AN INTEGRATED EVALUATION OF POTENTIAL PETROLEUM SYSTEMS OF THE SOUTHERN CARNARVON BASIN, WESTERN AUSTRALIA

by

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ABSTRACT

AN INTEGRATED EVALUATION OF POTENTIAL PETROLEUM SYSTEMS
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The Southern Carnarvon Basin is an elongate basin in Western Australia covering approximately 200,000km^2. There are two main regions: a western platform (Gascoyne Platform) with a Cambrian to Lower Carboniferous succession that has mostly flat-lying Cretaceous-Cenozoic cover; and an eastern set of half-grabens (Merlinleigh Sub-basin) forming a single mid-Carboniferous – Permian depocenter, now separated by a gneissic basement of the Carrandibby Inlier, which is considered to be a part of the Merlinleigh Sub-basin. The two regions have little in common except for sharing a Devonian to Lower Carboniferous succession and both have predominantly Paleozoic infill.

Tectonics processes recorded in the strata as demonstrated by several episodes of subsidence and sediment accommodation has shaped the Southern Carnarvon

Basin. Each episode generated distinct tectonostratigraphic megasequences, which are separated by major unconformities that recorded uplift and erosion.

The scope of the research involves interpreting seismic sections of the minimally explored basin to investigate the structural history and petroleum potential. The study area covers approximately 150,000 km^2 with roughly 6,461 line kilometers of 2D seismic coverage and data from 111wells. By integrating seismic interpretation with other available geophysical data, we will be able to better identify potential plays and further our understanding of the underexplored Southern Carnarvon Basin.

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NOMENCLATURE

Symbol	**Description**
°C	Degree Celsius
2D	Two Dimensional
3D	Three Dimensional
AI	Acoustic Impedance
CDP	Common Depth Point
DT	Sonic Log
KB	Kelly Bushing
km	Kilometer
km^2	Square Kilometer
m	Meter
msec	Millisecond
NMO	Normal Move Out
RC	Reflection Coefficient
RHOB	Density Log
RMS	Root Mean Square
sec	Second
SEGY	Seismic Data File
TB	Terabyte
TD	Time-Depth
TWT	Two-Way Time
UKOOA	Navigation File
VR	Vitrinite Reflectance

1. INTRODUCTION

1.1. AREA OF STUDY

The Southern Carnarvon Basin (Figure 1.1) is a northerly elongate sedimentary rift basin located in Western Australia (Eyles et al, 2002). The basin is primarily onshore and covers approximately 200,000 km^2 that is dominated by Ordovician to Permian depocenters. Multiple tectonic processes formed the basin that has resulted in the formation of many sub-basins (Gascoyne, Merlinleigh, Bidgemia, and Byro) and uplift in the area. Structural evolution occurred from the Ordovician-Silurian to the Late Permian.

Two major regions are found within the basin, the Gascoyne Province, to the west, with a Cambrian to Lower Carboniferous succession that has a mostly flat-lying Cretaceous cover and the Merlinleigh and Byro Sub-basin, to the east, that are a set of half-grabens forming a single mid-Carboniferous-Permian depocenter that is separated by a gneissic basement of the Carrandibby Inlier (Mory et al, 2004).

The Gascoyne Platform (Figure 1.2) is an area within the Southern Carnarvon Basin that covers about 86,000 km^2 and extends south along the western coast. This sub-basin contains Cambrian-Triassic succession underlying a thin Cretaceous-Cenozoic section (Iasky et al., 2003). The region is poorly explored with only 2,500 kilometers of 2D seismic coverage, and, only 24 petroleum exploration wells with only eleven being deeper than 1,000 meters. The area is structurally higher than the surrounding portions of the basin (Hocking, 1994). Structurally, the Gascoyne platform is bounded to the east by the Wandagee and Ajana Ridges and to the west by the Bernier Ridge, a basement ridge (Iasky et al., 2003; Lockwood and D'Ercole, 2003). Its northern margin is bounded by the Cardabia Transfer Fault Zone and the Geelvink Fault System and Northampton Complex bound the Gascoyne Platform to the southwest and southeast respectively. Petroleum potential has been best identified in the Silurian Coburn and Devonian Gneudna Formations as the main source rock intervals that are mature to overly mature (Iasky et al., 2003). Potential traps include fault traps and anticlinal structures that include the Tumblagooda Sandstones to the south and the Wittecarra Sandstone Member to the southwest being sealed by the Kockatea Shale.

The Merlinleigh Sub-basin (Figure 1.3) is an elongate northwesterly oriented sub-basin that has limited seismic coverage with only eight exploratory wells drilled, two of which that are deeper than 1,000 meters. Deposition in the sub-basin lasted from the Silurian through the Permian and is thought to exceed 5,000m in thickness. The Tumblagooda Sandstone is the oldest known sedimentary unit that has been reached. No Jurassic or Triassic rocks are present, but a thin wedge of Cretaceous sediments extends over its western margins. The sub-basin is bounded to the east by the Pilbara Craton, to the west by the Wandagee Ridge, to the north by the Marilla High, and to the south and south-west by the Carrandibby Ridge and Inlier and the Kennedy Fault System respectively. Sediments in the main part of the basin are flat lying with minor faulting and small anticlines are present. The western margin along and adjacent to the Wandagee Ridge is complexly faulted. The structural grain and predominant fault pattern run north-south. The faulting appears to have been originally of normal tensional type with later left-lateral movement which probably form the small anticlinal features, which appear to be fault controlled. Prospective plays have been identified in the Permian Byro and Wooramel Groups and in Carboniferous and Devonian sediments. The Wooramel clastics play is considered the most important hydrocarbon play in the Merlinleigh Sub-basin (Iasky et al, 1998).

