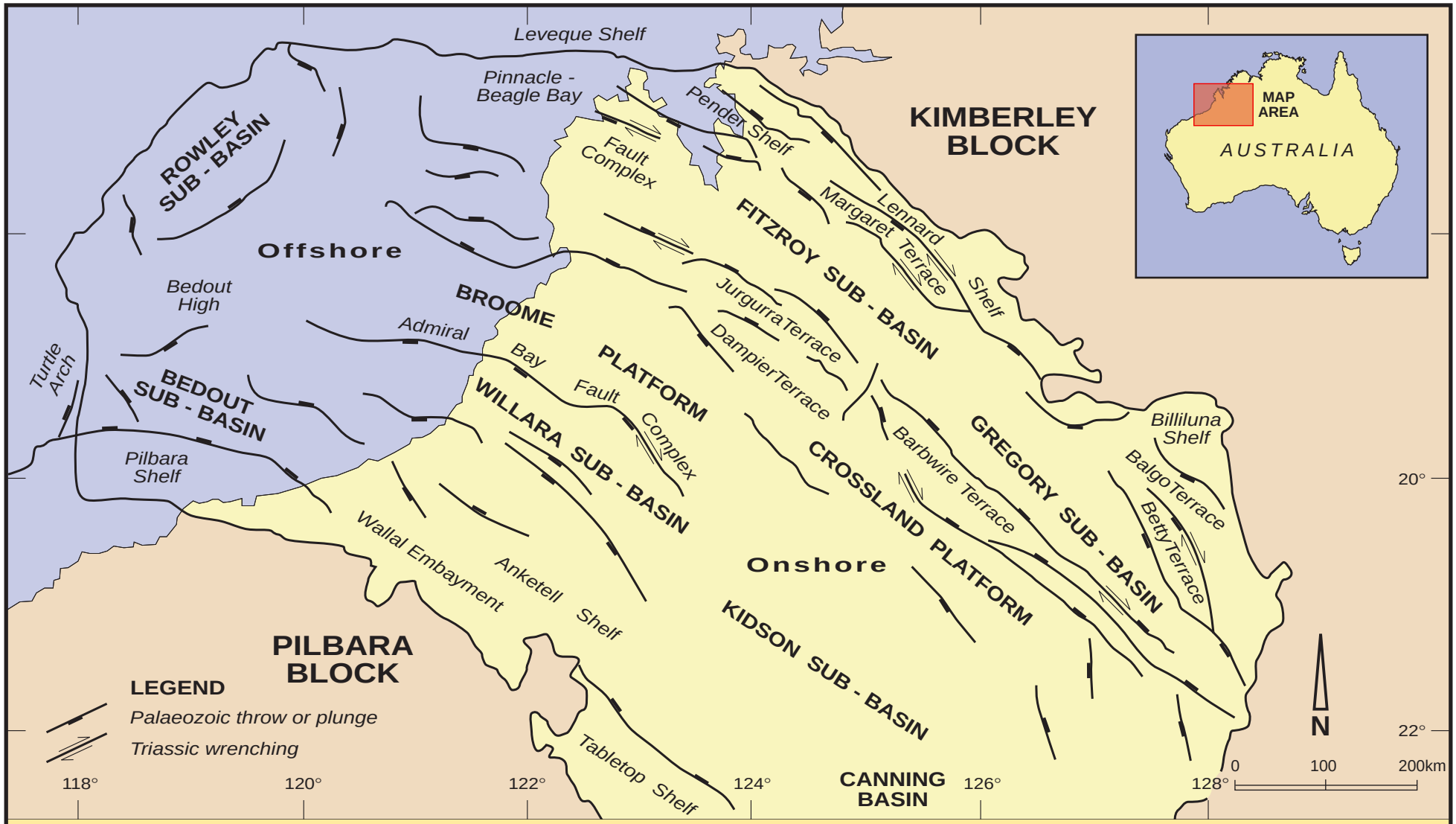

Figure 3.1. Tectonic Elements, Canning Basin, Northwest Australia (after Cadman et al., 1993)

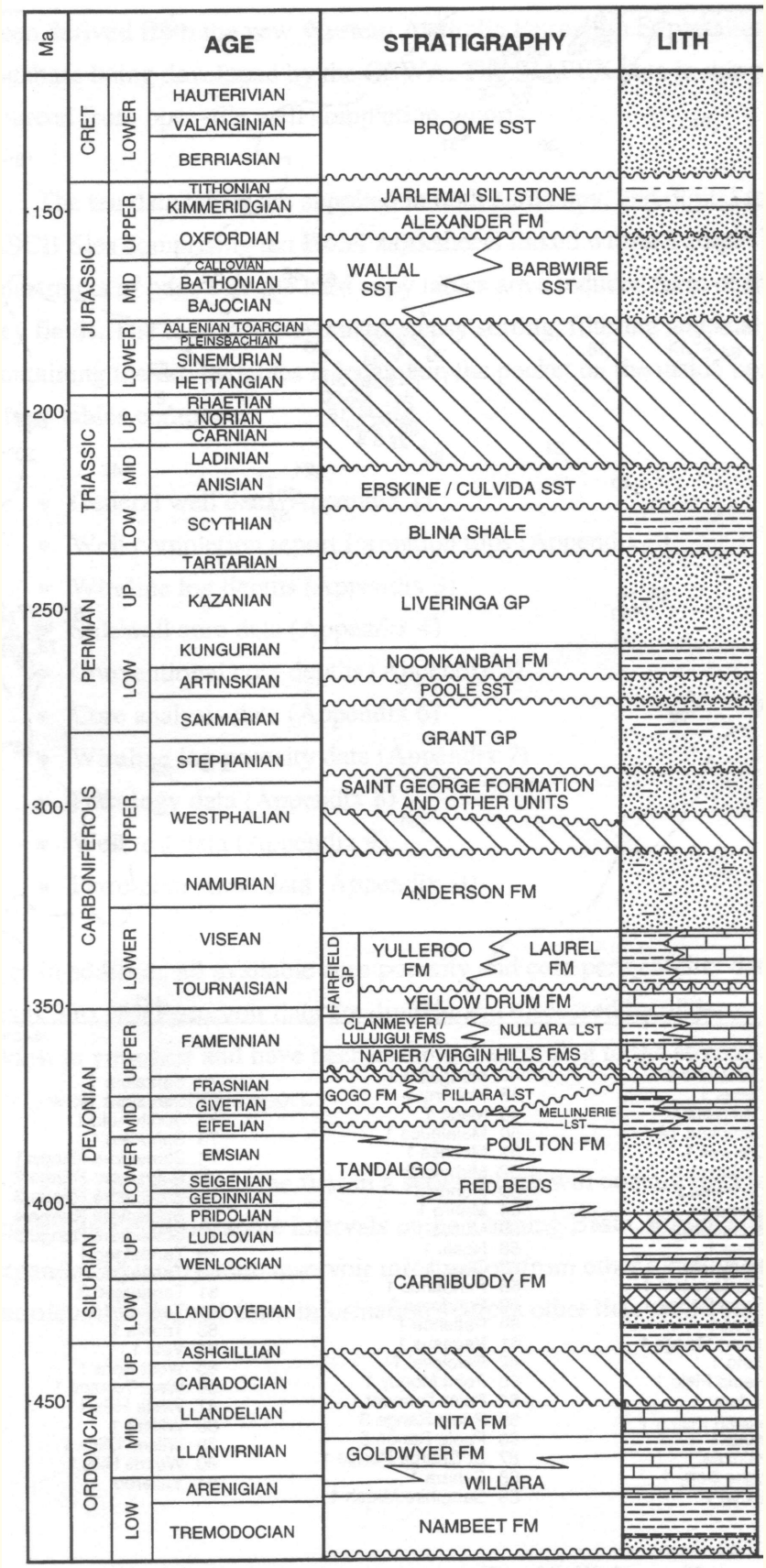

Figure 3.2. Generalised stratigraphy of the Canning Basin. (after Apak and Carlsen, 1996)

4. WELL SUMMARIES

White Hills-1 (Figure 4.1), Point Moody-1 (Figure 4.2) and Lake Hevern-1 (Figure 4.3) are the only three exploration wells within the study area. Stansmore Range-1 to 5 are also present but are only shallow stratigraphic wells. To the north of the study area are Ngalti-1 and Kilang Kilang-1 exploration wells and to the south are Wilson Cliffs-1 and Contention Heights-1. Further to the southwest of the release areas, but still of interest, are the Kidson-1 and Patience-1 exploration wells (Enclosures 2 and 3). Composite logs for all wells can be found as Enclosures 15–23).

4.1. NGALTI-1

Summary:

Ngalti-1 was drilled by Ranger Oil (Australia) Ltd in 1984, to a total depth of 2,758 m to test a tilted fault block on the Balgo Terrace. The primary objective was the Late Devonian Knobby Sandstone and the program was also designed to investigate Late Devonian stratigraphy beneath it. Secondary objectives comprised sandstones within the Knobby Sandstone, sealed by intraformational shales.

Ngalti-1 was drilled on a large fault bounded closure on the Balgo Terrace and primary structural closure is provided by a normal fault immediately southwest of the well. Age at total depth (TD) is Late Devonian.

Post Mortem:

For the objectives to succeed, the prospect relied on trap integrity of postulated Early Carboniferous shales of the Laurel Formation. No shows were encountered during drilling and wireline logs confirmed that all potential reservoir sandstones were water wet. However, the Knobby Sandstone proved to be an excellent reservoir, with average porosities of 20% and permeabilities up to 870 md in the upper part. Porosities gradually decreased with depth and little effective porosity exists in the well below 2000 m.

4.2. KILANG KILANG-1

Summary:

Kilang Kilang-1 was drilled by Ranger Oil (Australia) Ltd in 1984, to a total depth of 2,300 m where the age was recorded as Early Carboniferous. Primary objectives were the Early Permian Poole Sandstone and Late Carboniferous Grant Formation sealed vertically by the Early Permian Noonkanbah Formation. Shales within the Grant Formation were also expected to provide seal. Secondary objectives of the well comprised sandstones within the Early Carboniferous section.

Kilang Kilang-1 was drilled on an extremely large faulted anticlinal closure in the Gregory Sub-basin.

Post Mortem:

Reconstructions (carried out by Pontoon Oil and Minerals NL post-drilling) of the seismic sections over the structure to Top Poole Sandstone time indicate that prior to the Late Triassic – Early Jurassic wrench fault episode, there was little or no structural closure on the prospect. The structure at Poole Sandstone time was essentially a faulted

monocline. The critical dip missing is that to the northeast. Thus, the structure probably formed too late to entrap hydrocarbons migrating from sources in Early Carboniferous or older rocks.

No hydrocarbon shows of any significance were encountered in Kilang Kilang-1. Traces of methane were recorded at three different intervals; the maximum amount detected over the interval 2,150 m to 2,215 m.

4.3. WHITE HILLS-1

Summary:

White Hills-1 is probably the most interesting well in the study area due to the fact that fair oil and gas shows were recorded by Mobil when it was drilled in 1982. The well was drilled to a total depth of 4,148 m and was proposed to test a large faulted anticlinorium. It was drilled on the southern apex of the structure. The objectives were to test the hydrocarbon potential of the Early Carboniferous sandstones and carbonates and also Late Devonian sandstones under anticlinal, four-way dip closure.

Post Mortem:

Significant shows of fluorescence and gas were found over a 1,063 m interval in Anderson and Fairfield sandstones. Significant shows of gas were encountered throughout the Luluigui Formation to TD. White Hills-1 provided a valid test of the hydrocarbon potential of a large, well-defined anticlinal closure. Structural closure was evident from surface to total depth.

The absence of producible hydrocarbons may be attributed to the fact that the encountered hydrocarbons are residual in nature, or permeability is such that no oil will flow. Other factors may be: the poor sealing capability of the overlying section; faulting that may have produced leakage or poor quality source rock that may have generated only minor shows (Figure 4.1).

4.4. POINT MOODY-1

Summary:

Australian Aquitaine Petroleum Pty Ltd drilled Point Moody-1 in 1965, to a depth of 2,441 m. The main objective was to test the stratigraphic sequence within the Stansmore Gravity Trough. The well is situated on a structural high, the Point Moody anticline, and should adequately test the petroleum potential of Early Permian and older sediments. The age at total depth was Early Carboniferous.

Post Mortem:

Except for some gas shows in very small proportions, no signs of hydrocarbons were found. These small gas shows are not surprising in a section which contains many coal (lignite) fragments and where there are indications of brackish sediments, often deposited in a confined environment.

The discovery of a thick Early Permian sequence overlying the Carboniferous Anderson Formation must be considered as the main result of the drilling. The section penetrated can be compared with a similar one in the Fitzroy Graben. The structural position of

Point Moody is now stated as a southeasterly extension of the Fitzroy Sub-basin (Figure 4.2).

4.5. LAKE HEVERN-1

Summary:

Lake Hevern-1, drilled in 1998 by Amity Oil, is the most recently drilled well within the proposed permit area. The well was drilled to evaluate the potential of the Ordovician Nita and Goldwyer Formations. Secondary targets were prognosed within the sandstones of the Carribuddy Group and the Devonian Tandalgoo Formation.

The Lake Hevern prospect was defined from seismic mapping as a fault-controlled inversion structure, with four-way dip closure mapped at interpreted Top Ordovician. Structural closure was mapped throughout the pre-Permian section.

Post Mortem:

Reservoir quality varied from very poor to fair. The results of the drilling were disappointing in that virtually no sealing units were intersected and there was no evidence of any evaporites or halites. Minor gas shows were recorded in tight sandstones. The presence of the thin gas saturated sandstone sequence between 770–790 m indicates that seals may be formed by thin dolomitic shales and very low permeability sandstones (Figure 4.3).

4.6. CONTENTION HEIGHTS-1

Summary:

In 1973, Australian Aquitaine Petroleum Pty Ltd drilled Contention Heights-1 to a total depth of 1,791 m; the age at this depth was Ordovician. The objectives were to investigate Ordovician sandstone reservoirs, capped by a Devonian shale sequence and pinching out against the basement margin. These reservoirs were previously drilled in Wilson Cliffs-1 and the reservoir and hydrocarbon potential were expected to improve closer to the eastern basin margin.

Other objectives were to test the trap considered to be present along the southeastern margin of the Kidson Sub-basin, formed by the pinch-out of sands of the Early to Middle Ordovician Formations onto Proterozoic basement. The shale sequence of the Devonian – Ordovician Carribuddy and Goldwyer Formations was thought to provide a cap to these reservoirs.

The testing of the structure was not the main concern in choosing a drilling location, as the primary objective of the well was the evaluation of the Ordovician reservoir sequence.

Post Mortem:

No significant shows of oil or gas were detected. Traces of methane were detected from shales of the Ordovician Goldwyer Formation. Log analysis revealed that all reservoirs in the formations drilled were water saturated. Although the Ordovician sandstones were relatively shallow in this well, reservoir properties were poor with porosities ranging from 2–10% but with very little permeability.

The absence of hydrocarbons in both the Early and Middle Ordovician sequence has probably resulted from the lack of trapping mechanism at the time of hydrocarbon generation and migration.

4.7. WILSON CLIFFS-1

Summary:

Australian Aquitaine Petroleum Pty Ltd drilled Wilson Cliffs 1 in 1968, to a total depth of 3,722 m, to test a small closure related to a horst. Seismic coverage was insufficient to provide definitive proof of closure in the northeasterly direction.

The principal objective was to obtain a complete section of sediments to economic basement in the Kidson Sub-basin. The hydrocarbon potential of the Early Palaeozoic was to be tested. A third objective was the identification of seismic horizons mapped in the area.

Post Mortem:

No significant shows of oil or gas were detected. Traces of methane, ethane and propane were detected in the Middle Ordovician and minor weak fluorescence from solid hydrocarbons was also detected within this formation.

The Permian sequence and Early Devonian Tandalgoo Formation are quite porous and permeable but are fresh-water filled with no hydrocarbon indications. The Carribuddy Group still provides a good cap rock in the area and although minor traces of hydrocarbons were observed in the underlying Ordovician units, reservoirs are almost uniformly tight.

4.8. PATIENCE-1

Summary:

Patience-1 was drilled in 1986 to a total depth of 1,869 m by Sydney Oil Pty Ltd. The well was drilled to test a structural high in the southeast Kidson Sub-basin. Similarly, a small closure contained within a much larger east–west trending anticlinal structure, bounded to the south by a reverse fault, was to be tested. The primary objectives were the Mellinjerie Formation, the Tandalgoo Formation and the Carribuddy Group sands and dolomites. Poole Sandstone sands and Grant Group sands were a secondary objective. All units below the basal Grant unconformity were mapped as having four-way dip closure.

Post Mortem:

A small amount of liquid hydrocarbon was extracted from within sandstones of the Tandalgoo Formation and was found to be asphaltene, which was not biodegraded and probably sourced in-situ. The Tandalgoo Formation has excellent reservoir potential with good porosity and permeability. It is sealed by a thick claystone unit and appears to be a valid structural closure. Patience-1, however, was not adequately sourced at this level. Reservoir potential within the Grant Group was also excellent, although structural closure was not present. Tandalgoo Formation clastics exhibited excellent reservoir potential, and sands of this unit, adequately sourced, represent a very prospective target in the Kidson Sub-basin.

Results from this well showed that good potential reservoirs and seals exist, but the main problem is the lack of source, or the lack of migration pathways from source to reservoir.

4.9. **KIDSON-1**

Summary:

WAPET drilled Kidson-1 in 1965–1966 to a total depth of 4,431 m, primarily as a stratigraphic test of the Kidson Sub-basin. This well tested a structural terrace with about 30 m of closure over an area of 20 sq km, at a depth corresponding to the Upper Carribuddy Group horizon.

Post Mortem:

Kidson-1 succeeded in penetrating the Carribuddy Group and drilled a full Goldwyer Formation section before reaching total depth in the sandy Middle Ordovician. The Nita Formation was interpreted to be absent and no oil or gas shows were encountered.

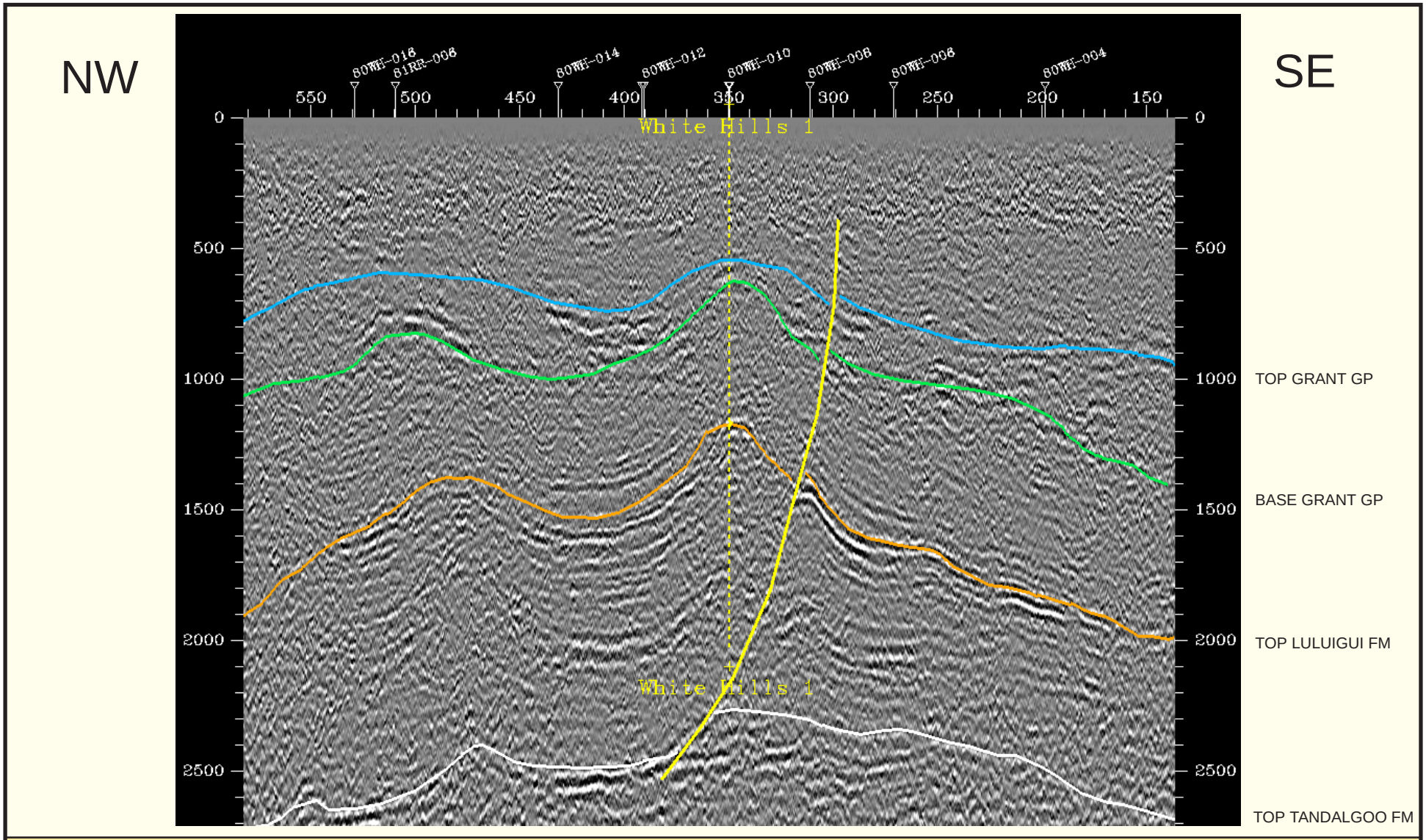

Figure 4.1. Seismic line 80WH-005 showing the location

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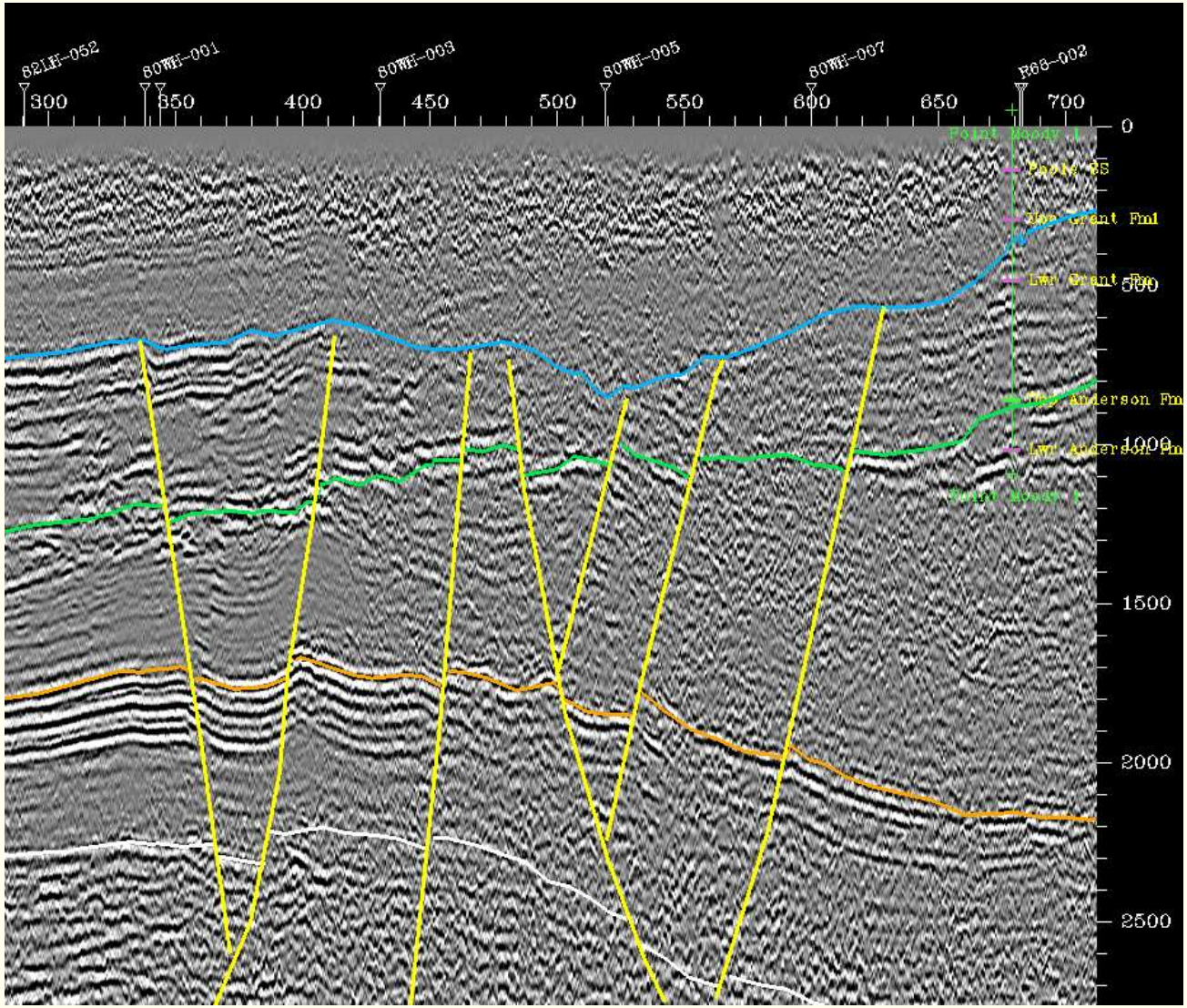
E



W

TOP GRANT GP

BASE GRANT GP

TOP LULUIGUI FM

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Figure 4.2. Seismic line 80WH-004 showing the location of Point Moody-1.

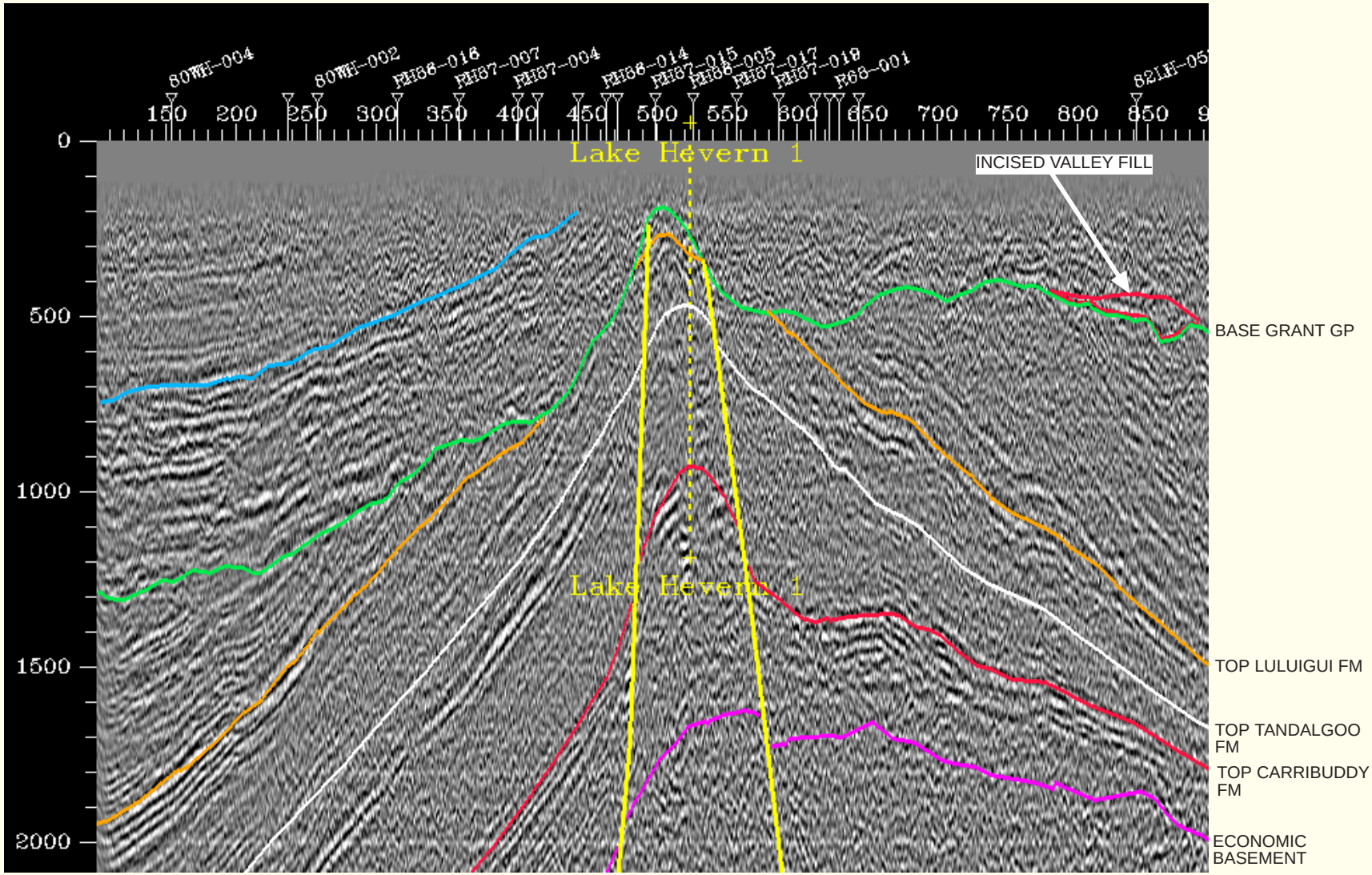

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Figure 4.3. Seismic line 82LH-052 showing the location of Lake Hevern-1.

5. PETROPHYSICAL OVERVIEW

A brief petrophysical study has been carried out on four selected wells in the vicinity of the study area (Enclosures 16, 17, 21 and 23). The wells Kilang Kilang-1, Patience-1, Wilson Cliffs-1 and White Hills-1 have been chosen based largely on log quality but also on location and intersected stratigraphy.

5.1. BULK VOLUME SHALE FRACTION (VSH)

The Gamma Ray (GR) log was used to calculate Vsh. Histogram plots were made for GR and the 3rd and 75th percentiles, taken as clean and shale values respectively, for first pass numbers. These were then compared to well log values, especially where sand volume is much lower.

5.2. POROSITY

For Kilang Kilang-1, the porosity was calculated using both Density and Sonic logs and the two were compared. The parameters used for the calculations are outlined in Table 5.1. Sonic and Density values for shale were calculated by cross plotting Density and Sonic against the calculated Vsh for each individual stratigraphic interval.

Fluid Time		189 ms/ft
Matrix Time	Shale	56.5 ms/ft
	Limestone	45 ms/ft
	Dolomite	40ms/ft
Fluid Density		1 g/cc (water)
Matrix Density	Shale	2.65 g/cc
	Limestone	2.71 g/cc
	Dolomite	2.85 g/cc

Table 5.1 Parameters used for petrophysical calculations

The PHID (porosity calculated from density) log gave more consistent values and so was used where available. The original PHID log was corrected for the presence of washouts by using a Vsh and DRHO (RHOB correction curve) with cutoffs of 0.65 and 0.1 respectively. This results in a much cleaner porosity log from which averages can be taken.

5.3. WATER SATURATION

The only well with any evidence of oil shows is White Hills-1, with the other wells Kilang Kilang-1, Wilson Cliffs-1 and Patience-1 being water wet. Pickett plots were generated for the water wet wells across the intervals, which correlate to White Hills-1, and a resistivity of formation water (Rw) was calculated (Table 5.2). As a guide the Drill-Stem Test (DST) in White Hills-1 over the interval 1052–1080 m MD (measured depth), in the Anderson Formation, recorded a salinity of 4000 ppm Cl^-, at 60 °C giving an Rw of 0.7. The salinities recorded in the other DSTs were affected by the salinity of the drilling mud, resulting in anomalously high values.

Formation	Temperature (°C)	Rw	M
Poole Sandstone	39	0.85	1.7
Grant Group	50	0.75	1.7
Anderson Formation	60	0.70	1.7
Fairfield Group	72	0.70	1.7
Luluigui Formation	76	0.65	1.7

Table 5.2 Rw calculated for each stratigraphic unit

5.4. AVERAGES

Average porosities were calculated using two sets of cutoffs. The first set has no porosity cutoff. The second set has a porosity cutoff calculated by plotting core porosity against core permeability in Patience-1 and deriving the porosity at 1 md (millidarcies). This creates a cutoff of 7%.

5.5. KILANG KILANG-1

Porosity was calculated using RHOB and values derived agree with those measured using a neutron density cross plot (Table 5.3).

Stratigraphic Interval	Depth (m)	Cut-off	Net Pay (m)	Pay / gross	Av Porosity	Potential		
						Res.	Seal	Source
Liveringa Gp	15.0-354.5							
Noonkanbah Fm	354.5-661.0							
Poole SS	661.0-803.5	1	99	0.69	0.1794			
		2	98	0.69	0.1807			
Upp. Grant Gp 1	820.0-885.0	1	40	0.61	0.1626			
		2	39	0.60	0.1660			
Upp. Grant Gp 2	950.0 - 1100.0	1	95	0.63	0.1244			
		2	79	0.53	0.1441			
Upp. Grant Gp 3	1140.0-1200.0	1	15	0.26	0.1842			
		2	15	0.24	0.1909			
Lwr. Grant Gp	1204.0-1448.0	1	227	0.93	0.1386			
		2	220	0.90	0.1413			
Anderson Fm 1	1448.0-1717.0	1	184	0.68	0.1146			
		2	171	0.63	0.1194			
Anderson Fm 2	1717.0-2300.0	1	339	0.58	0.0749			
		2	173	0.30	0.0944			

Table 5.3 Summary of Kilang Kilang-1 petrophysical results

5.6. PATIENCE-1

As RHOB was not recorded, porosity (PHIS) was calculated from the sonic (DT) log. From 0–362 mMD the DT curve recorded anomalously high porosities. This was also observed in Kilang Kilang-1. A PHID correction was derived from Kilang Kilang-1 (see below), which was then applied to Patience-1.

$$PHID = 0.4712 * PHIS + 0.0429$$

For the remainder of Patience-1, a Vsh cutoff was applied as for the PHID calculation.

Core porosity was slightly higher than the calculated porosity but within acceptable limits (Table 5.4).

Stratigraphic Interval	Depth (m)	Cut-off	Net Pay (m)	Pay / gross	Av Porosity	Potential		
						Res.	Seal	Source
Broome SS	6.0-200.0							
Jarlemai Sltst	200.0-220.0							
Alexander Fm	220.0-245.0	1	11	0.45	0.1865			
		2	11	0.45	0.1865			
Wallal SS	245.0-278.0	1	31	0.93	0.1991			
		2	31	0.93	0.1991			
Liveringa Gp	278.0-392.0	1	43	0.38	0.1874			
		2	43	0.37	0.1874			
Noonkanbah Fm	392.0-578.0							
Poole SS	578.0-772.0	1	69	0.36	0.1906			
		2	69	0.37	0.1912			
Grant Gp 1	772.0-830.0	1	23	0.40	0.2085			
		2	23	0.39	0.2118			
Grant Gp 2	860.0-1100.0	1	131	0.54	0.1603			
		2	124	0.52	0.1667			
Grant Gp 3	1120.0-1335.0	1	84	0.39	0.1211			
		2	69	0.32	0.1407			
Mellinjerie Fm	1335.0-1626.0	1	10	0.03	0.0794			
		2	6	0.02	0.0934			
Tandalgoo Fm	1626.0-1766.0	1	140	1	0.1526			
		2	139	0.99	0.1533			
Carribuddy Gp	1766.0-1869.0							

Table 5.4 Summary of Patience-1 petrophysical results

5.7. WHITE HILLS-1

The caliper log indicates numerous washouts in White Hills-1. A badhole log was created using a density correction (DRHO) cutoff of 0.1, showing which areas of the log are unreliable, preventing accurate porosity calculations from the density log (PHID). The sonic log appears suppressed and therefore calculated porosity (PHIS) is anomalously low. After generation, the PHID log was corrected with a Vsh cutoff of 0.6 and a DRHO cutoff of 0.1 and the PHIS log was corrected using a Vsh cutoff of 0.6. Given the anomalously low sonic porosities, it was decided to use the PHID curve for the saturation calculation noting where the borehole was poor (badhole log).

The parameters used for the saturation calculation were outlined previously in this chapter. The deep resistivity (ILD) curve was used for the Poole Sandstone, Grant Group and Anderson Formation as the laterolog deep resistivity (LLD) curve was not run over the upper formations. The LLD log was used in the Fairfield Group and Luluigui Formation as it is the more accurate of the two given the mud resistivity. The water saturation (Sw) was not calculated in the Luluigui Formation below 2,700 mMD where it becomes a shaley mudstone and formation fluids were to be expected. The Poole Formation shows little possibility of hydrocarbon saturation though it should be noted that in the upper units, the sonic porosity may be unreliable as explained in Kilang Kilang-1 and Patience-1. The Grant Group may host significant hydrocarbons although results from the drillhole were negative. This section of the well has been affected by numerous washouts, altering the log responses. The Anderson Formation and Fairfield Group are shown to be mainly water wet, with only a small amount of hydrocarbons. This agrees with the previous work and explains the small shows in these intervals (Table 5.5).

Stratigraphic Interval	Depth (m)	Cut -off	Net Pay (m)	Pay / gross	Av Porosity	Av Sw	Potential…..		
							Res.	Seal	Source
Poole SS	14.0-190.0								
Grant Gp A	190.0-362.0	1	19	0.12	0.3411	0.6654			
		2	19	0.12	0.3411	0.6654			
Grant Gp B	362.0-525.0	1	114	0.70	0.2178	0.5619			
		2	116	0.70	0.2178	0.5619			
Grant Gp C	525.0-632.0	1	40	0.37	0.2158	0.5884			
		2	40	0.37	0.2158	0.5884			
Grant Gp D	632.0-772.0	1	94	0.67	0.2055	0.5924			
		2	94	0.67	0.2055	0.5924			
Grant Gp E	772.0-868.0	1	15	0.15	0.2029	0.7195			
		2	15	0.15	0.2029	0.7195			
Grant Gp F	868.0-998.0	1	23	0.18	0.1480	0.6957			
		2	23	0.18	0.1480	0.6957			
Anderson Fm 1	998.0-1027.0	1	9	0.31	0.1402	0.7735			
		2	9	0.31	0.1402	0.7735			
Anderson Fm 2	1062.0-1090.0	1	7	0.25	0.1404	0.8959			
		2	7	0.25	0.1404	0.8959			
Fairfield Gp 1	1090.0-1670.0	1	7	0.01	0.3623	0.6494			
		2	7	0.01	0.3685	0.6428			
Fairfield Gp 2	1670.0-2125.0	1	1	0.00	0.4955	0.6807			
		2	1	0.00	0.4955	0.6807			
Luluigui Fm 1	2125.0-2685.0	1	41	0.07	0.4050	0.5300			
		2	41	0.07	0.4078	0.5324			
Luluigui Fm 2	2685.0-3001.0	1	Mud stone s N/A						
		2							
Luluigui Fm 3	3001.0-3300.0	1	Mud stone so N/A						
		2							

Table 5.5 Summary of White Hills-1 petrophyscal results

5.8. WILSON CLIFFS-1

Porosity was calculated from the RHOB log. Corrections were made over the whole log for Vsh and over the intervals 2,033 to 2,352 and 3,405 to 3,499 m MD for DRHO.

Below 2,850 m MD, a low porosity interval is noted possible due to secondary cementation. Alternatively, the grain density used may be slightly too low due to the presence of calcite or dolomite. This is, therefore, a slightly pessimistic porosity curve (Table 5.6).

Stratigraphic Interval	Depth (m)	Cut-off	Net Pay (m)	Pay/gross	Av Porosity	Potential		
						Res.	Seal	Source
Noonkanbah Fm	181.4-371.9							
Poole SS	371.9-579.1	1	137	0.66	0.1549			
		2	126	0.60	0.1644			
Grant Gp 1	579.1-640.0	1	60	0.98	0.1672			
		2	57	0.93	0.1737			
Grant Gp 2	640.0-966.8	1	256	0.78	0.1805			
		2	244	0.75	0.1873			
Mellinjerie Lst	1005 - 1094.2	1	46	0.51	0.1170			
		2	37	0.41	0.1346			
Tandalgoo Fm	1094.2 - 1778.5	1	682	0.99	0.2194			
		2	682	0.99	0.2196			
Carribuddy Gp A	1778.5 -2025	1	68	0.27	0.1634			
		2	54	0.22	0.1965			
Carribuddy Gp B	2025.0 - 2370.0	1	25	0.07	0.1261			
		2	16	0.05	0.1746			
Carribuddy Gp C	2370.0 - 2495.0	1	97	0.77	0.1823			
		2	87	0.69	0.1979			
Goldwyer Fm	2532.9 - 2847.4	1	1	0.00	0.0455			
		2	0	0.00	0.0000			
Mid / Lwr Fm	2850.0 - 3025.0	1	64	0.36	0.0301			
		2	5	0.03	0.1016			
Mid / Lwr Fm	3025.0 - 3400.0	1	9	0.02	0.0805			
		2	5	0.01	0.1135			

Table 5.6 Summary of Wilson Cliffs-1 petrophysical results

6. SEISMIC INTERPRETATION

Seismic data has been the main focus of this study. The data set is characterised by low density regional lines combined with small higher density surveys (Enclosure 4). The seismic quality ranges from very poor to good, but generally is of moderate quality.

6.1. SEISMIC DATABASE

Eight 2D seismic surveys acquired by various companies between 1970 and 1987 have been compiled for use in this study (Table 6.1). Overall, the study area can be considered to have low-density seismic coverage. Most of this seismic is confined to the north of the study area with large areas in the southwest not seismically surveyed. All seismic data were been scanned from paper and sepia copies and loaded into a Landmark Openworks database. No reprocessing or depth conversion has been undertaken by Troy-Ikoda.

Survey	Operator @ Acquisition	Date	Comments
Stretch Range	Australian Aquitaine	August 1970	182 line km
Billiluna	Ranger	June 1981	1247 line km
Roberts Range	Mobil	July 1981	776 line km
Lake Hevern	Mobil	June 1982	457.5 line km
Shell 308	Shell	March 1985	790 line km
Ryan High Regional	Shell	May 1986	645 line km
Ryan High	Shell	April 1987	472.7 line km
Bishop's Dell	Mobil	September 1987	1662.7 line km

Table 6.1 Seismic surveys incorporated in this prospectivity study.

6.2. SEISMIC QUALITY

Seismic data quality is mixed and ranges from very poor to good. Generally, the older the seismic survey the poorer the quality. Additionally, the geology, which contains varying lithologies and structural complexities, can affect the survey quality. A degree of resolution is considered to have been lost due to the seismic scanning process.

Figure 6.1 displays examples of the varying degrees of seismic quality within the data set. Approximately 15% of the data is considered poor with little, if any structure, interpretable; 65% is considered moderate with only major structures and stratigraphic boundaries imaged; 20% is considered of good quality with well-imaged smaller scale structures and stratigraphic boundaries interpretable. Overall, the seismic data set is considered adequate for regional geological interpretations.

6.3. SEISMIC INTERPRETATION & MAPPING

A total of five seismic horizons have been interpreted throughout the study area and are presented as time structure maps (Enclosures 5–9). The horizons chosen for interpretation provide a framework for reviewing the prospectivity of the study area. Individual seismic markers have been chosen based seismic quality and their geological significance (Figure 6.2).

Due to lack of well control, poor seismic quality, and coverage, confidence in the interpretation is considered only moderate. However, the accuracy of the interpretation and the stratigraphic framework constructed are of adequate resolution for a regional prospectivity study such as this, to provide relevant and meaningful results and conclusions.

'Basement'

This surface represents economic basement. This surface mainly represents crystalline basement. However, due to very poor seismic quality, the surface may also be combined with top salt and the limit of interpretable seismic.

This seismic event is represented by a low to moderate confidence pick that cannot be interpreted across the entire study area, hence no structure map is presented. Where present, no structure can be identified below this marker. The interpreted event marks the transition from a very noisy structureless seismic facies to a noisy seismic facies that shows evidence of poorly imaged structure.

Late Silurian

The Late Silurian event marks the top of a shale, claystone and salt succession known as the Carribuddy Group. This seismic marker is represented by a bright well-imaged event, denoting a major change in lithology from the Carribuddy Group shales to the overlying Tandalgoo Formation sandstones.

This seismic marker is of moderate confidence, having little well-control and situated deep in the sedimentary sequence, thus near the limit of the seismic resolution (Enclosure 5).

Middle Devonian

This Middle Devonian pick represents the Top Tandalgoo Formation. It is a moderate confidence, bright seismic marker delineating a major change in lithology from the aeolian Tandalgoo Formation sandstones to the overlying mixed shales and limestones of the Gogo, Mellinjerie and Luluigui Formations.

The surface is generally prominent and clearly imaged and has been mapped throughout the study area. The surface pinches out against the Late Carboniferous Base Grant event in the southwest corner. This aeolian succession appears to be at a constant depth (approx. 2,400–2,500 msec, note: no depth conversion has been undertaken) over most of the southern and central region. It deepens markedly into the Gregory Sub-basin in the northwest corner. An isochron map of the Top Carribuddy Group to Top Tandalgoo Formation interval is provided as Enclosure 10. This alludes to a Tandalgoo Formation depocentre, centred on White Hills-1 (Enclosure 6).

Late Devonian

This prominent, well-imaged and easily interpreted seismic marker represents the Top Luluigui Formation. This surface is of moderate to high confidence and has been mapped throughout the area. The event represents a transition from Luluigui Formation limestones and clastics to Fairfield Group shales (Enclosure 7).

The surface pinches out in the southwest corner against the Base Grant Group event, similar geometries being observed with the Top Tandalgoo Formation and Top Carribuddy Group mapped surfaces. Deepening into the Gregory Sub-basin is also apparent, however, a major high can be seen in the central region, centred on White Hills-1. This high coincides with thickening, highlighted by the isochron of the Top Tandalgoo Formation to Top Luluigui Formation interval (Enclosure 11).

Late Carboniferous

The Late Carboniferous seismic marker is the most extensively mapped surface with the highest confidence level in this study. It represents the Base Grant unconformity and is easily recognised as a strong, well-imaged reflector with typical and dramatic reflector truncations against the surface, as is expected in a major erosional unconformity.

The Base Grant Group to Top Luluigui Formation interval (Enclosure 12) represents the Fairfield Group and Anderson Formation successions. Two depocentres can be seen to the northwest (in the Gregory Sub-basin) and to the southeast near the basin margin (Enclosure 8).