This report focuses on the area with 2D seismic coverage (Figure 1.3) within the highly structured portion between the Merlinleigh Sub-basin and the Gascoyne Platform. The study integrated the use of well data and other geophysical data to help aide in the interpretations of four horizons; the Top Basement, Top Devonian, Base Lyons Group, and Top Callytharra were selected for their lateral continuity, structural significance, and relevance to hydrocarbon prospectivity. The aim is to expand on previous research to provide an updated understanding of the regional geology in the area and to use as a guide for future exploration programs.

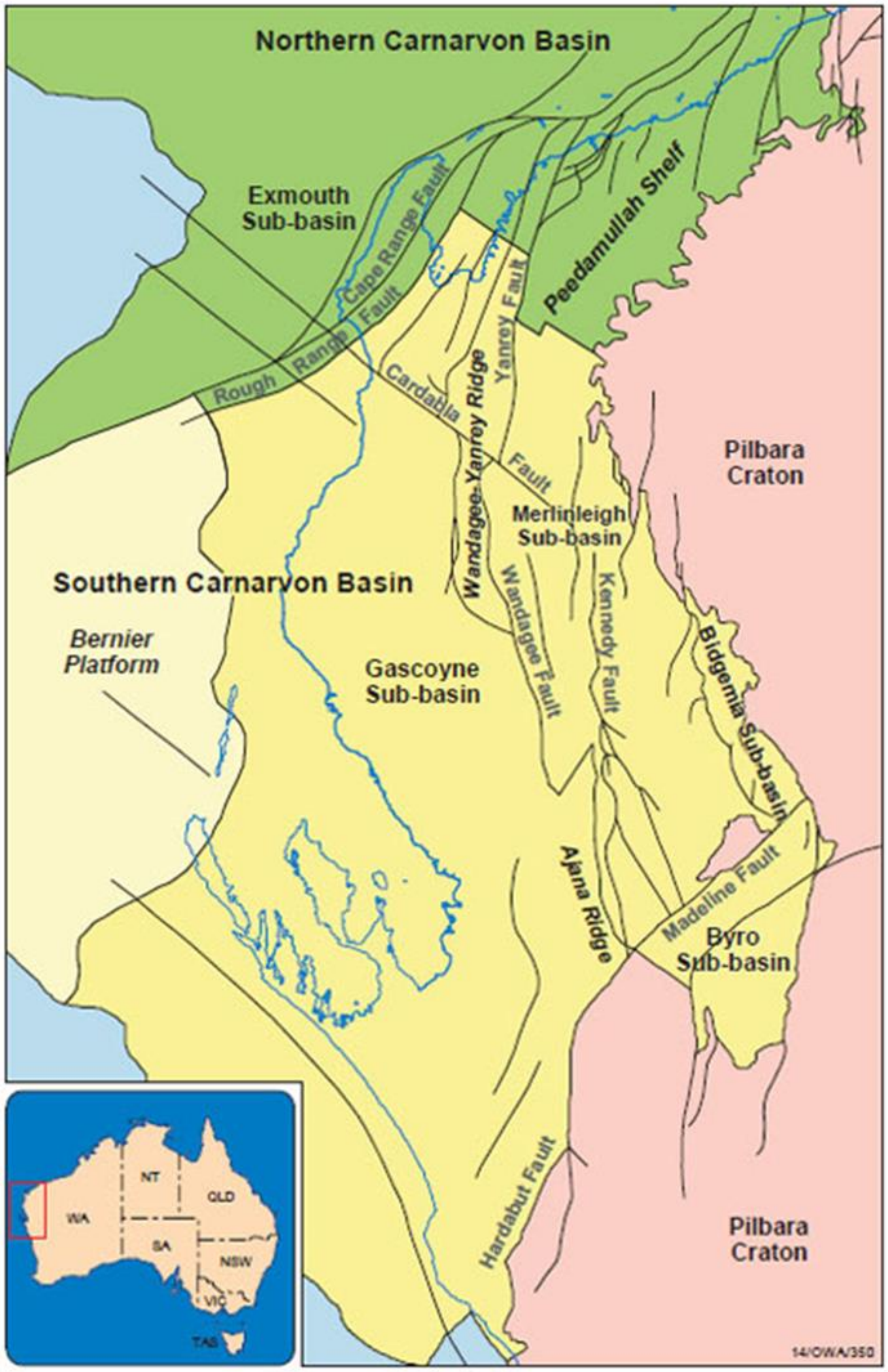


Figure 1.1 Map of the onshore Southern Carnarvon Basin

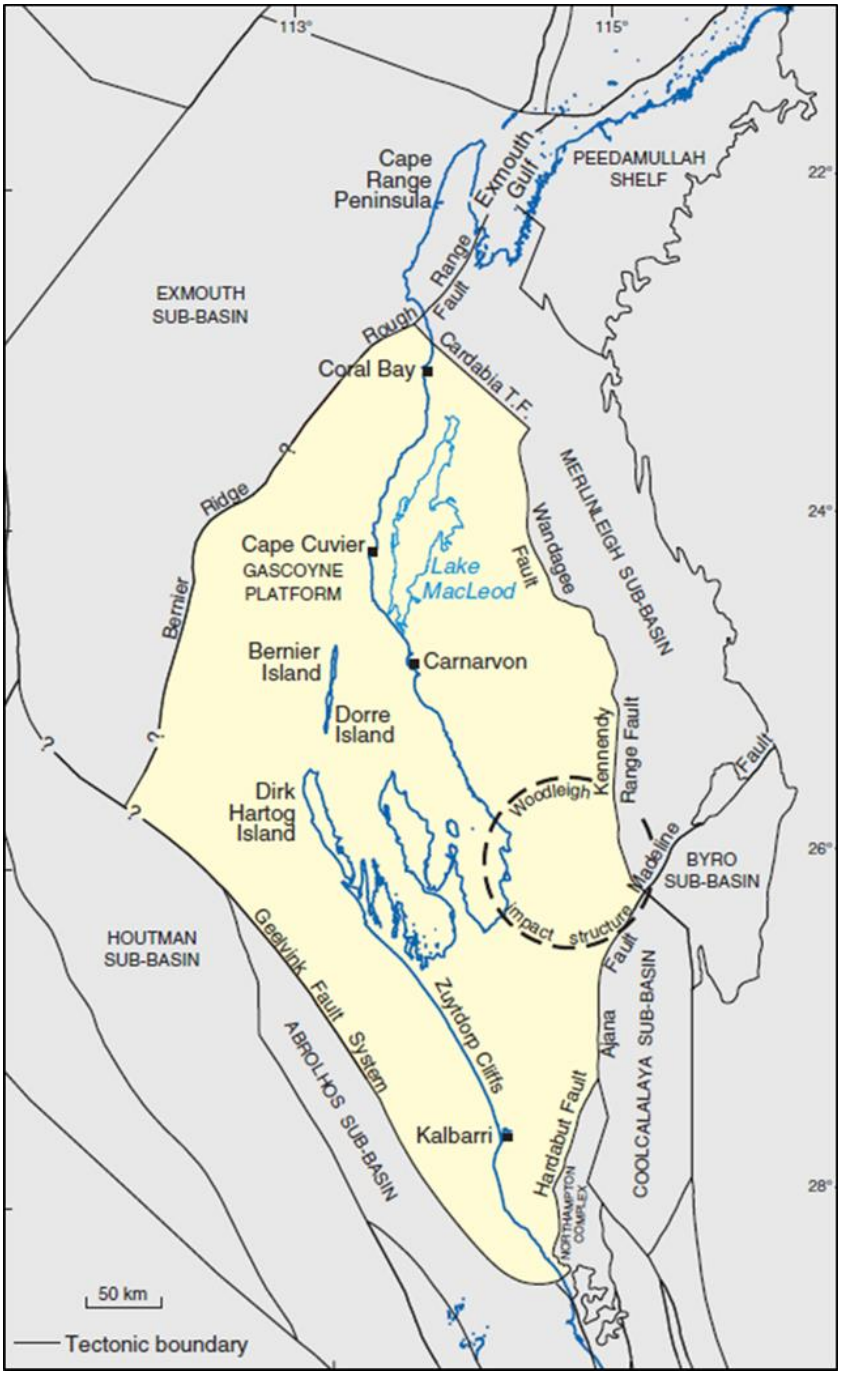


Figure 1.2 Location of the Gascoyne Platform displaying the regional tectonic framework (from Iasky et al., 2003)

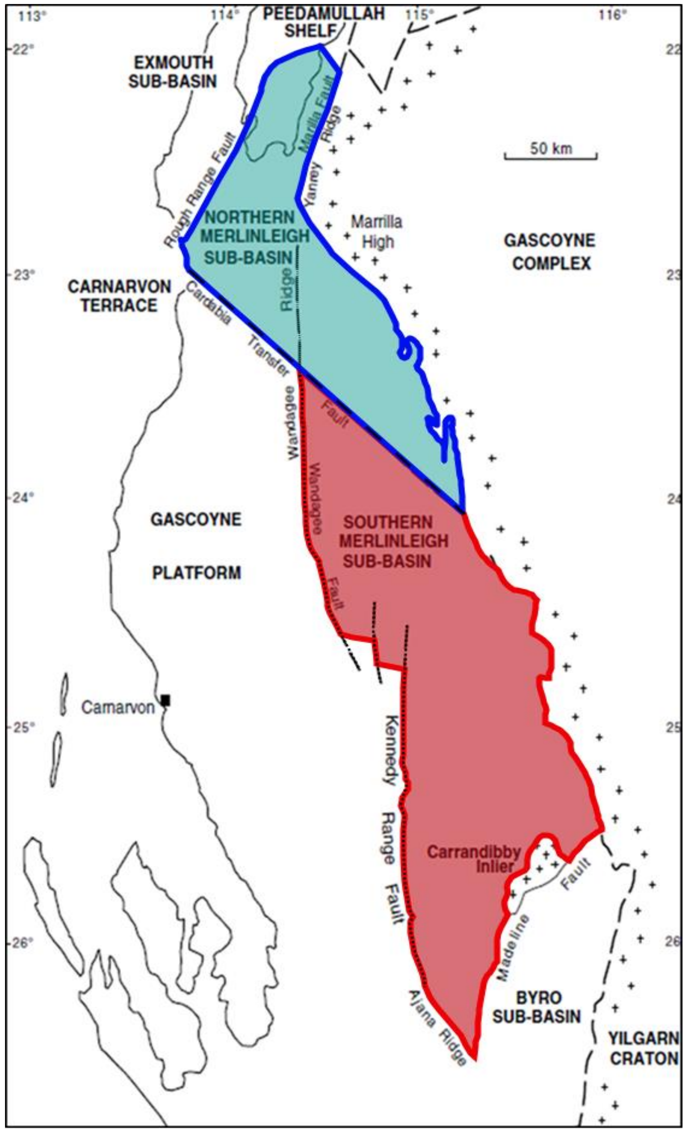


Figure 1.3 Location and regional tectonic framework of the Merlinleigh Sub-basin, onshore Southern Carnarvon Basin; Blue represents the Northern portions of the basin whereas the Red highlights the the Southern portions (modified from Iasky et al., 1998)