Early Permian

The Early Permian Top Grant Group unconformity has not been completely mapped due to a lack of seismic coverage. Where present, however, the surface is recognised as a prominent reflector displaying typical unconformity geometries (Enclosure 9).

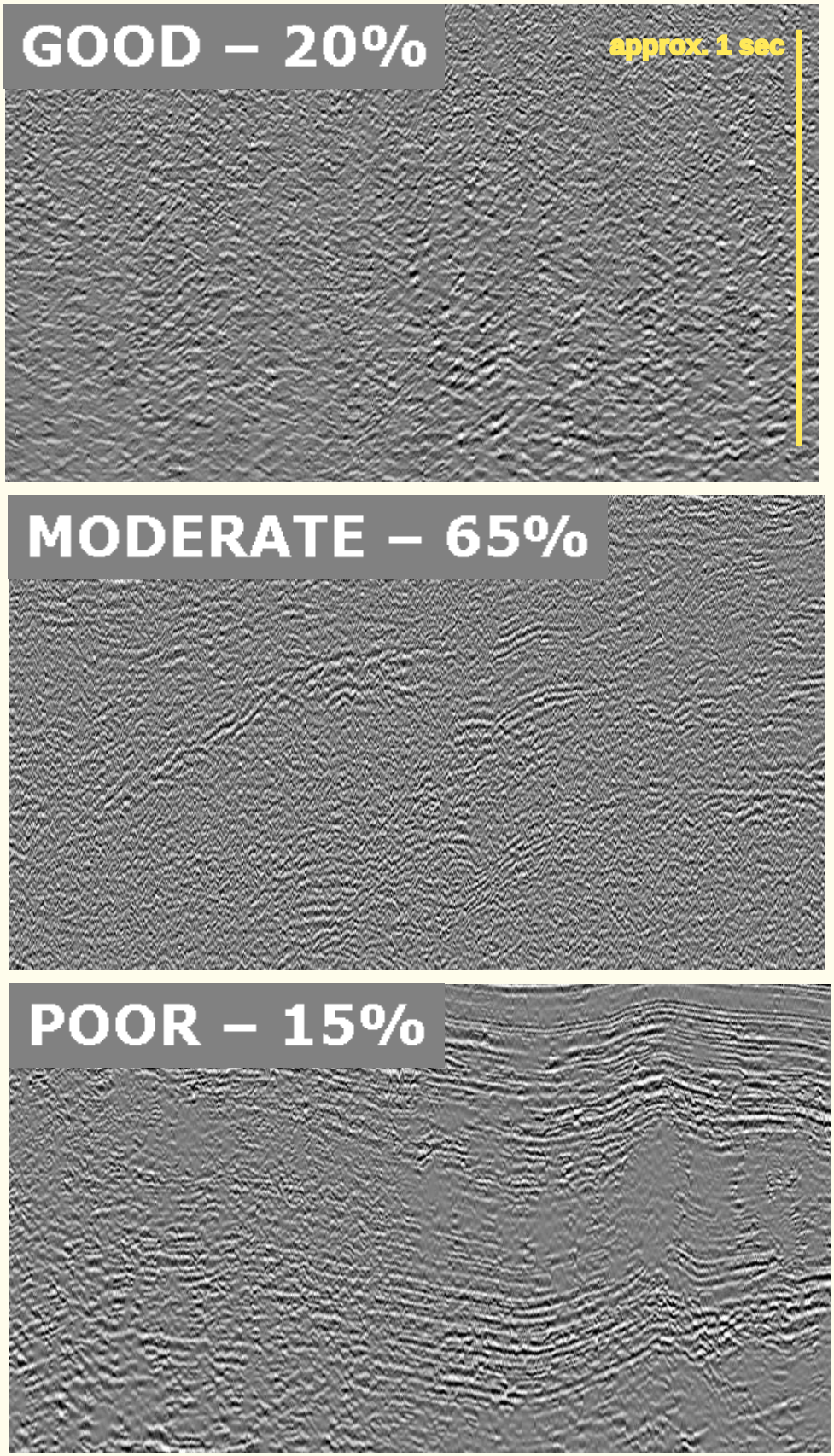

Figure 6.1. Seismic quality. Examples of the range in seismic data quality available within the study area. Approximately 15% can be considered POOR, 65% MODERATE and 20% GOOD.

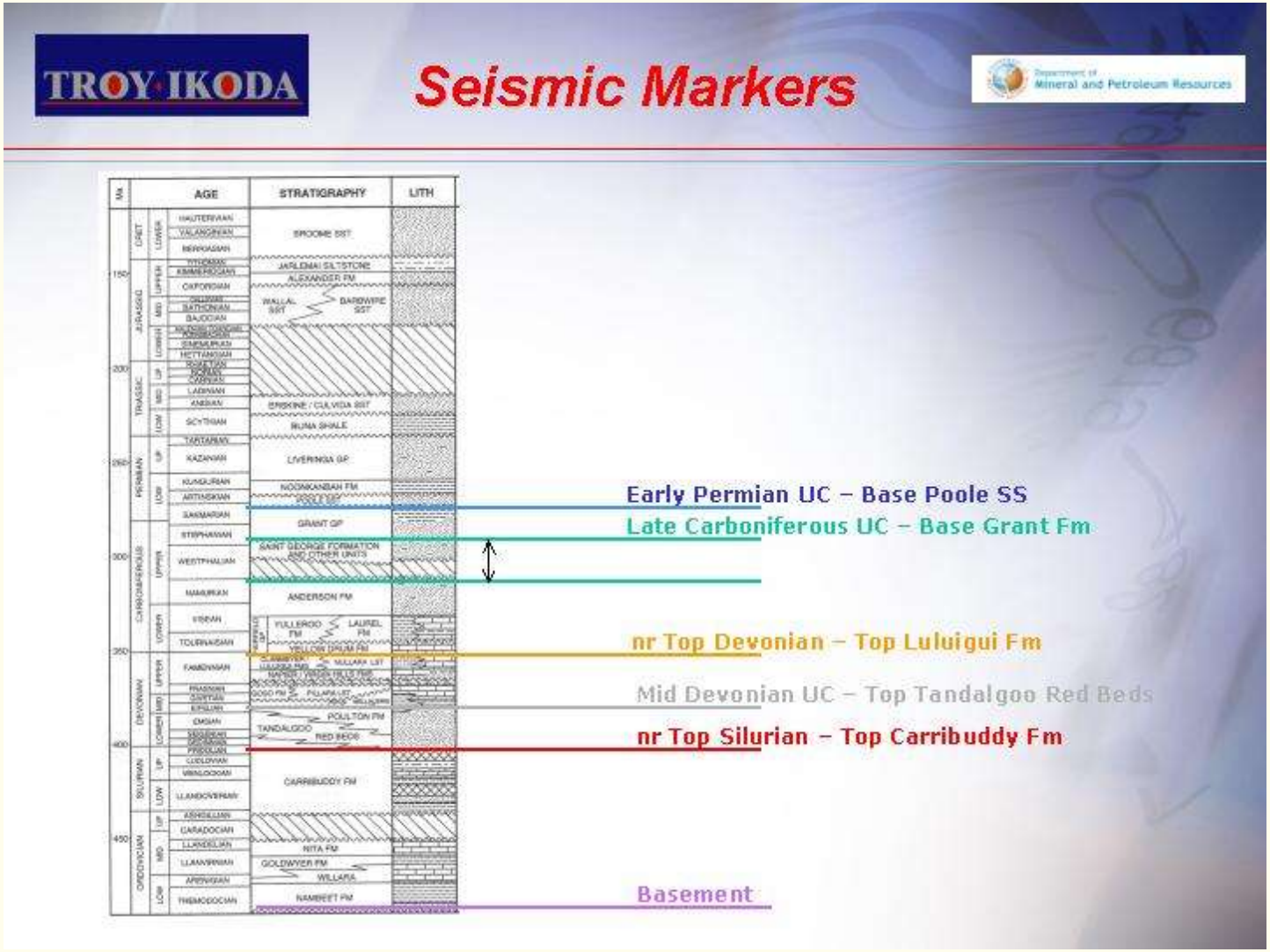

Figure 6.2. Mapped seismic markers.

7. THE PETROLEUM SYSTEM

7.1. HYDROCARBON OCCURRENCES

The Canning Basin has been known as a hydrocarbon-bearing basin for quite some time. The presence of commercial oil accumulations at Blina, Boundary, Lloyd, Sundown, and West Terrace confirm this (Table 7.1). However, exploration has generally focused on the northern basin/shelf and mid-basement arch areas.

Accumulation	Type	Location	Initial Recoverable Reserves (MMSTB) (90% Prob.)	Reservoir
Blina	Oil	Lennard Shelf	2.059	Yellow Drum / Nullara
Boundary	Oil	Lennard Shelf	0.017	Grant
Lloyd	Oil	Lennard Shelf	0.143	Anderson
Sundown	Oil	Lennard Shelf	0.303	Grant / Anderson
West Terrace	Oil	Lennard Shelf	0.154	Grant

Table 7.1 Commercial oil accumulations in the Canning Basin

The more southerly parts of the Canning Basin have seen little exploration with only oil and gas shows recorded and no commercial accumulations. The wells in and around the study area (Kidson-1, Patience-1, Wilson Cliffs-1, Contention Heights-1, Lake Hevern-1, Point Moody-1, White Hills-1, Kilang Kilang-1 and Ngalti-1) recorded several oil and gas indications; these occurrences are shown on Enclosure 3. The most notable hydrocarbon occurrences were those at White Hills-1. Significant shows of fluorescence and gas were found throughout sandstones of the Anderson Formation and Fairfield Group, with one DST recovering 38 degree API oil from the Fairfield Group. Significant gas shows were also noted throughout the Luluigui Formation. The oil encountered in White Hills-1 is believed to have been sourced from the Devonian Luluigui Formation.

Other wells in proximity to the study area displayed only minor (but encouraging) to trace oil and gas shows.

7.2. RESERVOIR

Reservoir rocks are found throughout the sedimentary sequence within the study area.

Tandalgoo Formation: Early – Middle Devonian

The Tandalgoo Formation contains the oldest potential reservoir to be found in the study area and consists of red quartzose sandstone with minor siltstone and rare limestone. These aeolian sandstones arguably have the best reservoir qualities in the study area, with porosities averaging 25% and permeabilities as high as 4,700 md (averaging 400–1200 md). Independent Troy-Ikoda petrophysics on Wilson Cliffs-1 and Patience-1 reveal porosities of 22% and 15% respectively.

Mellinjerie Limestone: Middle – Late Devonian

The Mellinjerie Limestone is a mixed succession, dominated by limestone and dolomite with minor shales and sandstones. This shallow restricted platform deposit is only found in the Kidson Sub-basin within the study area. Generally, it is considered to have reduced porosity due to diagenesis (Warris, 1992), and log-derived porosities from Patience-1 confirm low porosities of 7%. However, diagenesis also has the ability to enhance porosity and, until further work is carried out, the potential for high porosity limestone reservoirs within the Mellinjerie Formation cannot be ruled out. Thin sandstones encountered in Wilson Cliffs-1 have porosities over 10%, the extent and potential thickness of these beds, however, is unknown.

Luluigui Formation: Late Devonian

The Luluigui Formation is observed, predominantly in the northern region of the study area, as the formation is not present in the Kidson Sub-basin (the Mellinjerie Limestone being its time/depositional equivalent). The Luluigui marine succession is a dominantly silty shale and siltstone, although thin sandstones with good reservoir properties are present. White Hills-1 intersected 1175 m of Luluigui Formation, most of which was mudstone, however, sandstones near the top of the formation recorded high porosities; Lake Hevern-1, 23 km to the south, intersected approximately 56 m of Luluigui Formation, almost entirely sandstone. Elsewhere in the Canning Basin, oil shows are recorded in the Luluigui Formation from Blina-1 and Ellendale-1.

Fairfield Group: Early Carboniferous

The coastal to transitional marine succession of the Fairfield Group is a dominantly siltstone, shale and sandstone. It is present over the northern region of the study area, i.e. mainly the Gregory Sub-basin. White Hills-1 and Lake Hevern-1 both intersected Fairfield Group sediments. Lake Hevern-1 intersected an entirely sandstone interval in contrast to the White Hills-1 shale and sandstone succession. Core-derived porosities from White Hills-1 range from 9%–27% (0.1–3.6 md permeability) with log-derived porosities even higher in places.

Anderson Formation: Early – Late Carboniferous

The Anderson Formation is an alluvial plain to coastal transition sandstone, shale and siltstone succession. It is only found in the northern region of the study area, i.e. the Gregory Sub-basin. Log-derived porosities from Kilang Kilang-1 and White Hills-1 are 7%–12% and 14% respectively, with core-derived permeabilities from White Hills-1 reaching 72 md.

Grant Group: Late Carboniferous – Early Permian

The Grant Group is found throughout the Canning Basin and has been mapped extensively in the study area. The Grant Group was the first pulse of sedimentation after a major hiatus in the Middle to Late Carboniferous, and forms a basin wide unconformity. The Grant Group is a mixed clastic deposit of glacio-fluvial, glacio-lacustrine and alluvial origin. Log-derived porosities appear to be generally high and

range from 12% to 34%, however porosity generally deteriorates with depth due to secondary silicification (Warris, 1991).

7.3. SEAL

Good seals can be found throughout the sedimentary sequence encountered within the study area.

Potential sandstone reservoirs in the Luluigui Formation may be sealed intraformationally by basinal marine shales. However wells within the study area have intersected very sandy successions of Luluigui Formation, exhibiting only thick siltstone layers or thin shale beds as potential seals, alluding to proximity to source. White Hills-1 recorded thick interbedded mudstones and siltstones adequate for sealing, while Lake Hevern-1 displays a far sandier succession. Luluigui Formation shales form seals further northwest in the basin at Blina, on the Lennard Shelf, confirming their potential.

Potential sandstone reservoirs in the Fairfield Group may be sealed intraformationally by marine shales. However data is limited and as with the intersected Luluigui Formation, White Hills-1 records far more shaley sediments when compared to Lake Hevern-1, again alluding to a source to the north and possibly east.

Anderson Formation reservoirs may also be sealed intraformationally, with good thick alluvial mudstones intersected at White Hills-1 and Kilang Kilang-1.

The Grant Group reservoirs are sealed intraformationally by thick mudstones, good examples of which have been intersected at Ngalti-1, Kilang Kilang-1, Point Moody-1 and Patience-1. Reservoir rocks of older successions pinching out against the base Grant Group unconformity rely on a basal Grant Group seal. This seal has been modelled and predicted by ‘Sedsim’ (Griffiths and Young, 2002) to be present over much of the study area.

7.4. SOURCE

Significant source rocks occur basin wide and are present within the Gregory and Kidson Sub-basins.

The oldest potential source rocks, the Ordovician Goldwyer Formation, contain thick algal rich basinal marine shales; Foster (1986) recorded TOC values up to 6.4% from samples taken outside the study area. Goldwyer Formation shales have only been intersected in one well in the study area, Lake Hevern-1 (which encountered a high proportion of sandstone, downgrading the potential of the Goldwyer Formation in the study area).

The Devonian Gogo Formation is a significant source rock on the Lennard Shelf. Oil from the producing Blina field is sourced from this formation where TOC values over 2% have been recorded (Lehmann, 1986). The Gogo Formation is not adequately identified and mapped within the study area.

The Luluigui Formation and marine shales of the Fairfield Group are considered to have the greatest source potential in the study area. Additionally, these units may contain self-sourcing reservoirs. The marine shales of the Luluigui Formation sampled from White Hills-1 have a TOC of 1% and are classified as oil prone.

The Fairfield Group marine shales were sampled from White Hills-1 with a TOC of up to 2%, classifying them as oil prone source rocks. Their effectiveness is evidenced by sourcing the West Terrace, West Kora and Sundown oilfields, further to the northwest.

The Anderson Formation shales are also believed to be potential source rocks; good sections being intersected in White Hills-1, Kilang Kilang-1 and Point Moody-1, however, geochemical analysis has not been carried out.

Maturity / Timing

Generally, all potential source rocks within the study area reached maturity during three time periods:

1. Triassic to post Triassic – Noonkanbah and Anderson Formations.
2. Carboniferous to Permian – Gogo and Luluigui Formations and Fairfield Group
3. Devonian – Willara and Goldwyer Formations

Timing is an important aspect of the petroleum systems within the study area. As previously noted, good reservoir, seal, and source rocks are present throughout the sedimentary sequence. Thus, it is the timing of maturity and migration relative to trap formation that is critical.

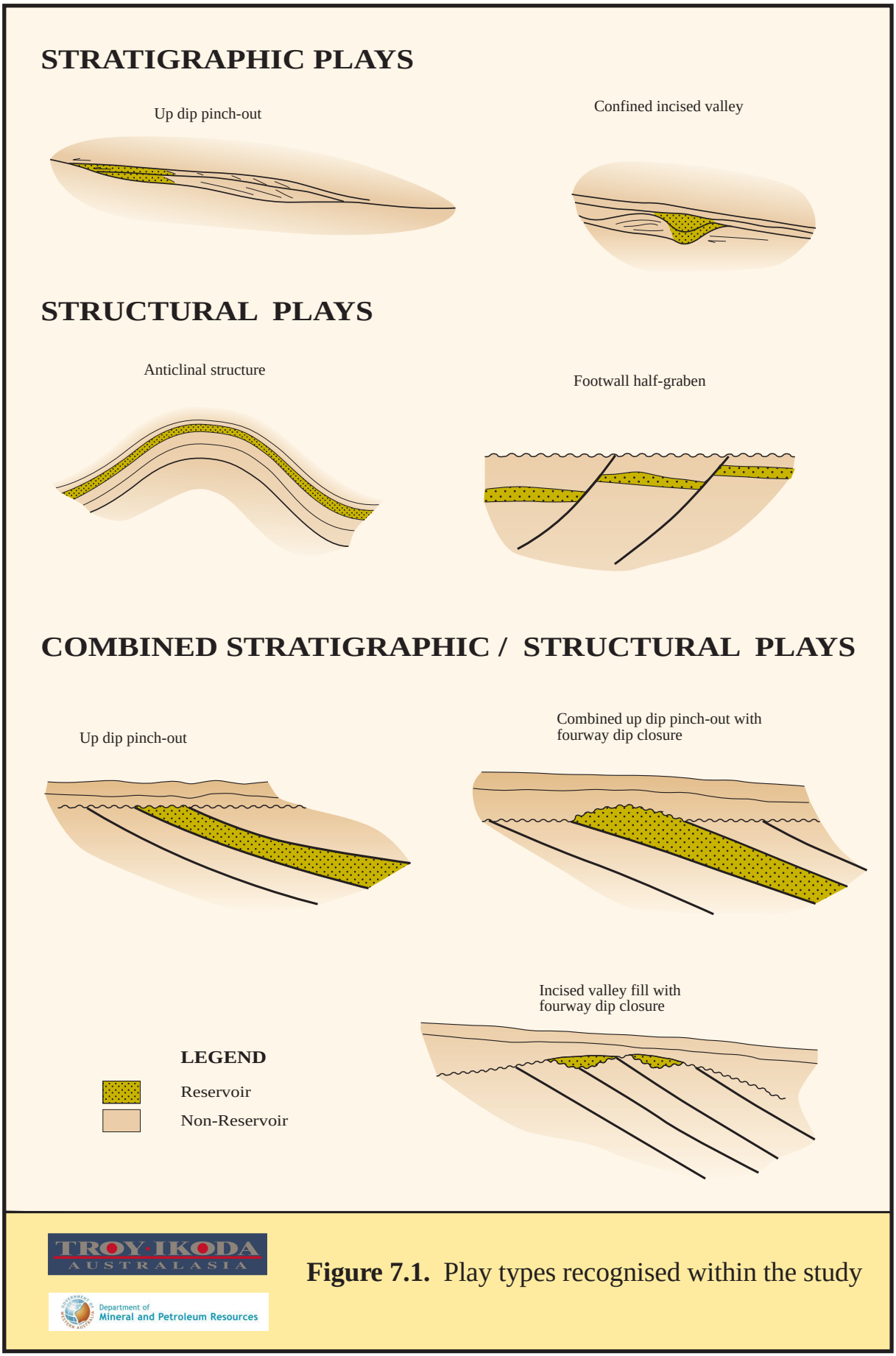

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Figure 7.1. Play types recognised within the study

8. PLAY CONCEPTS

Play concepts have been classified into three categories: stratigraphic, structural and combined play types (Table 8.1 and Figure 8.1), and are detailed in Enclosures 13, 14 and the following sections.

8.1. STRATIGRAPHIC PLAY TYPES

Updip Wedge-out / Pinch-out Play

Although seismic quality does not allow high-resolution facies mapping, intraformational facies changes are inferred, thus, updip facies changes with sufficient surrounding intraformational seals cannot be ruled out as a possible play type within the study area.

A possible scenario may be a change from marine Luluigui Formation facies to the time equivalent Nullara Limestones or Clanmeyer Formation at the basin margins and mid basin highs.

Intra-Grant Group pinch-out plays are also likely. Submarine fan formation, sourced from the east, may also provide likely pinch-out play scenarios. Pinch-out is formed by onlapping fan sediments against the slope apron. Basin floor fan and slope fan mounds may both form buried depositional relief traps.

Key risks include lateral strike closure and top seal formation.

Confined Incised Valley Play

This play type is characterised by the presence of channel infill lithologies acting as a reservoir, and surrounded by fine-grained sediments of an overbank facies as the sealing lithology. Structural traps are not necessarily required as sufficient closure can be provided along strike by the natural depositional relief and facies changes. Incised valley fills can be observed readily along the Base Grant Group unconformity. (See Section 8.3 for combined stratigraphic incised valley play with superimposed structure). However, improved seismic processing and/or newly acquired seismic data may reveal younger valley fills in the Grant Group.

Key risk include sufficient overbank fine facies blanketing channel fills to provide seal.

8.2. STRUCTURAL PLAY TYPES

Anticlinal Play

This play type is characterised by four-way dip structural closure formed by pre “Fitzroy Movement” tectonism, prior to hydrocarbon generation and migration. Anticlinal structures can be seen throughout the sedimentary succession within the study area and no distinct confined play fairway is evident. However, a preference for the margin of the Gregory Sub-basin is observed (Enclosure 14). Seals are provided by the overlying formation or by intraformational shales. See Section 9 for “Top Luluigui, L1” prospect details.

It is important to reiterate the significance of structures formed prior to the Fitzroy Movement for the successful accumulation of hydrocarbons specifically prior to or during hydrocarbon generation and migration. Wells drilled to date on large en echelon anticlinal structures related to the Fitzroy Movement have been unsuccessful in intersecting hydrocarbon accumulations. This is largely due to timing, with all hydrocarbon generative source rocks having reached maturity prior to trap formation (see Section 7). Figures 8.2 and 8.3 illustrate play timing associated with this play type.

Salt Related Play

Salt diapirism, producing deformation of overlying and adjacent sediments, creates structural closure in the form of anticlinal structures and updip pinch-outs against the intruding salt diapir. This play type is seen only in the southeast of the study area at the margin of the Gregory Sub-basin. Salt emplacement appears to be related to major basin bounding faults. Seal is provided by overlying formations or intraformational shales. See Section 9 for details of "A1 North and South Anderson Formation" prospects.

Timing of salt emplacement and subsequent diapirism is unknown. Brown et al. (1984) suggested that salt may be related to the Fitzroy Movement in the Triassic, which would discount this play type due to the timing of trap formation versus hydrocarbon migration. Seismic data quality is not high enough to infer trap formation timing based on structural relationships. However, it is likely that a number of salt movement phases have occurred throughout the Canning Basin, some of which may have occurred early enough for the accumulation of hydrocarbons (Figure 8.4).

Footwall, Half-Graben Play

This play type is characterised by half-graben geometries, where across fault juxtoposition of reservoir against sealing lithologies is required along the fault plane.

The play fairway (Enclosure 14) related to this play type is confined to the northeastern region of the study area. The Billiluna Shelf and Balgo Terrace display successive half graben formation prior to Grant Group deposition. Intense faulting is observed throughout the area. However, seismic data quality precludes adequate mapping of many of the features seen. More play fairways of this type are inferred to be present elsewhere in the study area. Improved seismic imaging is required to delineate these areas. See Figure 8.5 for a play timing diagram related to this play type.

Key risks include sufficient throw on faults to provide updip reservoir against seal juxtaposition. Faults oriented northwest to southeast are likely to be sealing at present, due to a present day compressional stress regime i.e. Sh max acts perpendicular to northwest-southeast trending faults (Denham et al., 1974).

8.3. COMBINED STRATIGRAPHIC / STRUCTURAL PLAY TYPES

Updip Stratigraphic / Structural Pinch-out Play

This play type is characterised by an updip stratigraphic pinch-out of Early Devonian to Late Carboniferous reservoirs against the regional Late Carboniferous Base Grant Group unconformity. The play fairway (Enclosure 14) is confined to the southern margins of the Gregory Sub-basin, where pre-Grant Group sediments sub-crop the Base Grant

erosional unconformity. Enclosure 9 shows the seismically mapped pinch-out edge of the Top Luluigui Formation, Top Tandalgoo Formation and Top Carribuddy Group superimposed onto the Base Grant Group two-way time (TWT) surface.

Leads and prospects associated with this play type can be grouped into the following:

1. Stratigraphic pinch-out where closure is provided by the Base Grant Group unconformity and surrounding intraformational seals. No positive relief at the unconformity surface means the underlying reservoir relies on good intraformational top and base seals, with closure provided depositionally along strike (Figure 8.6 and 8.7).

2. Combined stratigraphic / structural pinch-out where closure is provided by positive relief at the Base Grant Group unconformity. This positive relief relies on surrounding basal Grant Group seals only. See section 9 for details of the "T1 Tandalgoo Formation sub-cropping Base Grant Formation Anticline" prospect.

Key risks include the sealing capability of the Base Grant Group unconformity.

Confined Incised Valley with Anticlinal Closure

This play type is very specific and can be included in previous play type groups, however, its significance warrants separate consideration. A number of incised valleys can be readily observed at the Base Grant unconformity. This major erosional surface displays initial incision representing Late Carboniferous emergence and erosion. Anticlinal structures at Base Grant unconformity level provide four-way dip closure for the good quality valley fill reservoirs. See section 9 for details of the "G1 Base Grant Unconformity Incised Valley" prospect.

Key risks include the presence of a sufficient blanketing top seal and the timing of trap formation.

8.4. PLAY FAIRWAY MAP (Enclosure 14)

Enclosure 14 is a combined play fairway map. Individual play fairway maps based on each mapped surface are not warranted, as insufficient data exists to do so. Many leads and prospects associated with the various play types rely on intraformational seals, which have not been mapped.

The map shows the key elements of the petroleum system in the study area. Extent of source rocks, and associated hydrocarbon kitchens, are shown to be confined to the Gregory and Kidson Sub-basins. During the three-stated generative time periods, (see Section 7.4) there were oil and gas mature source rocks and thus hydrocarbon accumulation type (i.e. oil or gas) prediction is difficult. The extent of the prospective Devonian to Carboniferous reservoirs is shown, pinching out at the margin of the southern Gregory Sub-basin. Individual intraformational seals are not mapped and their extent is unknown. The important Base Grant unconformity seal is shown to extend over much of the study area and importantly over the pre-Grant Group reservoir pinch-outs.

Leads and prospects are shown and colour-coded based on play type. The leads and prospects displayed are not to be considered exhaustive, as recommended improved data acquisition is likely to increase prospectivity.

Play Concept	Reservoir	Seal	Source	Structure	Fairway	Risk	Example (Encl 14 & Fig 8.1)
Stratigraphic Play Concepts							
Updip Pinch-out	Grant Gp, Anderson Fm, Fairfield Gp, Luluigui Fm, Tandalgoo Fm	Intra-formational	Willara Fm, Goldwyer Fm, Gogo Fm, Luluigui Fm, Fairfield Gp, Anderson Fm (generating Dev. – Triassic)	Depositional with lateral along strike closure	'un-confined'	Strike closure and presence of top seal	(Enclosure 14 No.7)
Confined Incised Valley	Grant Gp	Intra-formational	Gogo Fm, Luluigui Fm, Fairfield Gp, Anderson Fm (generating Carb. – Perm.)	Depositional mound lateral along strike closure	Grant Gp	Surrounding seal	(None imaged only inferred)
Structural Play Concepts							
Anticlinal	Grant Gp, Anderson Fm, Fairfield Gp, Luluigui Fm, Tandalgoo Fm	Extra- & Intra-formational	Willara Fm, Goldwyer Fm, Gogo Fm, Luluigui Fm, Fairfield Gp, Anderson Fm (generating Dev. – Triassic)	Four-way dip closure pre-dating generation/ migration	'un-confined'	Timing of trap formation versus migration	(Enclosure 14 No s. 2, 3, 4) L1 Prospect
Salt Related	Grant Gp, Anderson Fm, Fairfield Gp, Luluigui Fm, Tandalgoo Fm	Extra- & Intra-formational	Willara Fm, Goldwyer Fm, Gogo Fm, Luluigui Fm, Fairfield Gp, Anderson Fm (generating Dev. – Triassic)	Four-way dip closure due to salt diapirism	Gregory Sub-basin faulted margins	Timing of trap formation versus migration	(Enclosure 14 No. 5) A1 North & South Prospects
Footwall Half Graben	Anderson Fm, Fairfield Gp, Luluigui Fm, Tandalgoo Fm	Fault seal	Willara Fm, Goldwyer Fm (generating Dev.)	Across fault reservoir, seal juxtaposition	Billiluna Shelf & Balgo Tce	Fault throw	(Enclosure 14 No. 6)
Combined Stratigraphic / Structural Play Concepts							
Updip Strat. / Struct. Pinch-out	Anderson Fm, Fairfield Gp, Luluigui Fm, Tandalgoo Fm	Base Grant unconformity	Anderson Fm, Gogo Fm, Luluigui Fm, Fairfield Gp (generating Carb. – Triassic)	Updip stratigraphic pinch-out against Base Grant unconformity	southern Gregory Sub-basin margin	Base Grant unconformity seal	(Enclosure 14 No. 1) T1 Prospect
Confined Incised Valley with Anticlinal Closure	Grant Fm	Intra-formational	Anderson Fm, Gogo Fm, Luluigui Fm, Fairfield Gp (generating Carb. – Triassic)	Four way dip closure	'un-confined'	Structural timing & intra-formational seal.	(Enclosure 14 No. 8)

Table 8.1 Play concepts

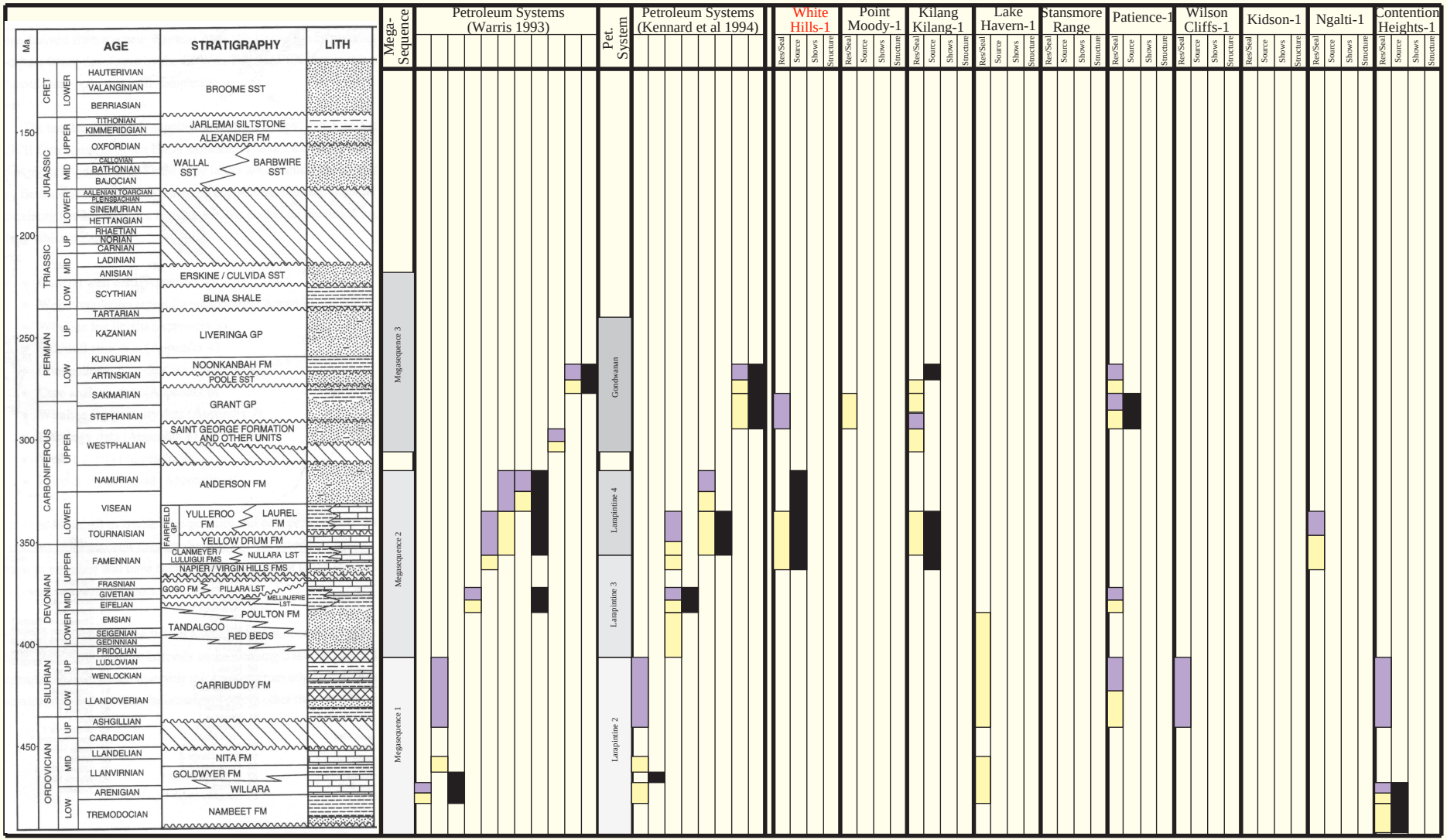

Figure 8.1. Petroleum systems chart. Published, recognised petroleum systems of the Canning Basin displayed along side petroleum system elements (res. / seal / source) targeted by the wells in and around the study area.

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Early formed Structural Play Timing

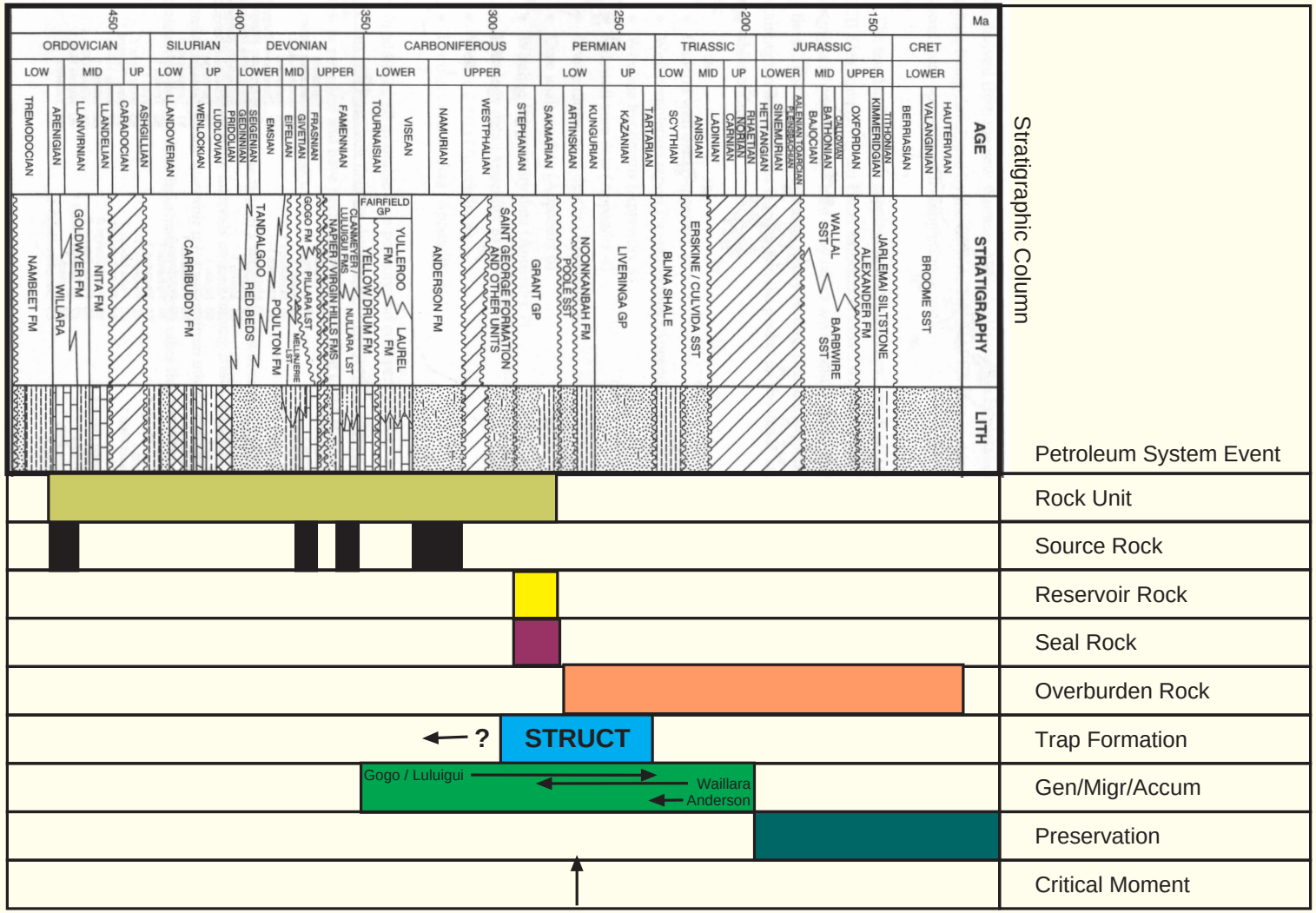

Figure 8.2. Petroleum system timing diagram of an early formed structural play.

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Late formed Structural Play Timing

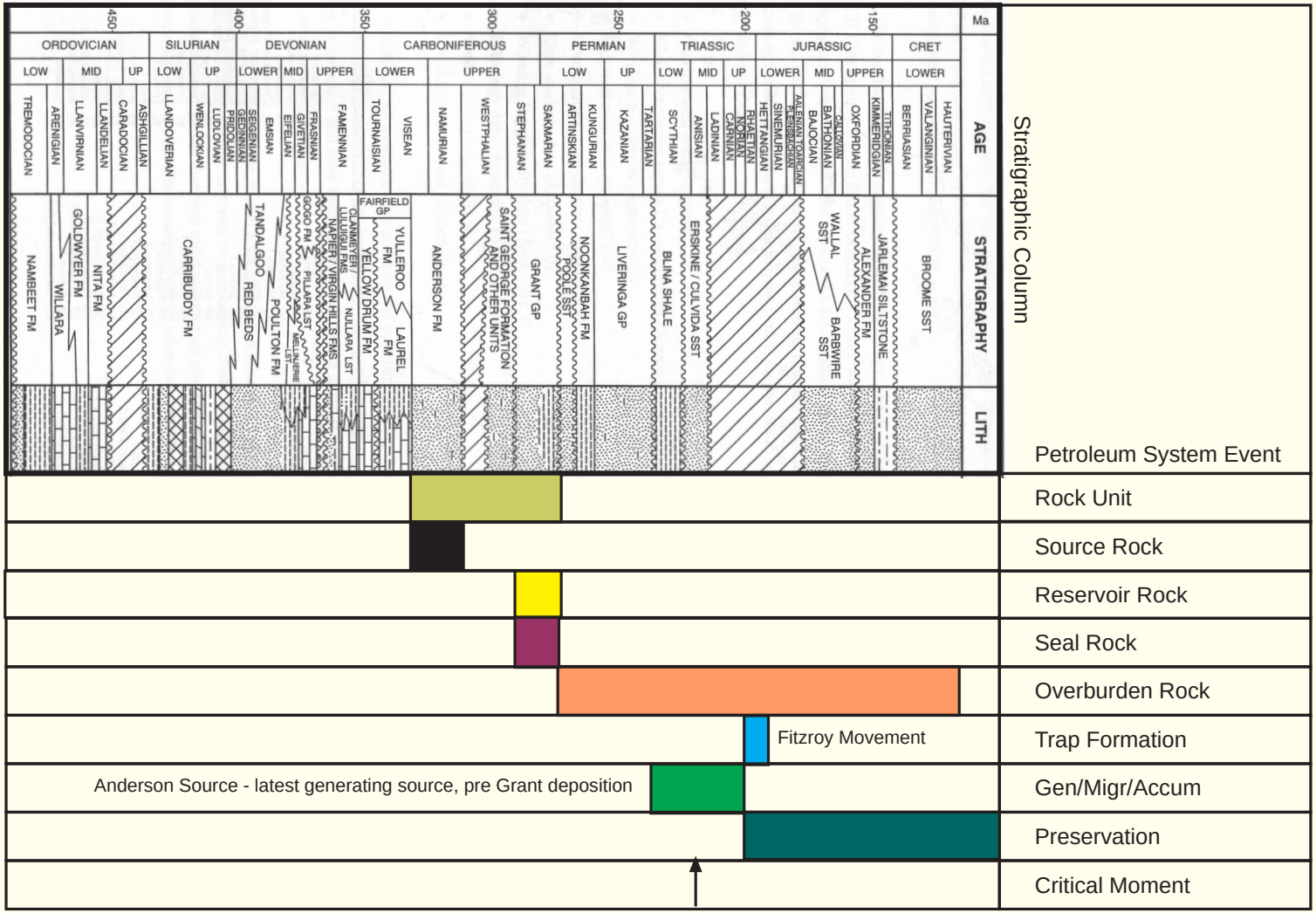

Figure 8.3. Petroleum system timing diagram of a late formed (Fitzroy-Movement) structural play.

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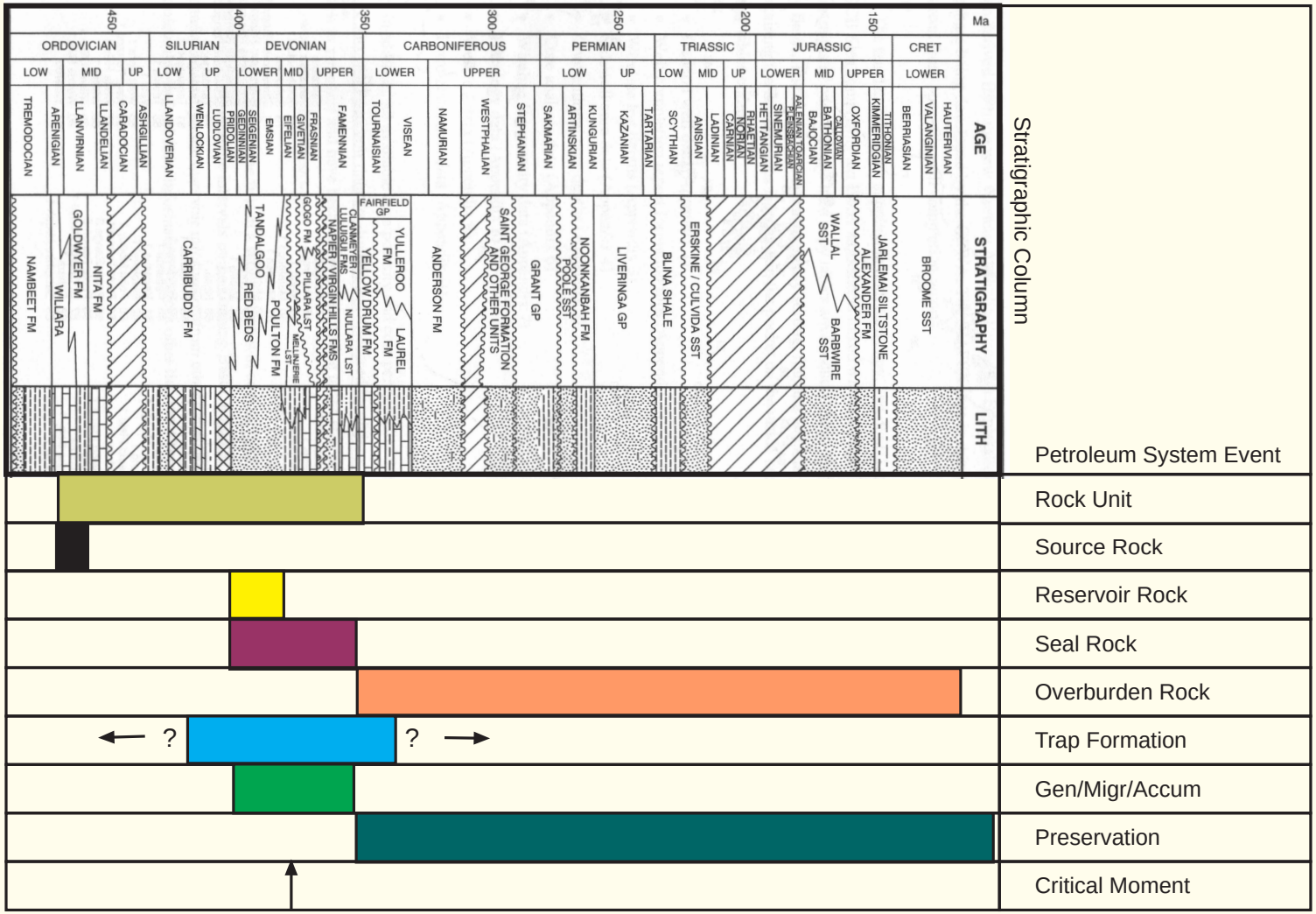
Salt related Structural Play Timing