1.2. PREVIOUS RESEARCH

Research of the Gascoyne Province concentrated on surface anticlines to the north prior to 1950's (Raggatt, 1936). Since then, mapping has been carried out by the Australian Geologic Survey Organization (AGSO) which include aeromagnetic and gravity surveys. In 1955, Western Australia Petroleum (WAPET) performed stratigraphic drilling of anticlinal features and topographic after the discovery of oil at Rough Range in the Birdrong Sandstone (Iasky et al., 1998, Crostella and Iasky, 1997)). In the 1970's WAPET, Conoco and Oceania conducted regional seismic and gravity surveys. The last exploration well was drilled in 1984 by Canada North West. Only stratigraphic drilling has been conducted by the Geological Survey of Western Australia in 1996 and Pace Petroleum in 1997.

The Merlinleigh Sub-basin has been reviewed by the Geological Survey of Western Australia (GSWA) to highlight prospective petroleum potential in the area which was a follow-up review to Crostella's (1995) report that detailed structures, stratigraphy, hydrocarbon shows, and source-rock maturity (Iasky, 1998). Exploration began in the area as early as the 1930s when hydrocarbon (HC) shows were discovered near the Wooramel River area (Woolnough,1928; Condit, 1935). Recent exploration efforts have focused on source rock studies (Mitchell, 1992; Ghori, 1996). In 1996, Ghori modeled maturity levels of

Devonian-Lower Permian units for source-rock potential which showed an increase in maturity towards the deeper parts of the sub-basin displaying gas-generating potential.

1.3. OBJECTIVES

The Northern Carnarvon Basin has had over 750 exploration wells drilled and is Western Australia's principal hydrocarbon-producing basin with most of the current production from conventional oil and gas plays (Barber, 2013), while the Southern Carnarvon Basin has only had roughly 24 exploratory wells out of the 111 total wells that were made available at the time of writing this report. There is evidence of other wells, however, they have not been included and are not available in the public domain. It is estimated that there is only one exploratory well per 5,000km^2. With sparse well and seismic data, the majority of the Southern Carnarvon Basin is still relatively underexplored both on- and offshore.

Based on a working knowledge of the basin, the aim of this thesis is to provide an extensive overview of the Southern Carnarvon Basin with respect to petroleum geology by using geophysical techniques. By combining seismic interpretation with other available geophysical data, the hope is to create a structural review that would lead to the identification of potential hydrocarbon plays in the highly structured areas between the Merlinleigh Sub-basin and the

Gascoyne Platform. A better understanding will help give insight into the processes that drive the petroleum systems within the Southern Carnarvon Basin. The research focuses on the areas in which seismic coverage was provided. All seismic data within the research area is 2D conventional reflection data and therefore interpretations will be regional in scale.

2. REGIONAL GEOLOGY

2.1. BASIN EVOLUTION

A megasequence is defined as a group of depositional sequences, bounded by major regional unconformities, created in response to large-scale processes such as plate tectonics and eustacy (Kennard et al., 1994). It is influenced to a lesser degree by depositional rates. A basin fill will typically contain several distinct megasequences, i.e. 'Syn-Rift'; 'Passive Margin'.

Phanerozoic stratigraphic infill (Figure 2.1& Figure 2.2) of the Carnarvon Basin has been recorded in the strata as evidence seen by several episodes of subsidence and sediment accommodation. Each episode generated discrete tectonostratigraphic megasequences, which are separated by major unconformities that recorded uplift and erosion in the Southern Carnarvon Basin (Kennard et al., 1994, Eyles et al., 2002, Iasky et al. 1998; Hocking et al., 1987).

Numerous continental blocks were arranged along the northern margin of Australia and India in the early Paleozoic (Figure 2.3). These are believed to have rifted at various times during the Paleozoic and early Mesozoic. Deposition along the current west and northwest margins of Australia during the early Paleozoic was confined to a series of roughly N.W.-S.E. trending basins. Deposition commenced in the Cambrian in the Bonaparte Gulf and Arafura basins, in the early Ordovician in the Canning Basin and in the Silurian in the Carnarvon and Perth basins. These basins are alternatively interpreted to be either "failed arms" to one or more early Paleozoic rifting events or intracontinental sag basins (Veevers, 1984). In the late Devonian-Carboniferous, a rifting phase is suggested, in which the continental fragments separated (Dolan and Associates, 1991). During the late Carboniferous to early Permian an ice-cap covered much of Gondwana resulting in deposition of glaciogenic sediments. Extensional tectonic activity and affiliated volcanism indicate a mid-late Permian rifting event. Continued rifting eventually led to the separation of Greater India from Western Australia and Antarctica during the Early Cretaceous. Magnetic anomalies initially showed spreading began in a northwest-southeast direction between Australia and India (Liu, 1983). However, a major change in the spreading axes is thought to coincide with the initiation of spreading between Australia and Antarctica during the late Cretaceous (Mutter, 1982).

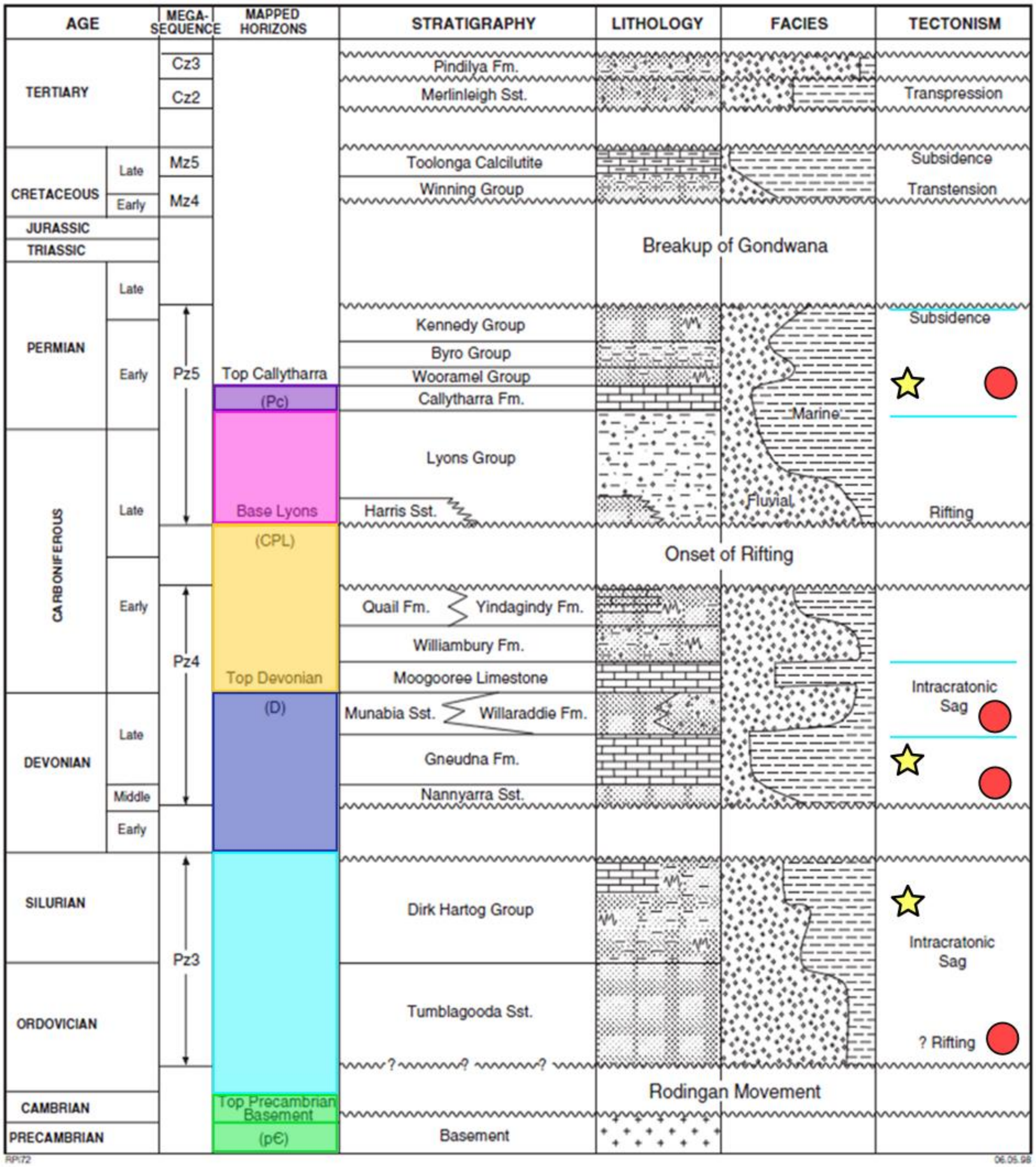


Figure 2.1 Stratigraphic column of the Merlinleigh Sub-basin displaying tectonic events associated with sediment infill. The mapped horizons are highlighted as Basement (green), Ordovician/Silurian (light blue) Devonian (blue), Carboniferous (orange), Lyons Group (pink), and Callytharra (purple) Source rocks are denoted as stars, reservoirs as red circles, and seals by a light blue line(modified from Iasky et. al, 2003)