Stratigraphic Column

Petroleum System Event

Rock Unit

Source Rock

Reservoir Rock

Seal Rock

Overburden Rock

Trap Formation

Gen/Migr/Accum

Preservation

Critical Moment

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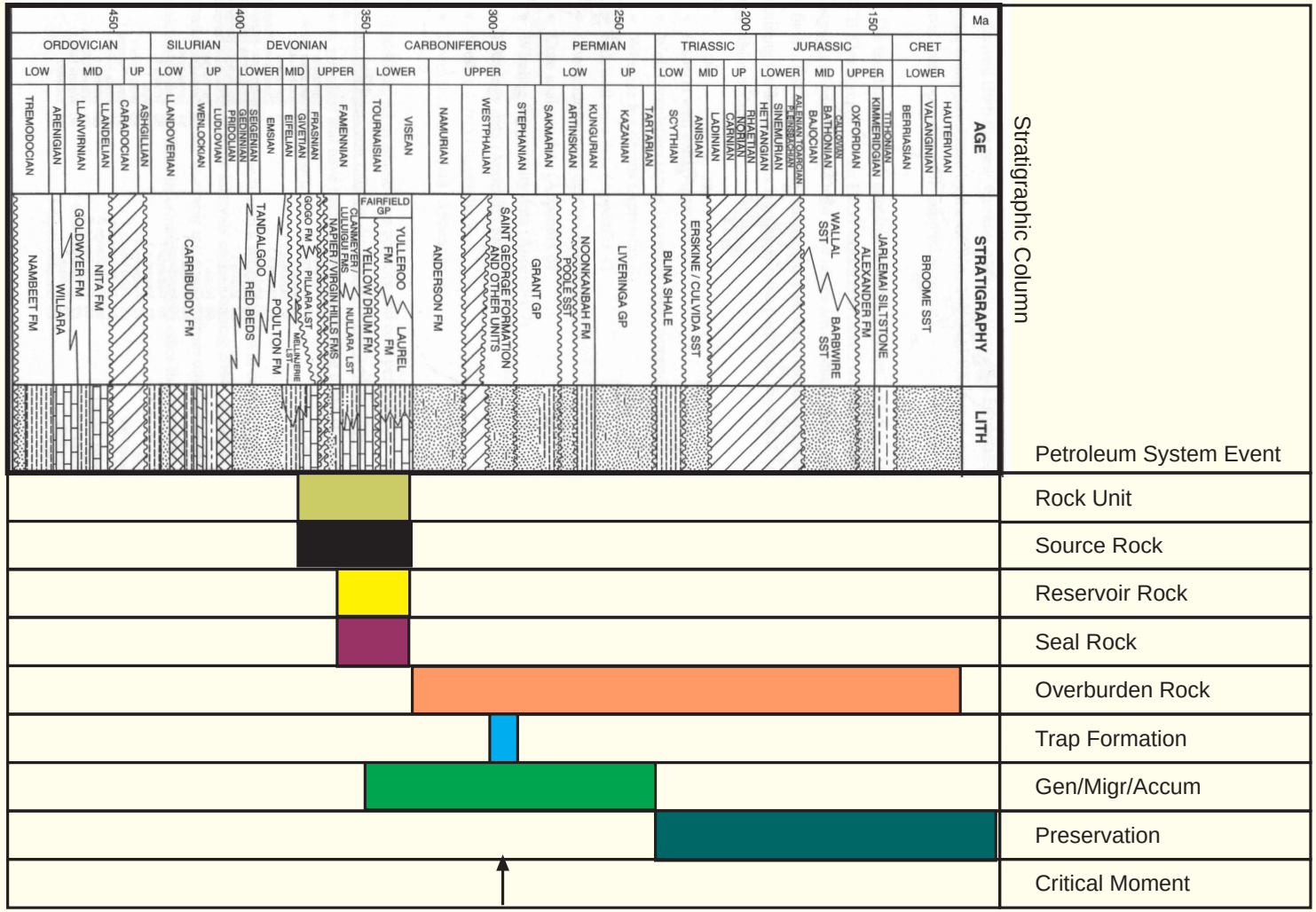
Figure 8.4. Petroleum system timing diagram of a structural play related to salt diapirism.

Early formed Half Graben Structural Play Timing



Stratigraphic Column

Petroleum System Event

Rock Unit

Source Rock

Reservoir Rock

Seal Rock

Overburden Rock

Trap Formation

Gen/Migr/Accum

Preservation

Critical Moment

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Figure 8.5. Petroleum system timing diagram of an early formed half graben structural play.

Combined Stratigraphic / Structural Play Timing

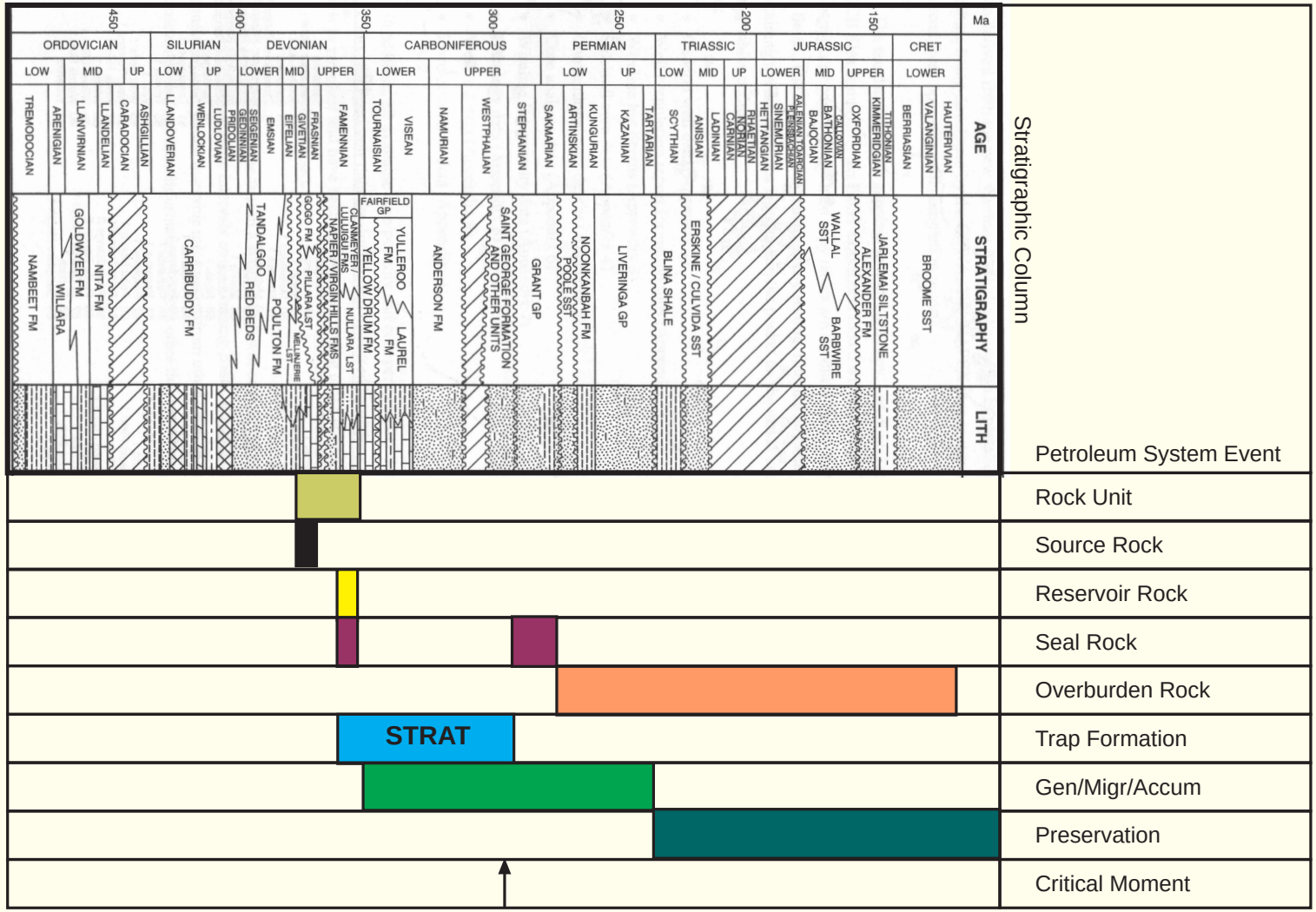

Figure 8.6. Petroleum system timing diagram of an example of a combined stratigraphic / structural play with Luluigui Formation reservoir and Gogo Formation source.

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Combined Stratigraphic / Structural Play Timing

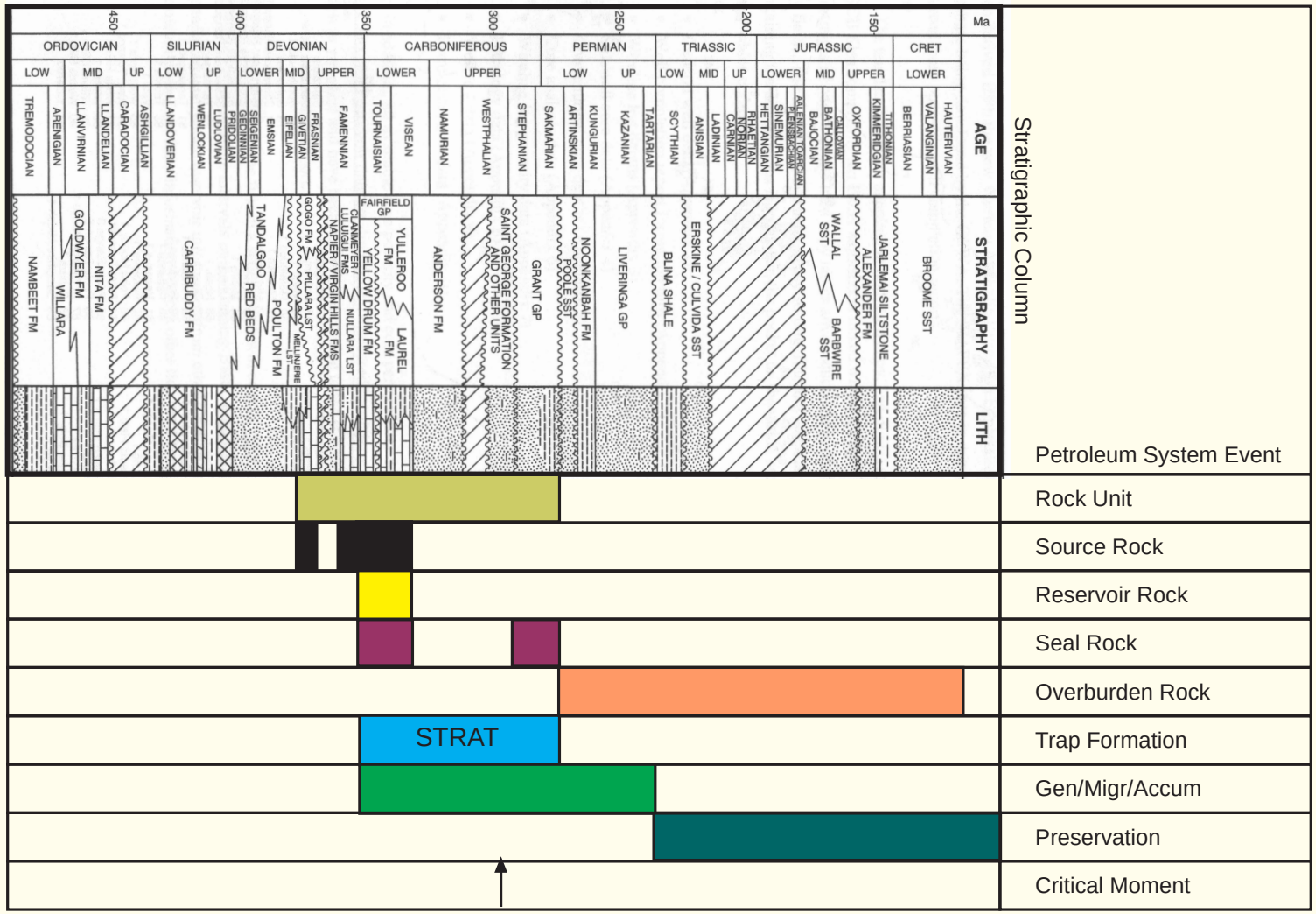

Figure 8.7. Petroleum system timing diagram of an example of a combined stratigraphic / structural play with Fairfield Group reservoir and Gogo Formation, Luluigui Formation and Fairfield Group source.

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9. PROSPECTIVITY AND ECONOMICS

9.1. PROSPECTIVITY

A number of different and varied play types have been identified in the study area. These include: stratigraphic plays such as confined channels and reservoir pinch outs, structural plays such as four-way dip closed anticlines, fault dependant closures and possibly salt related features, and combined structural-stratigraphic traps such as reservoir sub-crop configurations.

Each of the three application areas contains a variety of plays, and various leads have been identified (Enclosure 14). In addition four representative leads have been interpreted in greater detail and worked up to present volumetrics and reserves. These prospects are as follows:

Prospect G1:

Incised valley in lower Grant Group encased in overbank fine-grained sealing facies. The channel is clearly visible from seismic data and the infill has a bright and chaotic seismic-stratigraphic character indicative of sand cored channel fill. The channel sits within a structural high at Base Grant unconformity level, providing a structural high and four-way dip closure (Figures 9.1 and 9.2).

Prospect A1:

Anderson Formation Reservoirs in a structural trap configuration, four-way dip closed and fault and dip closured structures, beneath basal Grant Group shale. The structure may be the result of salt diapirism, with salt movement related to the presence of a major basin-bounding fault (Figures 9.3 and 9.4).

Prospect L1:

Luluigui Formation four-way dip closed anticline, formed by tectonic activity prior to the Fitzroy Movement, thus providing trap formation prior to the main phase of hydrocarbon generation and migration within the study area. Shale at the base of the Anderson Formation, or intraformational seals within the Luluigui Formation will provide top seal (Figures 9.5 and 9.6).

Prospect T1:

Sub-crop of the Tandalgoo Formation reservoirs beneath the Base Grant unconformity, coincident with a structural high at the Base Grant. Base seal for the stratigraphic trap will be either provided by: intraformational seals within the Tandalgoo Formation, or shale at the top of the Carribuddy Group as in the Patience-1 well (Figures 9.7 and 9.8).

The well summary sheets following detail volumetrics, reserves and risked reserves calculations, and associated parameters, for each of the above prospects.

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Risked Volumetric Estimate Summary Sheet

Client: DME **Country:** Australia / Canning Basin

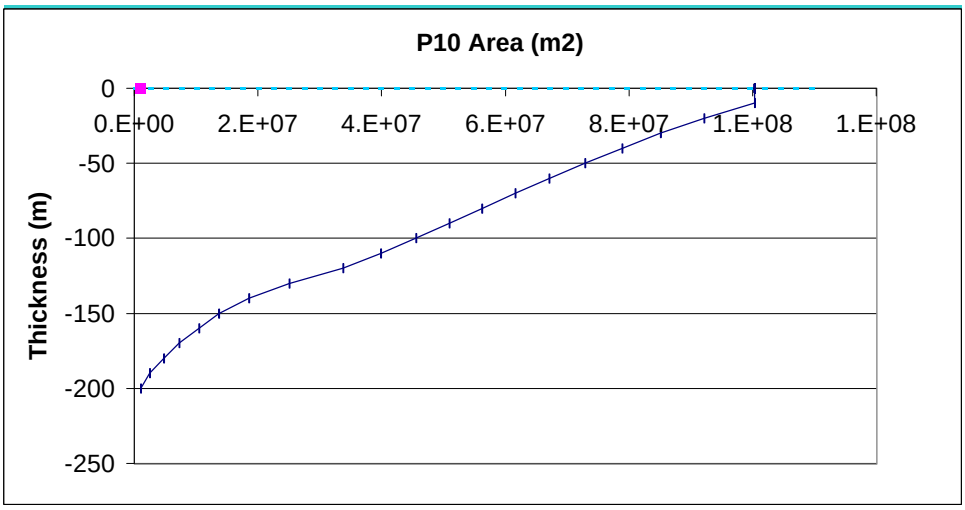
Prospect: G1 **Reservoir:** Base Grant Channel

Parameter	Units	P90	ML	P10	Distrib (Mean)	Comments	Engineer
GRV	m3	5.16E+09	6.88E+09	9.17E+09	7.12E+09	Triangular	AP
Area	m2		1.00E+08				AP
h_{gross}	m		120				AP
Area*h	m3	0.00E+00	1.20E+10	0.00E+00			Calc
Area*h v GRV	%	0%	175%	0%			Calc
N:G	v/v	0.18	0.3	0.6	0.38	Little data	AP
Porosity	v/v	0.15	0.18	0.22	0.18	Log 14% / Core 20% in nearest well	AP
Shc, (1-Sw)	v/v	0.55	0.65	0.8	0.65		AP
B_o	rb/stb	1.05	1.16	1.25	1.155013		AP
HC vol-GRV Ratio	stb/m3	0.49425	0.63447	0.88570		Internal check	Calc
Pressure	psia	1128.664	1128.664				AP
Temperature	F			0	0		AP
RF	%	15%	20%	30%	22%	Permeability could be 10-1000 MD good sweep	AP
Conversion factor:		m3	to MMstb	6.2905E-06			AP
STOIIP	MMstb	459.03	1,309.46	4,874.55	1,754.00		Calc
UR	MMstb	68.85	261.89	1,462.37	388.96		Calc
Cumulative	MMstb	-		-			
Resources	MMstb	68.85	261.89	1,462.37	388.96		Calc

Note: Yellow and Green Boxes to be independently QC'd.
Items in Blue font are inputs. Green boxes are Crystal Ball Inputs which must reflect the input data.

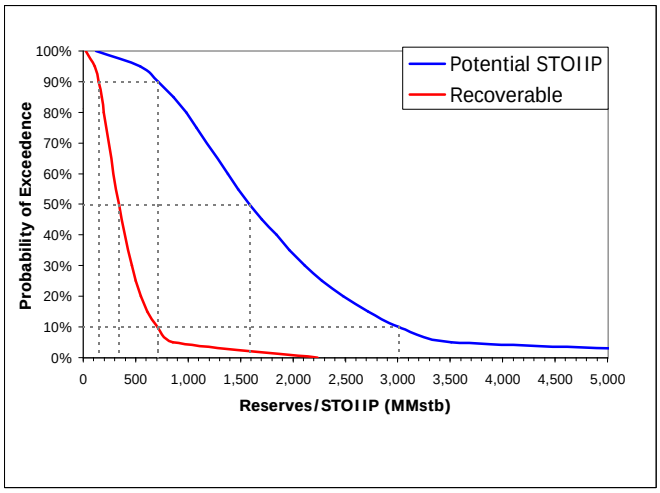
Reservoir	95%	Channel clear on seismic
Source	70%	Residual oil column in White Hills well. No oil shows in Point Moody & Lake Hevern.
Trap	80%	Good 4 way closure
Seal	50%	No Base Grant shales intersected in Lake Hevern well - may not seal
Timing	60%	Timing of Anticline unknown
Total Risk	**15.960%**	

Area Thickness Curve



Crystal Ball Output Distributions

	Probability	Potential STOIIP	Potential Recoverable	Risked
	100%	123.68	24.70	
	95%	540.76	110.41	
P90	**90%**	**714.81**	**147.38**	**23.52**
	85%	860.80	177.15	
	80%	980.87	197.42	
	75%	1,079.30	219.56	
	70%	1,180.67	244.44	
	65%	1,282.08	266.39	
	60%	1,377.41	288.46	
	55%	1,479.71	314.37	
P50	**50%**	**1,587.45**	**339.75**	**54.22**
	45%	1,706.06	367.00	
	40%	1,840.74	396.11	
	35%	1,968.34	425.10	
	30%	2,113.83	461.02	
	25%	2,279.19	500.22	
	20%	2,478.70	547.34	
	15%	2,714.99	609.81	
P10	**10%**	**3,009.71**	**706.55**	**112.76**
	5%	3,507.49	854.57	
	0%	7,974.86	2,235.77	



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Risked Volumetric Estimate Summary Sheet

Client: DME **Country:** Australia / Canning Basin

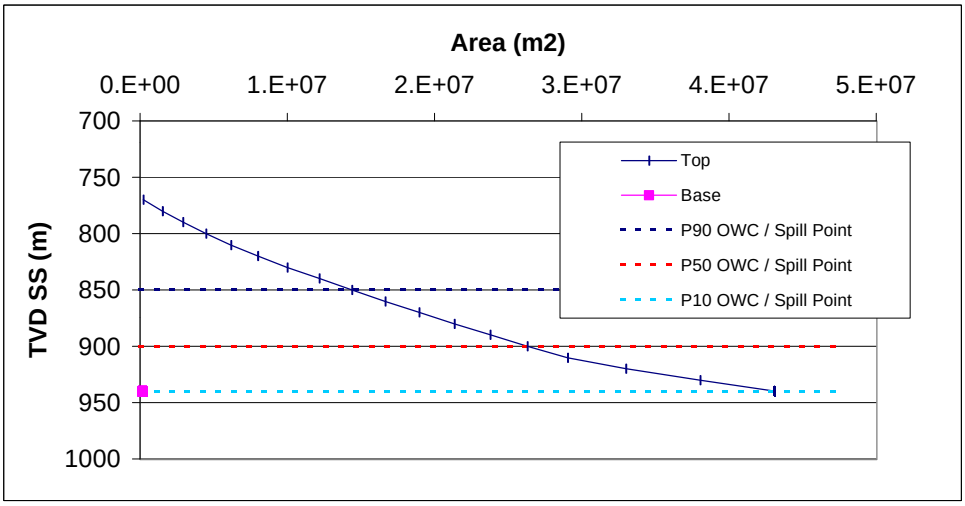
Prospect: A1 North **Reservoir:** Anderson Formation

Parameter	Units	P90	ML	P10	Distrib (Mean)	Comments	Engineer
GRV	m3	5.26E+08	1.54E+09	2.88E+09	1.42E+09	Log Normal	AP
Area	m2		1.44E+07				AP
h_{gross}	m		50				AP
Area*h	m3	0.00E+00	7.19E+08	0.00E+00			Calc
Area*h v GRV	%	0%	47%	0%			Calc
N:G	v/v	0.15	0.2	0.35	0.24	66% reservoir with 25-30% N/G	AP
Porosity	v/v	0.1	0.15	0.23	0.16	Log 14% / Core 25% in nearest well	AP
Shc, (1-Sw)	v/v	0.55	0.65	0.8	0.65		AP
B_o	rb/stb	1.05	1.15	1.25	1.155013		AP
HC vol-GRV Ratio	stb/m3	0.32950	0.53333	0.92596		Internal check	Calc
Pressure	psia	1128.664	1128.664				AP
Temperature	F			0	0		AP
RF	%	7%	15%	30%	18%	Permeability could be 1-60 MD	AP
Conversion factor:		m3	to MMstb	6.2905E-06			AP
STOIIP	MMstb	25.97	163.81	934.60	199.32		Calc
UR	MMstb	1.82	24.57	280.38	35.97		Calc
Cumulative	MMstb	-		-			
Resources	MMstb	1.82	24.57	280.38	35.97		Calc

Note: Yellow and Green Boxes to be independently QC'd.
Items in Blue font are inputs. Green boxes are Crystal Ball Inputs which must reflect the input data.