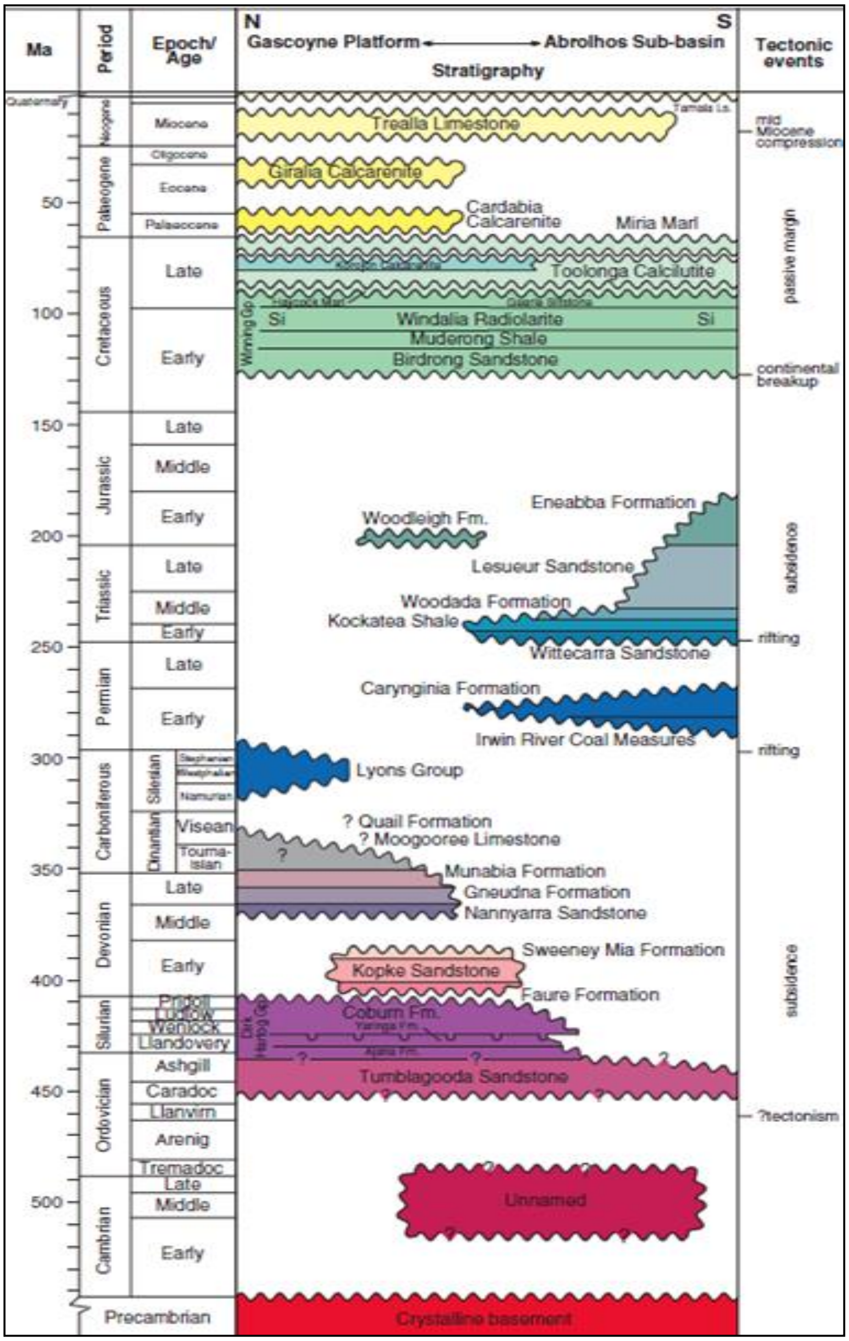


Figure 2.2 Stratigraphic column of the Gascoyne Platform with tectonic events (from Iasky, et. al, 2003)

The Southern Carnarvon Basin has gone through several tectonic processes from Ordovician-Silurian to the Late Permian and up to the present day (Table 1). The structural history and stratigraphy is correlated to a series of Tethys related rifting events:

Table 1 Timing of structural history of the Carnarvon Basin with regards to specific phase (Dolan and Associates, 1991)

Silurian - Mid-Devonian	***-***	***Interior Cratonic Phase***
Mid-Devonian - Mid-Carboniferous	***-***	***Tethys I Rift Phase***
Late Carboniferous - Early Permian	***-***	***Tethys I Passive Margin***
Early Permian – Late Permian	***-***	***Tethys II Rift Phase***
Early Triassic – Early Jurassic	***-***	***Tethys II Passive Margin***
Mid-Jurassic - Early Cretaceous	***-***	***Tethys III Rift Phase***
Early Cretaceous - Miocene	***-***	***Tethys III Passive Margin***
Miocene - Recent	***-***	***Tethys III Destructive Margin***

2.1.1. SILURIAN – MID-DEVONIAN

The Southern Carnarvon Basin deposition began in the Late Ordovician to Early Silurian with a mixed sequence of carbonates and clastics (Dolan et al, 1991). This intracratonic phase of the basin development is recognized by three redbed-carbonate cycles (Moray et al., 2003). The first cycle is poorly understood. The second cycle is believed to have lasted from the Late Ordovician to Late Silurian. A significant portion of this sequence is non-marine and there is evidence for active faulting during deposition suggesting there were localized rifting events within the cratonic basins. The third cycle during Early Devonian was marked by a transgressive non-tectonic marine carbonate sequence. Depositional controls are presumed to be local rather than widespread and related to tectonic events within or immediately adjacent to the basin (Mory et al., 2003).

2.1.2. MID-DEVONIAN – MID-CARBONIFEROUS

The Middle Devonian – Early Carboniferous succession is preserved regionally in the Merlinleigh Sub-basin and partially in the Gascoyne Platform. This Devonian portion of the succession is fairly consistent between the two sub-basins, implying that the Merlinleigh Sub-basin did not become a separate entity until the mid-Carboniferous (Mory et al., 2003). Correlations within this interval are widespread and it is believed that there were controls on deposition that might be related to global climate rather than basin tectonics or local seaways. The Tethys I Rift Phase concluded with a period of uplift and erosion during the mid-Carboniferous that is discernable by a prominent unconformity. This unconformity is thought to correspond to the break-up unconformity associated with the initiation of ocean-floor spreading between the Gondwana Margin and the Turan/Tarim micro-continents (Dolan et al., 1991).