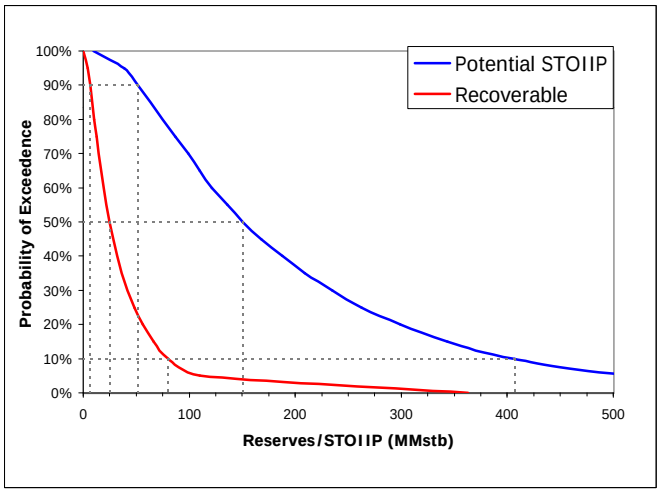
Reservoir	75%	Silification of Anderson in Point Moody. Unmapped extent of Anderson?. No Anderson intersected in Lake Hevern
Source	70%	Residual oil column in White Hills well. No oil shows in Point Moody & Lake Hevern.
Trap	60%	Only one Seismic line delineates structure. Salt Related ?
Seal	50%	Sandy Base Grant in White Hills & Point Moody may not seal
Timing	25%	Timing of Faulting
Total Risk	**3.938%**	

Area Thickness Curve



Crystal Ball Output Distributions

	Probability	Potential STOIIP	Potential Recoverable	Risked
	100%	9.54	0.04	
	95%	38.60	4.07	
P90	**90%**	**51.52**	**6.49**	**0.26**
	85%	63.18	8.47	
	80%	74.63	10.31	
	75%	86.92	12.44	
	70%	98.81	14.48	
	65%	110.13	16.84	
	60%	121.39	19.09	
	55%	136.08	21.75	
P50	**50%**	**150.50**	**24.63**	**0.97**
	45%	167.80	28.19	
	40%	187.76	32.18	
	35%	209.09	36.48	
	30%	235.13	41.68	
	25%	262.69	48.29	
	20%	299.18	56.05	
	15%	343.52	66.22	
P10	**10%**	**407.24**	**80.07**	**3.15**
	5%	530.74	109.95	
	0%	1,461.57	362.79	



TROY IKODA AUSTRALASIA PTY LTD

Risked Volumetric Estimate Summary Sheet

Client: DME **Country:** Australia / Canning Basin

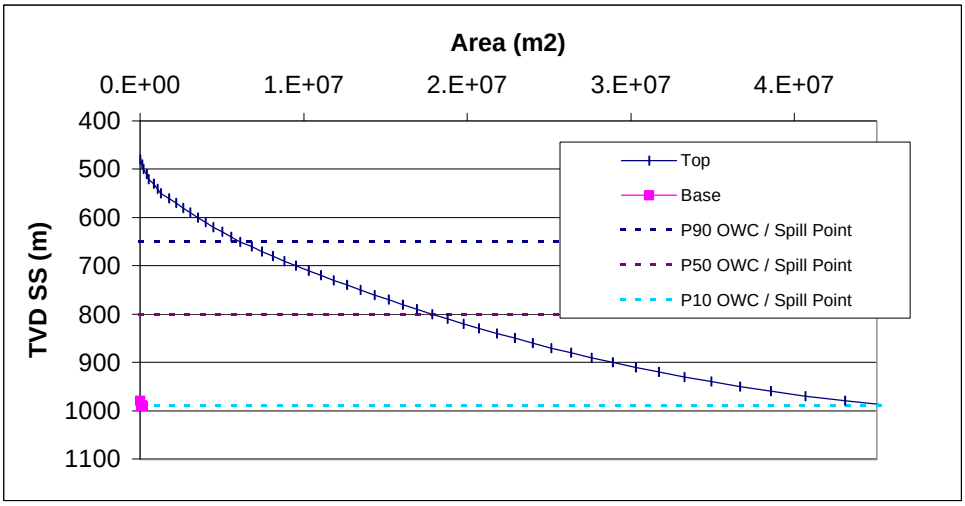
Prospect: A1 South **Reservoir:** Anderson Formation

Parameter	Units	P90	ML	P10	Distrib (Mean)	Comments	Engineer
GRV	m3	3.96E+08	2.14E+09	7.71E+09	2.43E+09	Log Normal (truncated to 9.00E9)	AP
Area	m2		1.18E+07				AP
h_{gross}	m		50				AP
Area*h	m3	0.00E+00	5.92E+08	0.00E+00			Calc
Area*h v GRV	%	0%	28%	0%			Calc
N:G	v/v	0.15	0.2	0.35	0.24	66% reservoir with 25-30% N/G	AP
Porosity	v/v	0.1	0.15	0.23	0.16	Log 14% / Core 25% in nearest well	AP
Shc, (1-Sw)	v/v	0.55	0.65	0.8	0.65		AP
B_o	rb/stb	1.05	1.15	1.25	1.155013		AP
HC vol-GRV Ratio	stb/m3	0.32950	0.53333	0.92596		Internal check	Calc
Pressure	psia	1128.664	1128.664				AP
Temperature	F			0	0		AP
RF	%	7%	15%	30%	18%	Permeability could be 1-60 MD	AP
Conversion factor:		m3	to MMstb	6.2905E-06			AP
STOIIP	MMstb	19.56	228.16	2,497.51	339.86		Calc
UR	MMstb	1.37	34.22	749.25	61.34		Calc
Cumulative	MMstb	-		-			
Resources	MMstb	1.37	34.22	749.25	61.34		Calc

Note: Yellow and Green Boxes to be independently QC'd.
Items in Blue font are inputs. Green boxes are Crystal Ball Inputs which must reflect the input data.

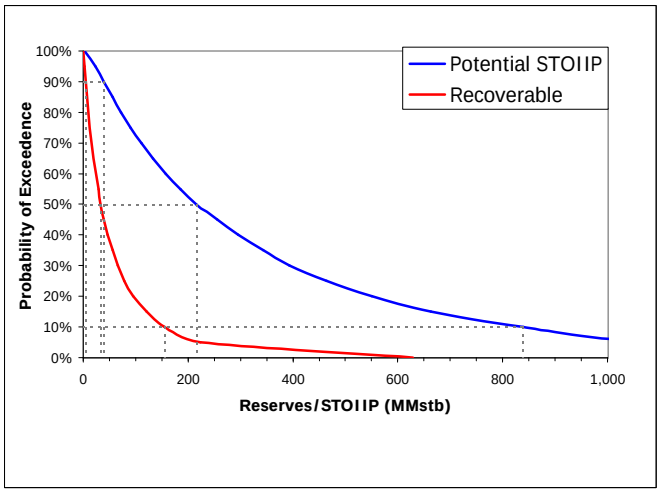
Reservoir	75%	Silification of Anderson in Point Moody. Unmapped extent of Anderson?. No Anderson intersected in Lake Hevern
Source	70%	Residual oil column in White Hills well. No oil shows in Point Moody & Lake Hevern.
Trap	55%	Fault Sealing Required.
Seal	50%	Sandy Base Grant in White Hills & Point Moody may not seal
Timing	25%	Timing of Faulting (Fitzroy)
Total Risk	**3.609%**	

Area Thickness Curve



Crystal Ball Output Distributions

	Probability	Potential STOIIP	Potential Recoverable	Risked
	100%	2.07	0.02	
	95%	23.41	2.88	
P90	**90%**	**39.41**	**5.26**	**0.19**
	85%	55.87	7.46	
	80%	72.51	10.15	
	75%	90.75	12.81	
	70%	110.54	16.24	
	65%	133.23	19.61	
	60%	157.35	23.98	
	55%	185.25	28.73	
P50	**50%**	**216.35**	**33.34**	**1.20**
	45%	255.46	39.37	
	40%	294.99	46.15	
	35%	342.91	55.65	
	30%	392.90	65.50	
	25%	463.59	78.49	
	20%	550.91	95.25	
	15%	663.38	121.24	
P10	**10%**	**838.88**	**155.64**	**5.62**
	5%	1,104.08	223.64	
	0%	2,901.74	628.42	



TROY IKODA AUSTRALASIA PTY LTD

Risked Volumetric Estimate Summary Sheet

Client: DME **Country:** Australia / Canning Basin

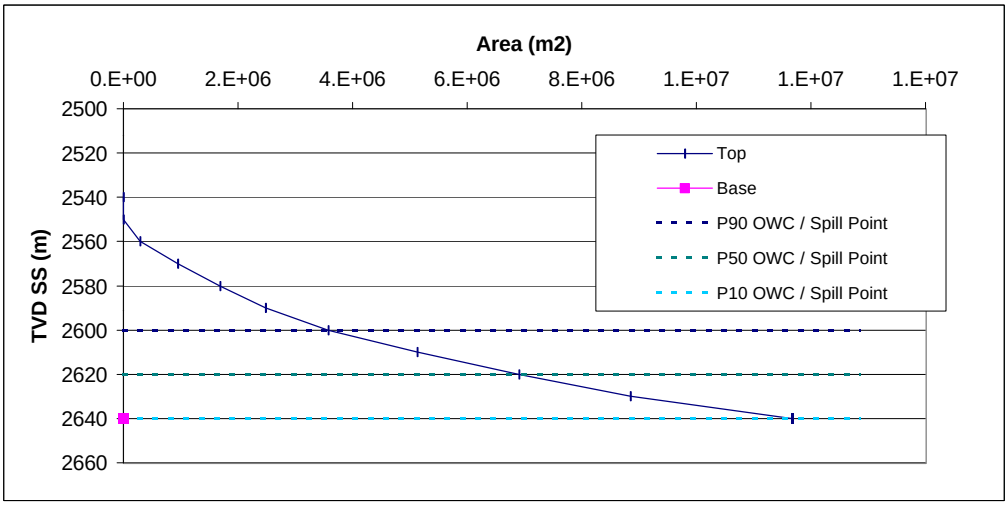
Prospect: L1 **Reservoir:** Top Luluigui Reservoir

Parameter	Units	P90	ML	P10	Distrib (Mean)	Comments	Engineer
GRV	*m3*	7.19E+07	1.76E+08	3.57E+08	2.11E+08	Triangular	AP
Area	*m2*		3.57E+06				AP
h_{gross}	*m*		75				AP
*Area*h*	*m3*	*0.00E+00*	*2.68E+08*	*0.00E+00*			Calc
*Area*h v GRV*	*%*	*0%*	*153%*	*0%*			Calc
N:G	v/v	0.12	0.17	0.21	0.17	500m gross, 150m of reservoir with 40-60% N/G	AP
Porosity	*v/v*	0.2	0.27	0.35	0.27	Log suggests good porosity in sand encountered	AP
Shc, (1-Sw)	*v/v*	0.55	0.65	0.8	0.65		AP
B_o	*rb/stb*	1.1	1.2	1.25	1.18		AP
HC vol-GRV Ratio	*stb/m3*	*0.62905*	*0.91999*	*1.40907*		Internal check	Calc
Pressure	*psia*		*3527.075*				AP
Temperature	*F*			*0*	*0*		AP
RF	*%*	15%	20%	35%	24%	Good sand if present	AP
Conversion factor:		*m3*	*to MMstb*	6.2905E-06			AP
STOIIP	MMstb	5.43	27.45	105.62	33.25		Calc
UR	MMstb	0.81	5.49	36.97	8.10		Calc
Cumulative	MMstb	-		-			
Resources	MMstb	0.81	5.49	36.97	8.10		Calc

Note: Yellow and Green Boxes to be independently QC'd.
Items in Blue font are inputs. Green boxes are Crystal Ball Inputs which must reflect the input data.

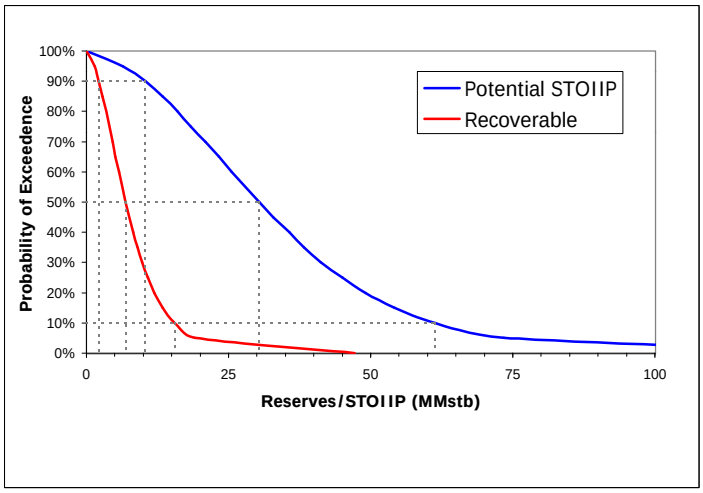
Reservoir	50%	Sands recorded at Top Luluigui but extent unknown.
Source	75%	Residual oil column in White Hills well. No oil shows Kilang kilang
Trap	90%	Good well defined four way dip closure
Seal	70%	Base Fairfield shales recorded in White Hills. However full extent unknown
Timing	90%	Structure formed well before migration.
Total Risk	**21.263%**	

Area Thickness Curve



Crystal Ball Output Distributions

	Probability	Potential STOIIP	Potential Recoverable	Risked
	100%	0.02	0.00	
	95%	6.47	1.42	
P90	**90%**	**10.33**	**2.17**	**0.46**
	85%	13.40	2.87	
	80%	15.95	3.44	
	75%	18.40	4.02	
	70%	20.96	4.57	
	65%	23.28	5.12	
	60%	25.53	5.72	
	55%	27.89	6.31	
P50	**50%**	**30.41**	**6.92**	**1.47**
	45%	32.90	7.49	
	40%	35.73	8.23	
	35%	38.24	8.99	
	30%	41.17	9.80	
	25%	45.03	10.82	
	20%	49.12	11.97	
	15%	54.15	13.37	
P10	**10%**	**61.34**	**15.51**	**3.30**
	5%	73.41	19.04	
	0%	138.18	47.17	



TROY IKODA AUSTRALASIA PTY LTD

Risked Volumetric Estimate Summary Sheet

Client: DME **Country:** Australia / Canning Basin

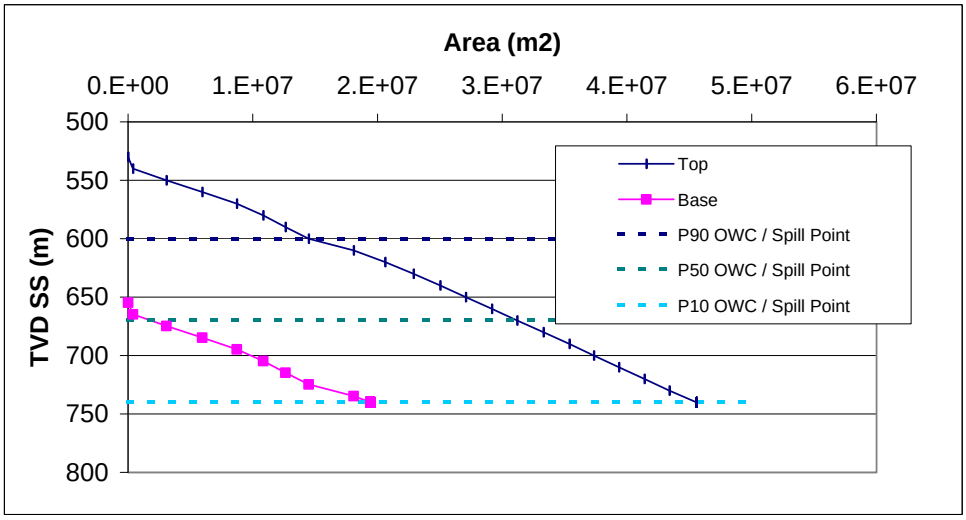
Prospect: T1 **Reservoir:** Tandalgoo Formation

Parameter	Units	P90	ML	P10	Distrib (Mean)	Comments	Engineer
GRV	m3	4.88E+08	2.14E+09	4.08E+09	2.54E+09	Log Normal (truncated)	AP
Area	m2		0.00E+00				AP
h_{gross}	m		200				AP
Area*h	m3	0.00E+00	0.00E+00	0.00E+00			Calc
Area*h v GRV	%	0%	0%	0%			Calc
N:G	v/v	0.4	0.6	0.7	0.56	60% of interval 99% reservoir	AP
Porosity	v/v	0.15	0.18	0.25	0.20	Log 14% / Core 25% in nearest well	AP
Shc, (1-Sw)	v/v	0.55	0.65	0.8	0.65		AP
B_o	rb/stb	1.05	1.13	1.2	1.128759		AP
HC vol-GRV Ratio	stb/m3	0.49425	0.65132	1.04842		Internal check	Calc
Pressure	psia	1128.664	1128.664				AP
Temperature	F			0	0		AP
RF	%	15%	25%	35%	25%	Permeability could be 400-1200 MD	AP
Conversion factor:		m3	to MMstb	6.2905E-06			AP
STOIIP	MMstb	96.43	834.97	2,993.65	1,010.43		Calc
UR	MMstb	14.47	208.74	1,047.78	252.88		Calc
Cumulative	MMstb	-		-			
Resources	MMstb	14.47	208.74	1,047.78	252.88		Calc

Note: Yellow and Green Boxes to be independently QC'd.
Items in Blue font are inputs. Green boxes are Crystal Ball Inputs which must reflect the input data.

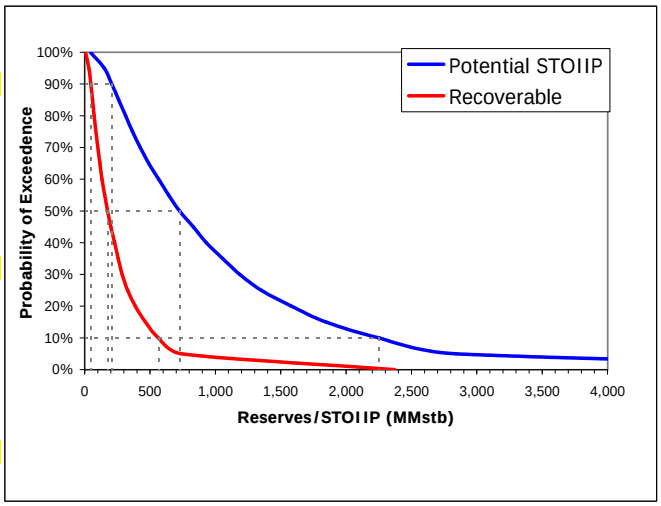
Reservoir	50%	Based on Lake Hevern 1 well: Tandaloo cemented to reduce porosity
Source	65%	Residual oil column in White Hills well. No oil shows in Point Moody & Lake Hevern.
Trap	80%	Good 4 way closure & well defined pinchout edge
Seal	30%	No Base Grant shales intersected in Lake Hevern well - may not seal
Timing	75%	Development of pinchout predates migration
Total Risk	**5.850 %**	

Area Thickness Curve



Crystal Ball Output Distributions

	Probability	Potential STOIIP	Potential Recoverable	Risked
	100%	43.99	6.71	
	95%	149.32	32.43	
P90	**90%**	**207.44**	**46.52**	**2.72**
	85%	259.85	59.87	
	80%	313.48	72.05	
	75%	366.02	85.98	
	70%	424.82	99.95	
	65%	489.80	115.99	
	60%	566.16	132.49	
	55%	641.06	153.14	
P50	**50%**	**726.38**	**175.42**	**10.26**
	45%	830.86	199.08	
	40%	930.38	229.16	
	35%	1,055.51	256.00	
	30%	1,185.83	286.26	
	25%	1,350.19	328.60	
	20%	1,580.34	386.93	
	15%	1,847.31	465.78	
P10	**10%**	**2,252.63**	**564.83**	**33.04**
	5%	2,839.03	740.28	
	0%	7,301.35	2,372.67	



9.2. CANNING BASIN DEVELOPMENT CONCEPT AND ECONOMICS

Study of the regional course 2D seismic grid has identified a number of potential structures and play types. Due to the seismic line spacing, it is generally the larger structures that have been identified and worked up. Further north in the basin there are a number of smaller accumulations (up to 2 MMbbls recoverable, i.e. the Blina Field) that are on production or have been abandoned.

Relatively small oil accumulations can readily be made commercial in the onshore Canning Basin. Typically, the development concept would evolve around a small low cost production and storage facility, including a loading station with oil trucked ultimately to the export terminal at Broome, 500 km away.

This gazettal acreage is in a relatively remote area of the country, southeast of the existing Canning Basin fields. Although the area is remote, there are existing loading stations on the Great Northern Highway that could be used as the initial point of delivery. These are accessible by trucking along the Canning Stock Route, which passes just to the north of the application areas. Multiple discoveries may warrant a pipeline or rail link to Broome or to the south coast. There is a fair level of mining activity in the area, which could provide a possible market for gas or electricity from a small gas to power generation project.

It has been assumed that due to the remote location, if the accumulations contain oil, the associated gas production not used onsite for own power generation, will be flared.

Further north in the basin, there have been several commercial discoveries with wells flowing at initial rates of between 200 and 1,000 bopd. It is on a similar basis that rudimentary conceptual development planning and economics have been calculated for this area.

The well drilling and completion costs are expected to be relatively low and for economic purposes, it has been conservatively assumed each well would cost US$0.75MM. Although four production wells have been assumed for the forecast, it was assumed an additional well was factored into the economics to as a dry hole / disposal well.

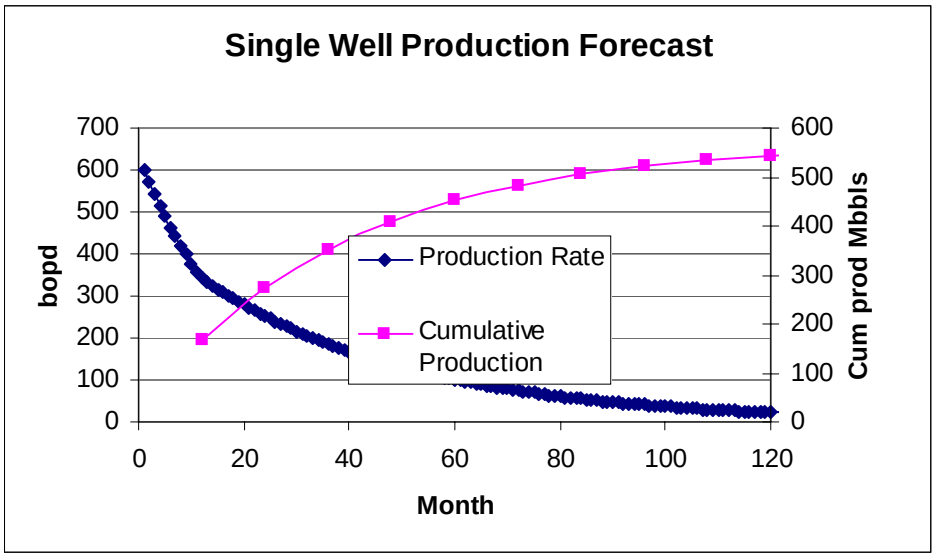
The smallest of the identified prospects, L1, has (in the event of a discovery) an estimate of between 2.17 and 15.5 MMbbls recoverable hydrocarbons (P90 and P10 respectively) with the probable resources estimated to be 6.92 MMbbls.

To demonstrate the commerciality of the region, production economics were prepared with the following assumptions.