2.1.3. LATE CARBONIFEROUS – EARLY PERMIAN

The Carnarvon Basin during Late Carboniferous (Figure 2.3 A) was part of the passive margin facing the spreading Tethys Ocean to the north and was deposited with minimal internal fault activity (Dolan, 1991). The sequence is predominantly a glacigene marine facies which is often referred to as the Gondwana Series. The Lyons Group consisted of up to five kilometers of shallow-marine to non-marine passive margin sequence that were deposited along the eastern margin of the basin where subsidence initially exceeded sediment influx. During this time, the Alice Springs Orogeny ended in central Australia (Eyles et al., 2002) and is believed to have caused relatively rigid cratonic plates that may have transmitted stress across the continent causing the Southern Carnarvon Basin to undergo listric normal faulting associated with isostatic compensation and uplift (Mory et al., 2003). As sedimentation rates slowed as the basin expanded, siltstone and carbonates accumulated in an offshore setting forming the Callytharra Formation. The Wooramel Group, according to Eyles et al. (2002), resulted from the progradation of fluvial and deltaic wedges that accumulated coarse-grained sand facies. Following slow deposition rates, renewed rifting-related subsidence led to the rapid deposition of the Byro and Kennedy Groups (Hocking et al, 1987).

2.1.4. EARLY PERMIAN – LATE PERMIAN

The rifting event that preceded the development of Tethys II Ocean was marked by extensional faulting along the western margin of the Perth and Carnarvon basins. Along the western margin the Kennedy and Byro Groups were deposited into fault bounded half-grabens. It is believed that the western margin was a failed arm of the Permian rift system and as such was intimately involved in the rifting process (Dolan and Associates, 1991). Culmination of the Tethys II rifting even is marked by a regional unconformity.

2.1.5. EARLY TRIASSIC – EARLY JURASSIC

During this time, the Carnarvon Basin was again part of the Tethys Ocean passive margin. The Triassic Locker Shale sequence (Figure 2.3 B) is representative of a transgressive cycle with a basal sandstone and a fully marine shale (Dolan and Associates, 1991). The transgressive sequence is followed by a regressive mixed clastic sequence that largely consists of marginal to non-marine fluvial facies. It is important to note that the non-marine portion increases towards the south away from the spreading ocean basin.

2.1.6. MID-JURASSIC – EARLY CRETACEOUS

During the Tethys Rift III phase (Figure 2.3 C-E), the Carnarvon Basin was subjected to extensional faulting followed by a period of uplift and erosion. The major event of the break-up of Greater India and Australia is marked by the Cretaceous Unconformity. The Jurassic saw sea-floor spreading followed by major growth faults in offshore areas with thick sedimentary sequences (Iasky et al., 1998). Northwesterly faults in the basin were reactivated. Where the Paleozoic sequences underwent Jurassic subsidence, they were buried too deep to be of any economic importance (Dolan and Associates, 1991).

2.1.7. EARLY CRETACEOUS – MIOCENE

The Tethys III Passive Margin (Figure 2.3 F) was a time the Carnarvon Basin saw low subsidence rates as the spreading ocean basin continued to the west and northwest. During this event, a partially starved, prograding carbonate shelf sequence was established (Dolan and Associates, 1991).

2.1.8. MIOCENE – RECENT

The past ten million years (Figure 2.3 G-H) has seen the collision of the northern Australian continental margin and the Indonesian arc. Compressive stresses reactivated preexisting faults, which has caused inversion structures in the

Carnarvon Basin with major strike-slip components and widespread folding (Dolan and Associates, 1991; Iasky et al., 1998).