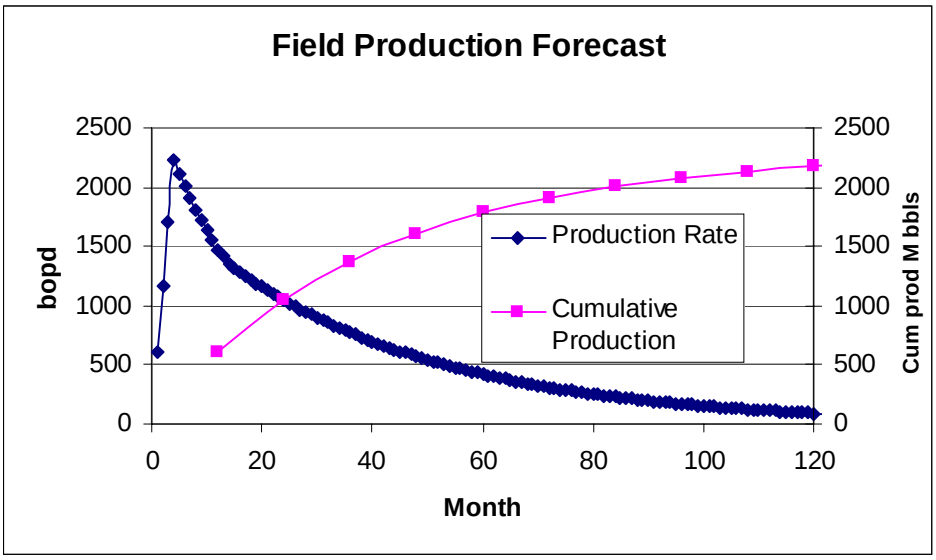
- The L1 prospect is drilled and is a discovery: Recoverable oil is 2.17 MMbbls.

- Four development wells are drilled, the average initial well rate was assumed to be 600 bopd. Declining at a rate of 5% per month for the first year and at a rate of 2.5% thereafter.

Based on these assumptions, the average forecast for a single well is shown below.



Four production wells drilled consecutively will produce a production forecast as below.



The production facilities for a peak rate of approximately 2,000 bopd are estimated to cost US$1.5MM (based on the assumption that where possible, reconditioned equipment is utilised). This cost will include a basic tanker loading facility. An additional US$0.5MM CAPEX cost has been assumed to account for additional items such as a gravel road link, or loading / storage facilities at existing loading stations on the Great Northern Highway. In addition US$0.5MM has been assumed for infield flowlines, roads, and support facilities.

At a peak production rate of 2,000 bopd, fifteen 20 tonne tanker trucks per day would be required to export the crude to the existing loading stations on the Great Northern Highway. Due to the distance, a trucking cost of US$4.00 per bbl has been assumed. All trucks will be on a rental basis.

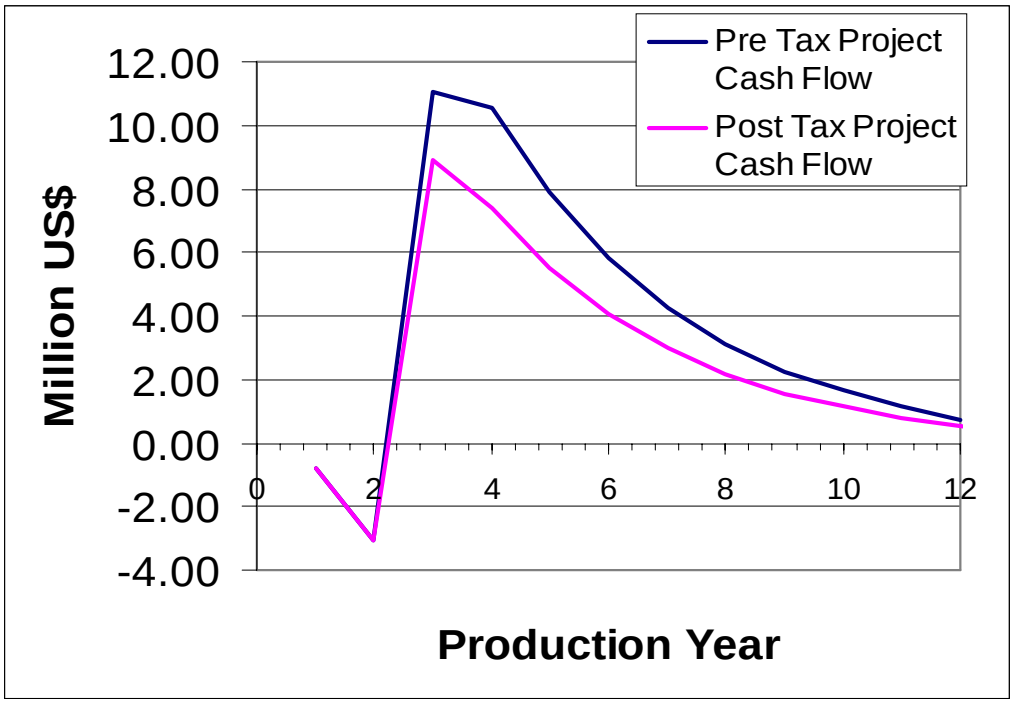
A variable operating cost of US$0.50 per bbl has also been assumed with a fixed operating cost of US$360M per year. It is assumed that each well will require a workover with well intervention costs of US$0.1MM per well at the rate of one well for four consecutive years during the mid-life of the field.

The following Base Case economic assumptions have been made:

- An oil price of $16 per bbl escalated at 3% per annum
- CAPEX and OPEX escalation rates of 3% per Annum.
- Wellhead Royalty rate of 10% with a 50% allowable deduction of operating costs.
- A Petroleum Resource Rent Tax (PRRT) of 0%, as PRRT is applicable to offshore fields only.
- Income tax has been applied at 30%.

Based on these assumptions, the economic results suggest the following:

1. The maximum capital exposure is approximately US$3–6.7MM depending on when expenditure occurs relative to production
2. The payout period is 3 years, assuming development commences 1 year after discovery.
3. The economic limit of the field is calculated to be approximately 100 bopd.
4. The NPV of the project based on a 10% discount rate is approximately US$4.33MM.



Base Case Project Cash flow

Oil Price Sensitivity

A range of oil price scenarios were run and the results are shown in the table below:

Oil Price US$/bbl	Post Tax NPV @ 10% Discount Rate US$MM
15	3.49
16	4.33
20	8.86
25	13.64
30	18.42

Upside Potential

Multiple discoveries or a single discovery of 20 MMbbl recoverable could warrant construction of an export pipeline or rail link from the region, improving project economics even further.

The use of deviated or horizontal producer wells could reduce the required well count for development and the introduction of artificial lift could extend the field life or initial well rates, thereby reducing the required well count with its associated reduction in CAPEX and exposure.

Summary and Conclusion

The development scenario laid out above is by no means optimised but has been produced to demonstrate the potential commerciality of even a small discovery in the

area. If a discovery is made in the L1 prospect, which as mapped has P50 recoverable oil reserves of 6.92 MMbbls, or 3 times the recoverable hydrocarbons assumed in the economics presented, then applying a CAPEX and fixed OPEX multiplier of 1.5 and a production multiplier of 3, the economic calculations suggest an NPV of US$23.77MM at a discount rate of 10%.

A P10 NPV of US$47.3MM at a discount rate of 10% was calculated by assuming a multiplier of 5 for the fixed OPEX and CAPEX and a production multiplier of 7.

These values were input into a simple EMV calculation shown below to give a "risked NPV" for the project.

L1 Prospect, Canning Basin EMV Analysis

Geological Risk Estimates

Reservoir	50%	Sands recorded at Top Luluigui but extent unknown.
Source	75%	Residual oil column in White Hills well. No oil shows Kilang kilang
Trap	90%	Good well defined four way dip closure
Seal	70%	Base Fairfield shales recorded in White Hills. However full extent unknown
Timing	90%	Structure formed well before migration.
Total Risk	**21.263%**	

			P50 NPV
Drill	21.3%	discovery	23.77 US$MM
	78.7%	dry hole	**Cost** -1 US$MM

EMV = (Probability Of Success x NPV of Success) - (Cost Of Failure x Probability of Failure)

P50 EMV **4.27**

Cost of failure has been taken as:

Dry well cost of	0.75 US$MM
Technical Studies	0.25 US$MM
Total	**1 US$MM**

L1 Prospect EMV Summary

Size	Reserves MMbbls	NPV US$MM	Risked NPV US$MM	EMV US$MM
P90	2.17	4.33	0.92	0.13
P50	6.92	23.77	5.05	4.27
P10	15.51	47.31	10.06	9.27

Although there are many other variables that could be included in such a calculation, the above calculation clearly demonstrates the value of further evaluation of the prospect.

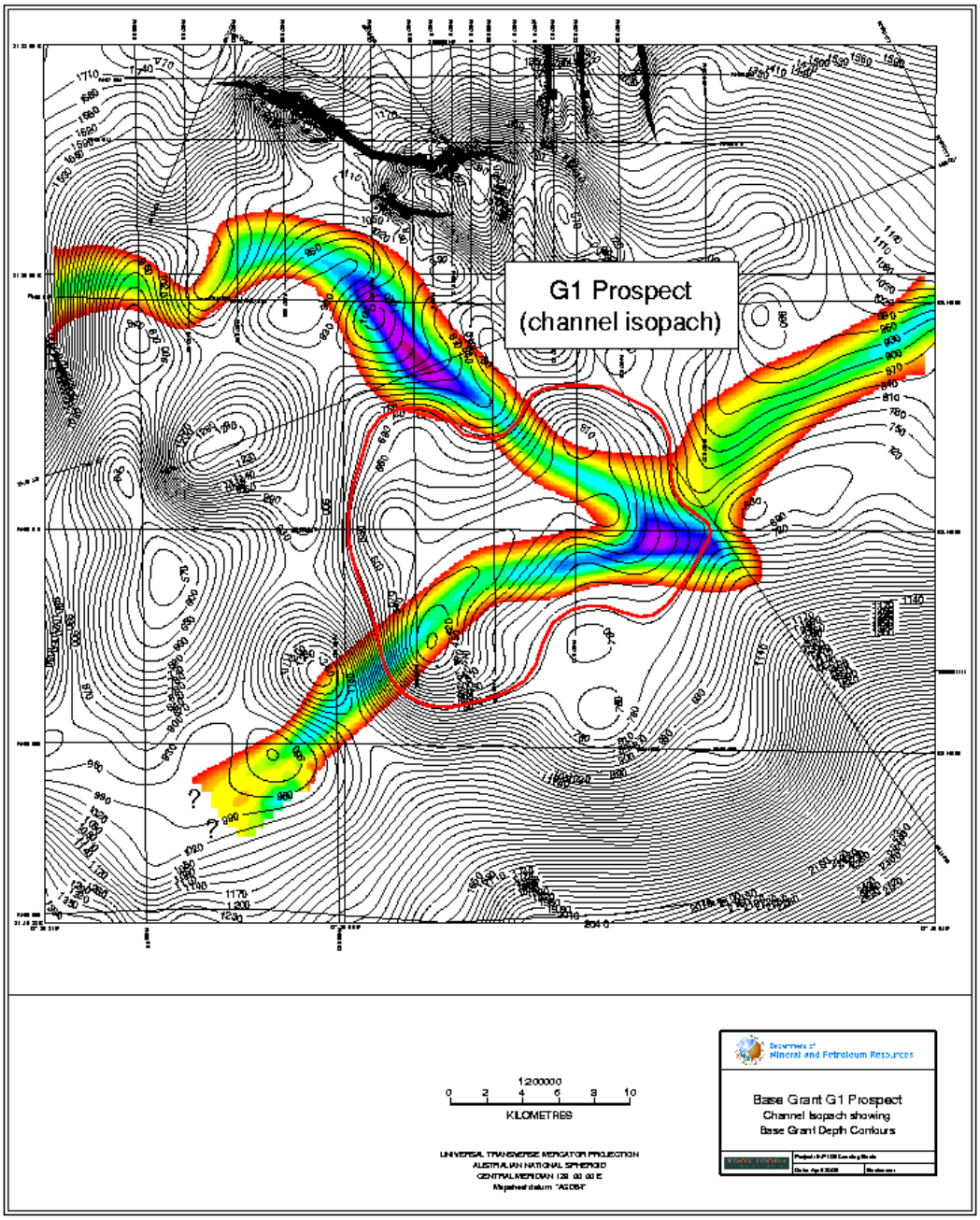
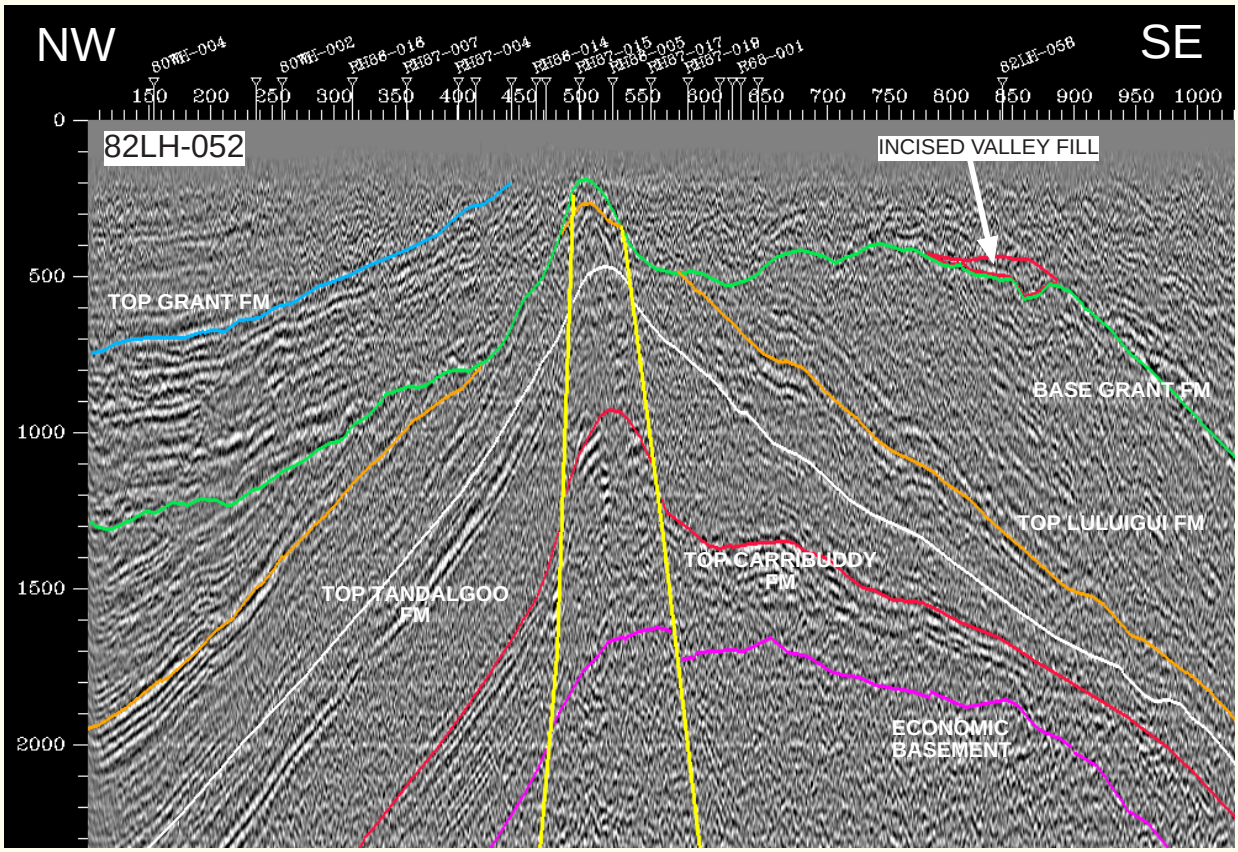


Figure 9.1. G1 prospect - An isopach map of an incised valley fill reservoir at the Base Grant Group unconformity (see Figure 9.2).



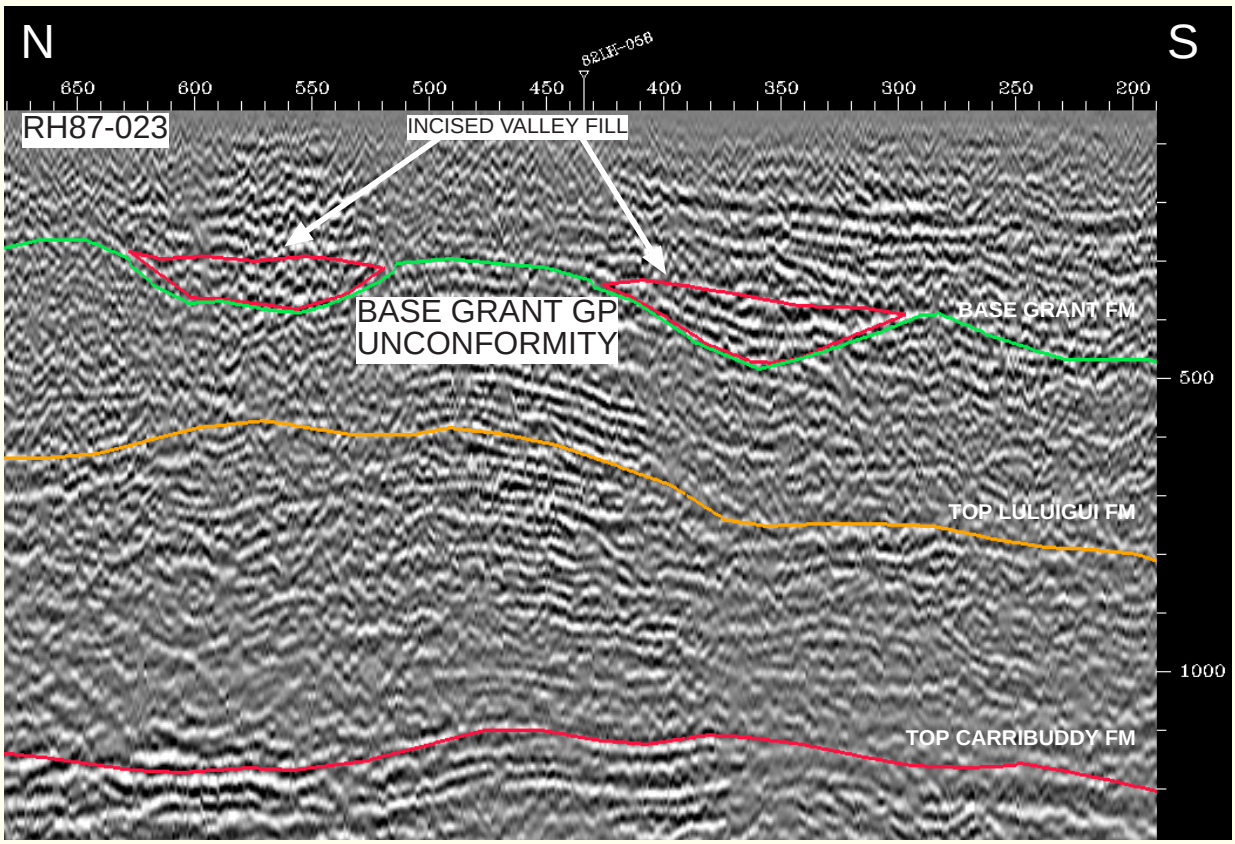


Figure 9.2. G1 prospect - Seismic lines RH87-023 & 82LH-052 showing incised valley fill reservoirs at the Base Grant Group unconformity.

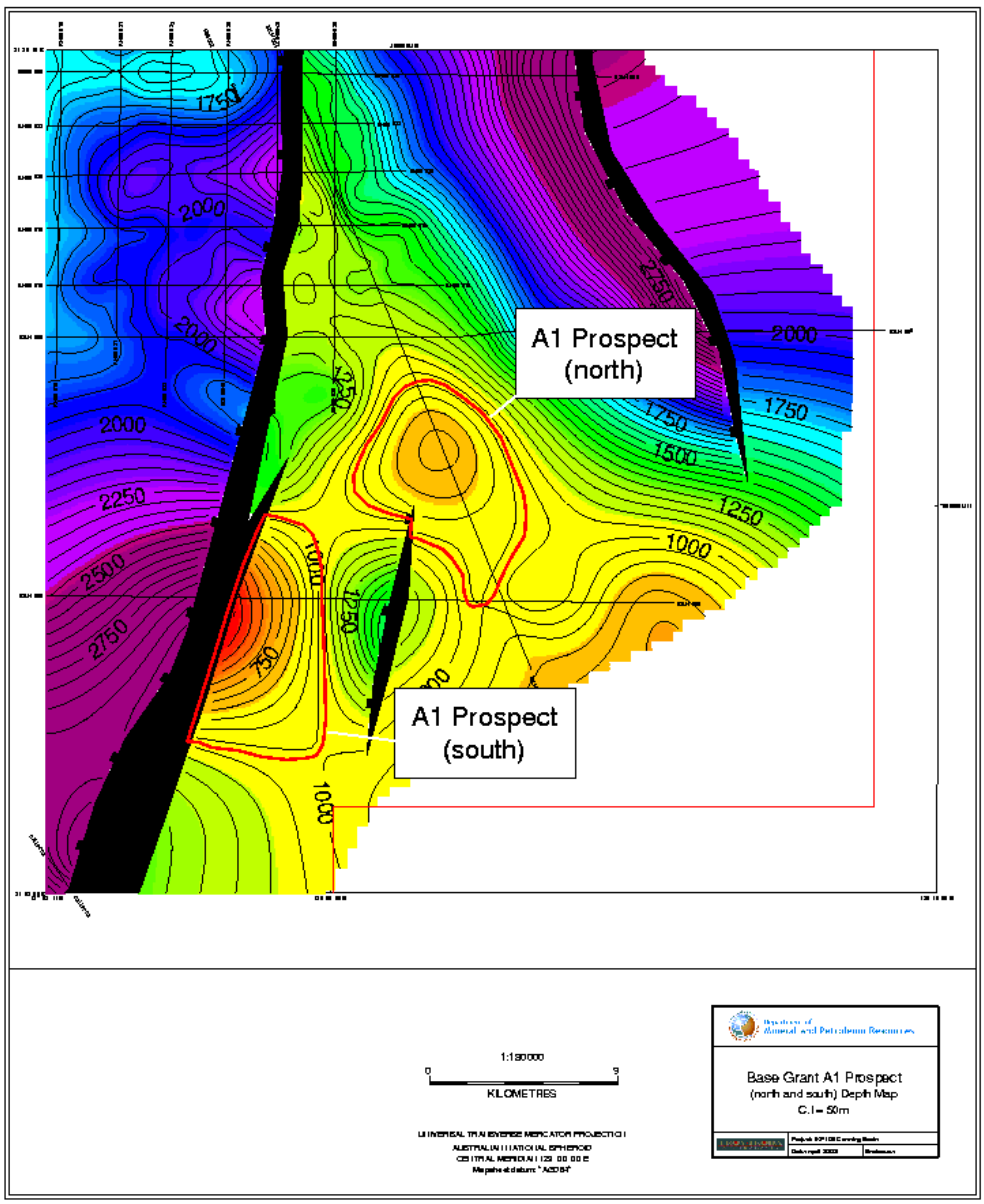


Figure 9.3. A1 prospect - A depth map showing the location and structure of A1 north and A1 south.

NW SE

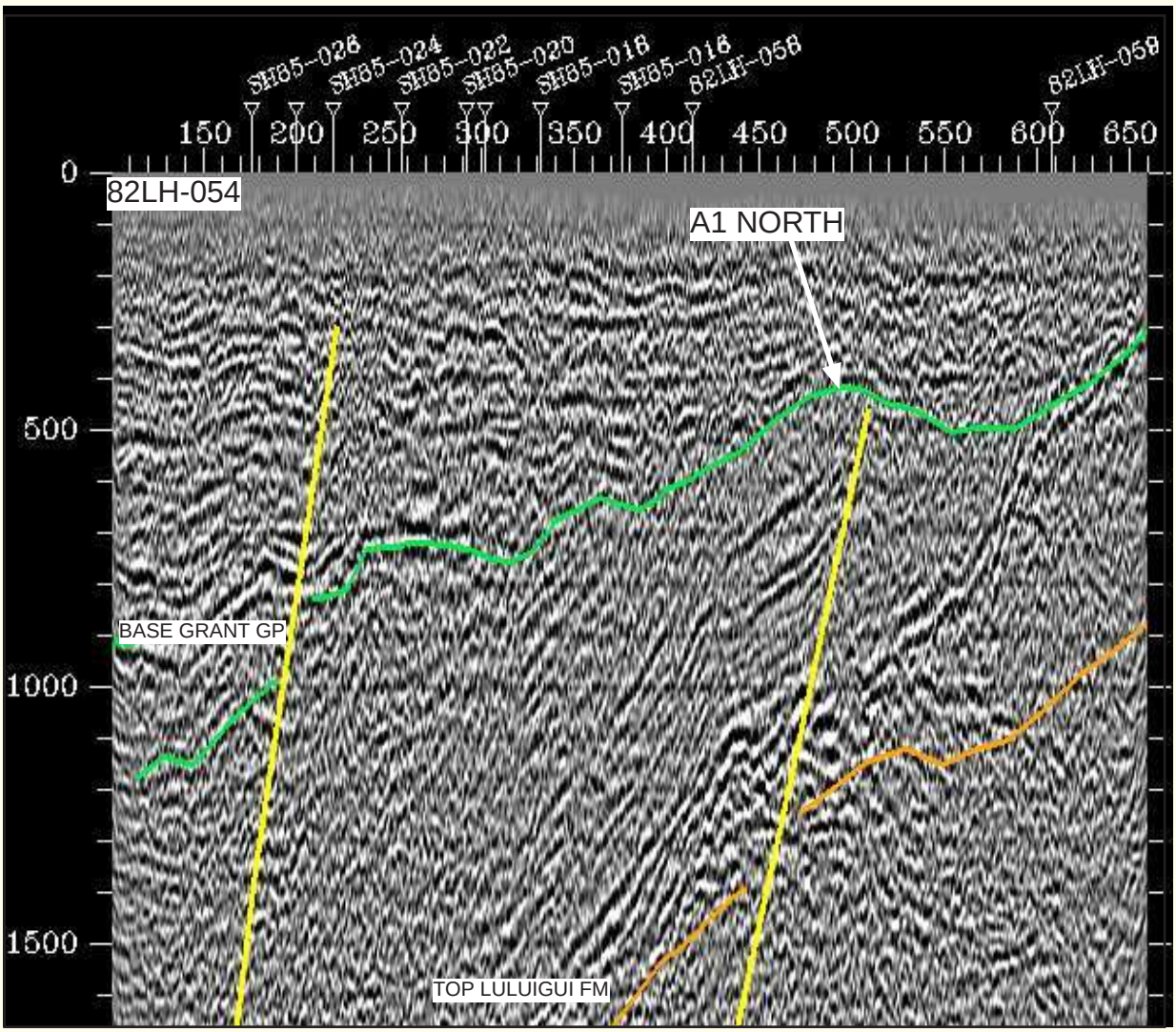


Figure 9.4. A1 north prospect - Seismic line 82LH-054 showing structural closure (possibly salt related).

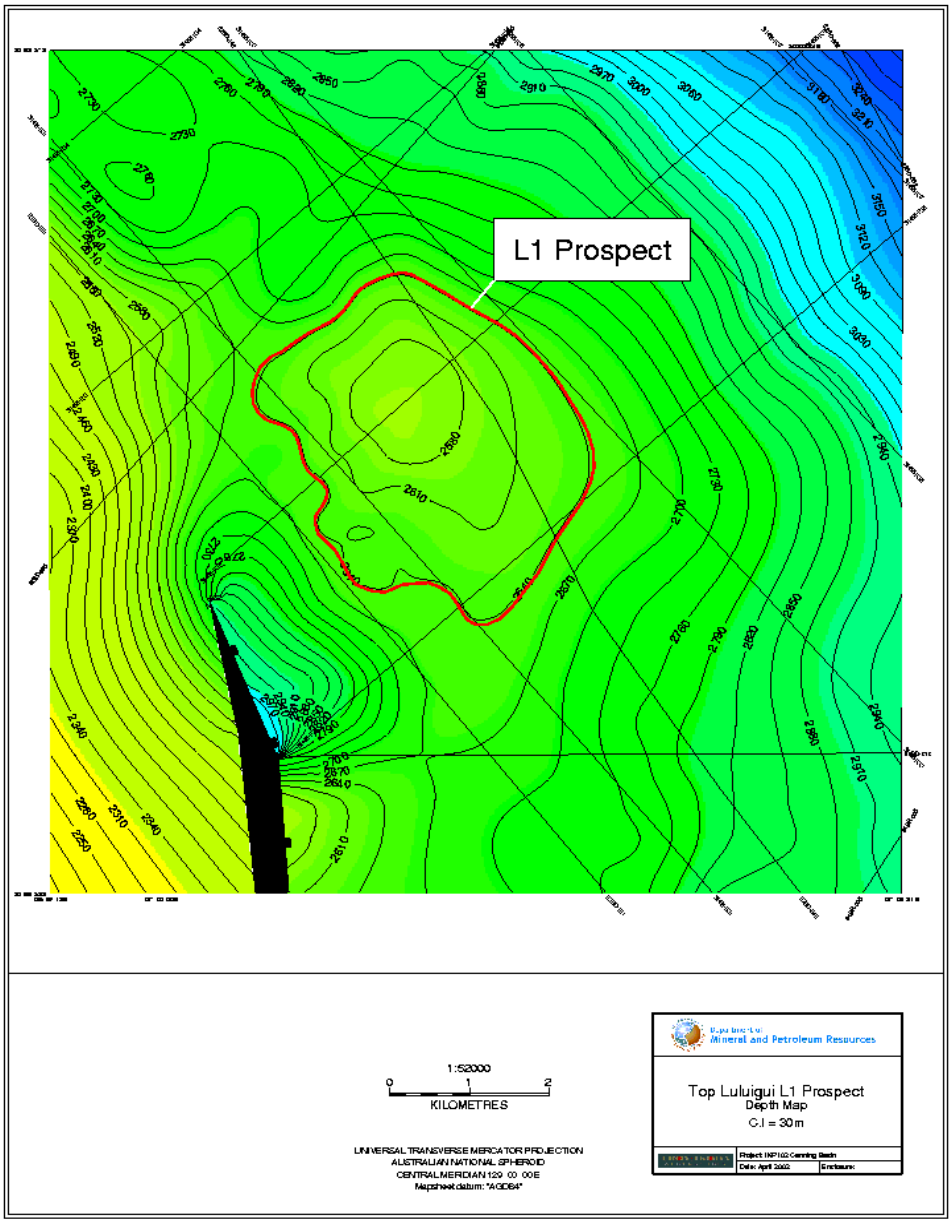


Figure 9.5. L1 prospect - A depth map showing the anticlinal structure of the L1 prospect..

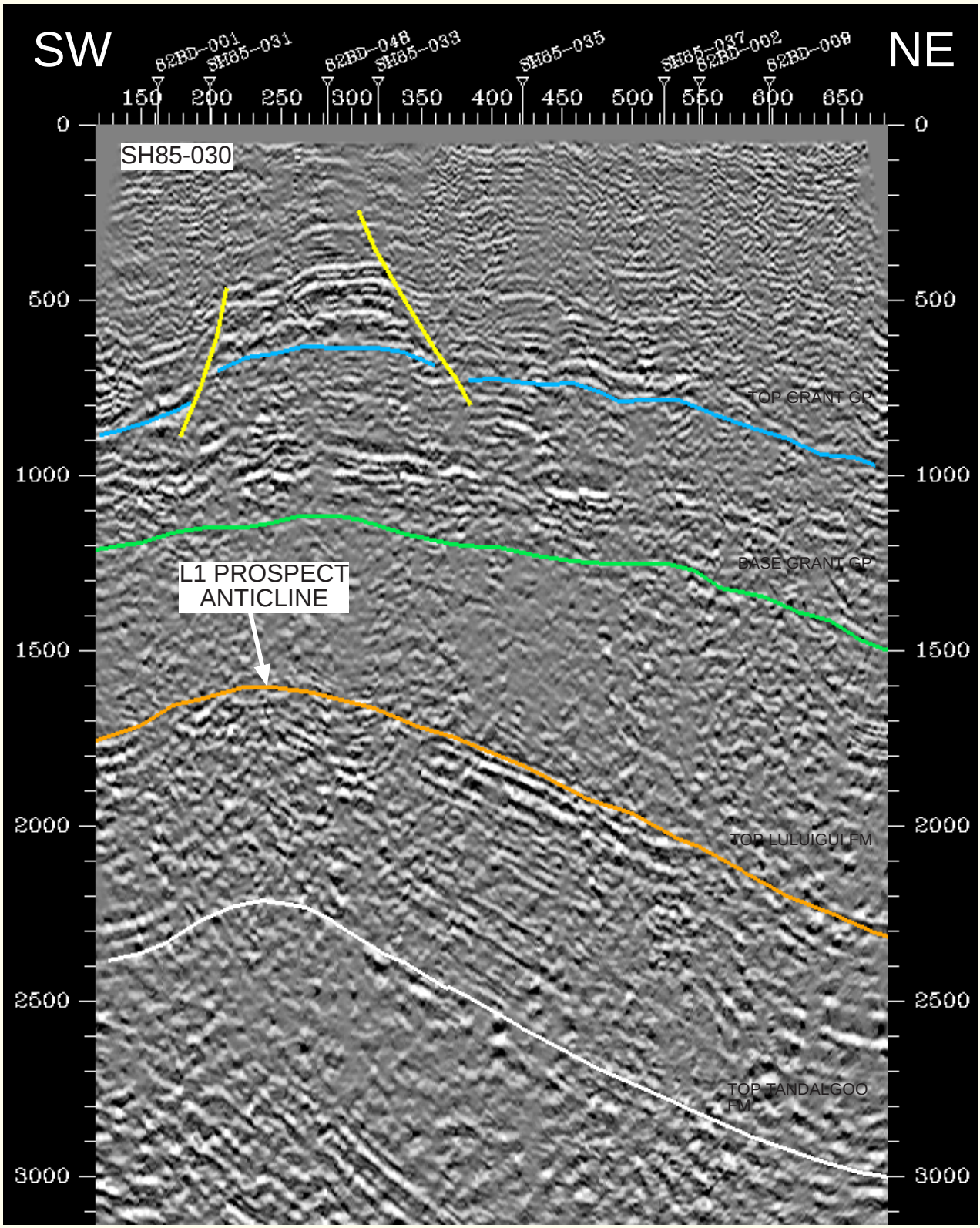


Figure 9.6. L1 prospect - Seismic line SH85-030 showing early formed anticline structures.

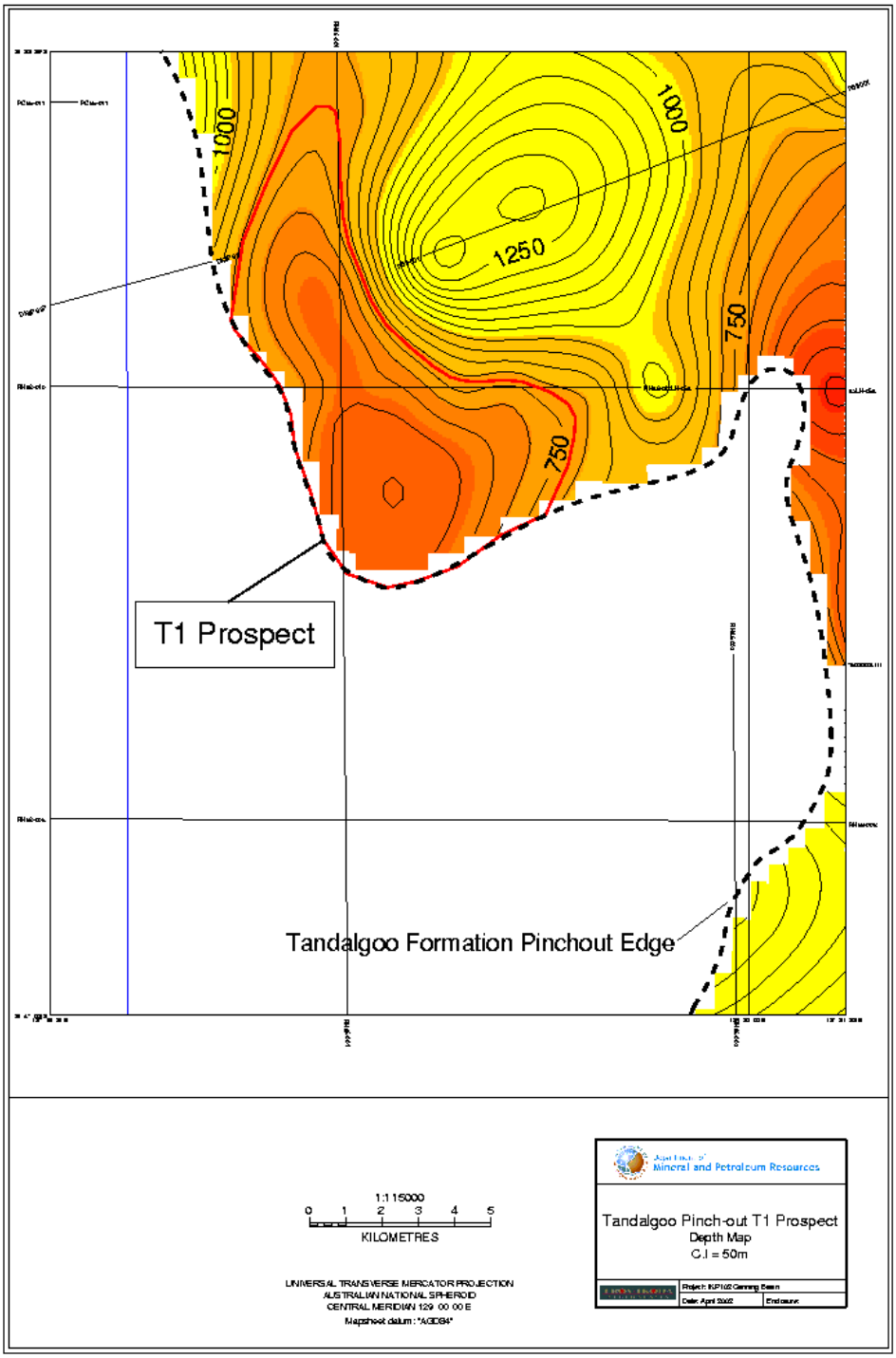


Figure 9.7. T1 prospect - A depth map showing the anticlinal structure at the Tandalgoo Formation pinch-out edge.

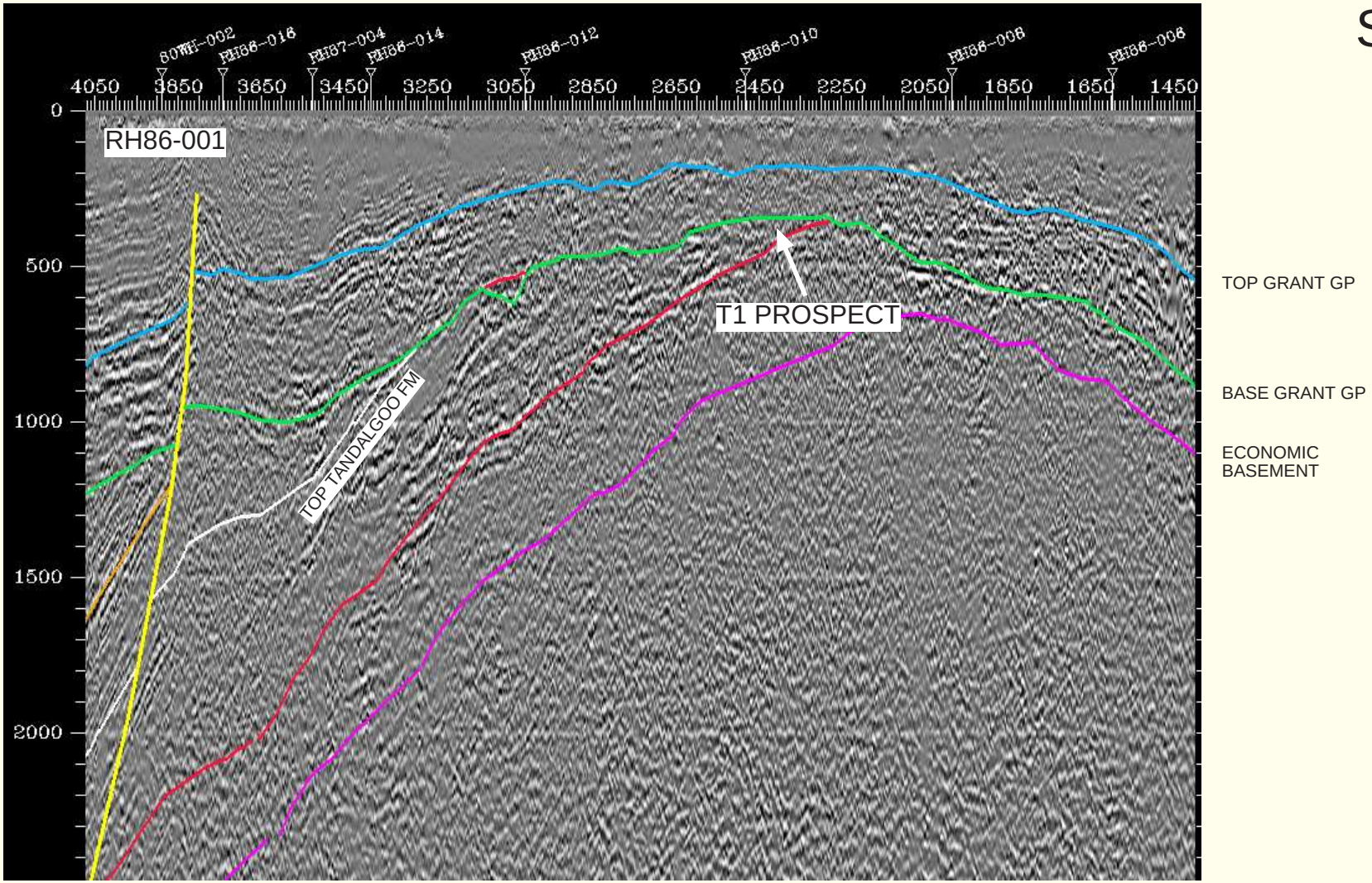


Figure 9.8. Prospect T1 - Seismic line RH86-001 showing the up-dip pinch-out of the Tandalgoo Formation against the Base Grant Group unconformity.

10. CONCLUSIONS

The Canning Basin is one of a series of large intracratonic basins that spans northwestern and central Australia. The onshore Canning Basin comprises up to 15 km of prospective Palaeozoic, Mesozoic and Cainozoic sediments. The study area in the southeast onshore Canning Basin covers four major structural provinces; 1) the Billiluna Shelf and Balgo Terrace on the basin margin to the north, 2) the Gregory Sub-basin, 3) the mid-basin arch Barbwire Terrace and Crossland Platform, and 4) the Kidson Sub-basin. The Canning Basin is known to be prospective, with five commercial oil fields in operation to the northwest; the study area in the southeast is prospective but can be considered frontier territory.

Data available in and around the study area of interest is generally sparse and of only moderate quality. However, it has been concluded to be of sufficient quality to undertake this regional prospectivity study. Seismic data consists of eight 2D surveys (acquired between 1970 and 1987) and is generally of low to moderate quality. Coverage is moderate and confined mainly in the northern parts of the study area. Landsat images, and magnetic and gravity data are also available over the entire study area, but have only been deemed useful for seismic structural interpretation quality control. Three exploration wells are present in the area (Point Moody-1, White Hills-1 and Lake Hevern-1), only one of which (White Hills-1) displays promising hydrocarbon shows.

Due to sparse and limited data coverage (especially in the south) and resolution, assessment of the petroleum prospectivity of the study area is complete, albeit more focused on the northern Gregory Sub-basin and its margins. The Silurian to Late Carboniferous interval has been the focus, again due to data coverage and resolution. Six horizons have been seismically mapped for this study, the choice of which has been due to geological significance, but constrained by seismic data quality.

Wells drilled to date in and around the area have generally been unsuccessful in locating hydrocarbon accumulations primarily due to the lack of structural closure (originally unrecognised due to poor seismic data quality) and the timing of hydrocarbon migration pre-dating targeted traps.

Good reservoir, seal and source rocks can be found throughout the geological succession within the study area. A summary of the main reservoir formations is given in Table 10.1. Many potential reservoir formations contain good intra-formational seals.

Reservoir	Age	Lithology	Dep. Env.	Quality	Areal Extent
Tandalgoo Fm	Devonian	Clastic	Aeolian	Thick, High Por. & Perm.	Gregory Sub-basin
Mellinjerie Lst	Devonian	Carbonate	Marine Platform	Thin, Moderate Por. & Perm	Kidson Sub-basin
Luluigui Fm	Devonian	Clastic	Mixed Marine	Thin, Moderate Por. & Perm.	Gregory Sub-basin
Fairfield Gp	Carboniferous	Clastic	Marine Transition	Thin, High Por., Low Perm.	Gregory & Kidson Sub-basins
Anderson Fm	Carboniferous	Clastic	Alluvial	Thick, Moderate Por. & Perm.	Gregory Sub-basin
Grant Gp	Carboniferous-Permian	Clastic	Glacial, Alluvial	Thick, High Por. & Perm.	Gregory & Kidson Sub-basins

Table 10.1 Summary of main reservoir formations within the study area

Source rocks in the area reached maturity during three main time periods: 1) Triassic to post Triassic – Noonkanbah and Anderson Formations, 2) Carboniferous to Permian – Gogo and Luluigui Formations and Fairfield Group, and 3) Devonian – Willara and Goldwyer Formations. Trap timing versus maturity is concluded to be the critical factor in locating hydrocarbon accumulations. The presence of reservoirs, seals and adequate source is not a problem within the study area. However, identifying structures pre-dating source maturity is the key to successful exploration.

Stratigraphic, structural and combined stratigraphic / structural plays have been identified. Without high resolution seismic, stratigraphic play type prospects are difficult to locate and map. As mentioned earlier, the timing of trap formation is critical and without detailed structural analysis of the area, any structural play type prospect is risky. Thus, the combined stratigraphic / structural plays are considered the most prospective at this stage. Specifically, it is the Devonian to Carboniferous reservoirs sub-cropping the Base Grant unconformity at their pinch-out edge along the southern Gregory-Sub-basin margin that are deemed most prospective. Structure has been formed by erosion and subsequent Grant Group deposition in the Late Carboniferous, leaving trapped reservoirs to be charged by source rocks mature during the Late Carboniferous, Permian and Triassic (Gogo Formation, Luluigui Formation, Fairfield Group and Anderson Formation).

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