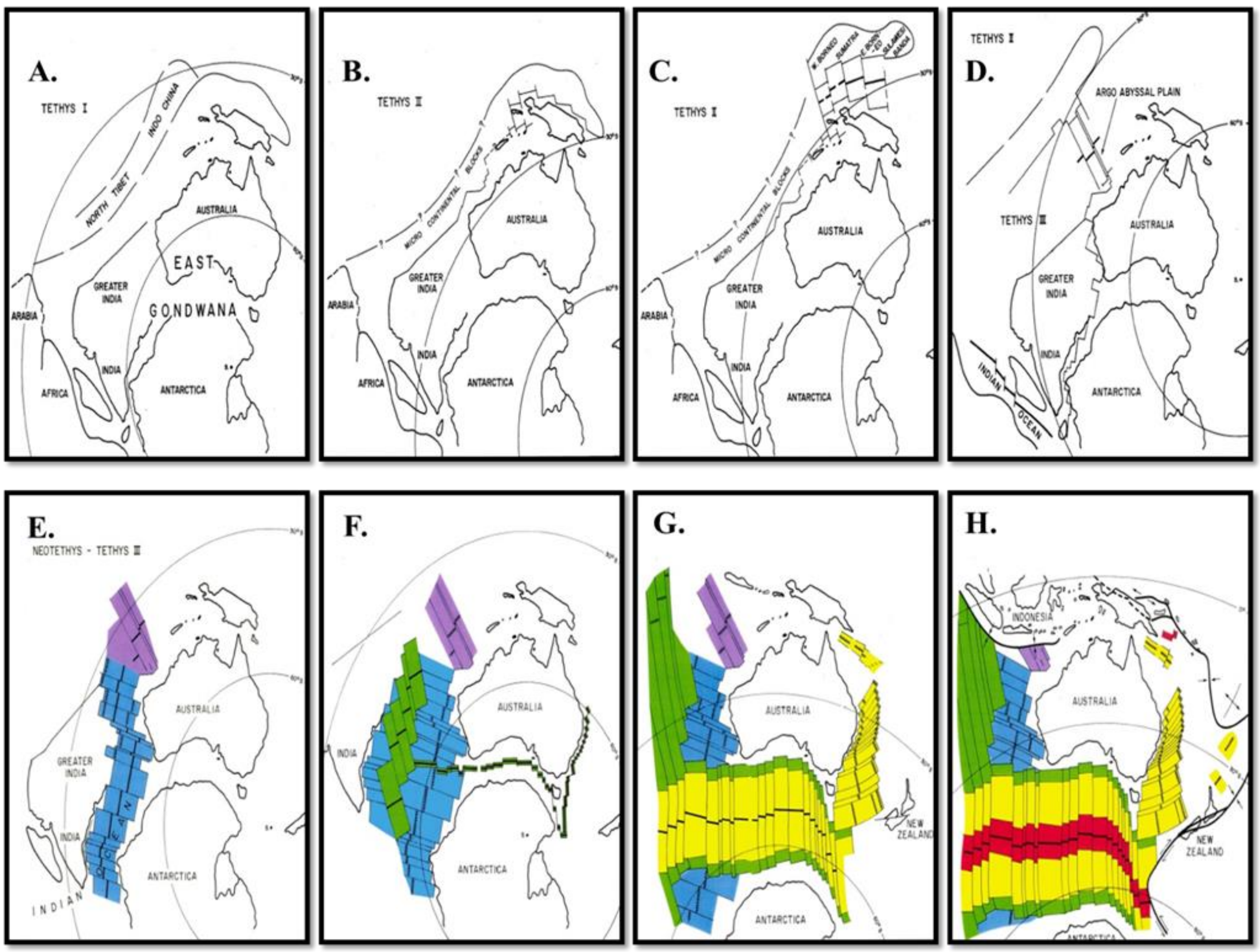


Figure 2.3 Basin history with respects to the break up and dispersal of Gondwana (from Dolan and Associates, 1991) A.Late Carboniferous to Early Permian reconstruction B.Late Triassic reconstruction C. Late Jurassic reconstruction D. Early Cretaceous (Late Neocomanian, 128ma) reconstruction E. Early Cretaceous (Albian, 108ma) reconstruction F. Late Cretaceous (Campanian, 82ma) reconstruction G.Late Miocene (10ma) reconstruction H. Present day Australia

2.2. GEOLOGICAL STRATIGRAPHY

2.2.1. ORDOVICIAN

TOOMBLAGOODA SANDSTONE

The Toomblagooda Sandstone is the oldest unit in the Southern Carnarvon basin and is limited to the subsurface in the Merlinleigh Sub-basin. It has been partially penetrated in a number of wells in the southern onshore, but has not been reached in the north or in the Merlinleigh Sub-Basin with the exception of Quail-1 and Wandagee 1 (Figure 2.5). The depositional environment is described a fluvial braid plain and fan to marginal marine (Hocking, 1991). Estimated thickness is roughly 2,000 to 3,500 meters, but at outcrop, the unit is over 1,000 meters thick (Dolan and Associates, 1991). At outcrop, the Tumblagooda Sandstone overlies the crystalline basement of the Northampton Block. Clarke and Teichert (1948) described the unit to be dominated by redbed sandstone facies, with rare siltstone and mudstone. The age of the unit is based off Telychian conodont faunas that have been identified (Mory at al., 1998b). In Quail 1 and Wandagee 1, the contact is abrupt, and may represent an unconformity (Playford et al., 1975), a fault contact, or a very abrupt cutoff of the supply of terrigenous clastic material. The top of the section in Quail-1 is white to pale pink, porous and friable, which is interpreted in the Well Completion Report (1964) as representing subaerial exposure and leaching.

2.2.2. SILURIAN

DIRKHARTOG FORMATION

The Dirk Hartog Group conformably and disconformably overlies the Tumblagooda Sandstone in northern portions of the basin, but is absent further south. This is probably due to late Paleozoic or Mesozoic erosion (Mory et al., 2003). The Dirk Hartog Formation consists predominantly of carbonates and evaporates (Hocking, 1987), with minor siltstones, sandstones and terrigenous mudstones. The basal formation (Ajana Formation) is described as an oxidized siltstone overlain by shoaling-up cycles of gray sand mudstones, laminated dolomitic mudstones, and wackestone (Gorter et al., 1994). The Dirk Hartog Formation was deposited in a tidal flat playa/lacustrine setting (Hocking, 1991). Hocking (1994) further describes the Dirk Hartog Group to have been deposited in a relatively restricted marine environment, with brief connections to an open-marine environment throughout the Silurian.

2.2.3. MIDDLE DEVONIAN

NANNYARRA SANDSTONE

The Nannyarra Sandstone is the product of a major marine transgression that unconformably lies atop the Dirk Hartog Formation. It is composed of sandstone, minor siltstone deposited in a shallow-marine to coastal setting associated with marine transgression (Hocking et al., 1987). Trends within the Nannyarra Sandstone display both a coarsening upward and downward profile. Upper portions appear to have been deposited in an open marine environment, suggesting an overall transgression throughout the deposition of the Nannyarra Sandstone (Dolan, 1991). At Quoabba 1 (Figure 2.5), the Nannyarra Sandstone is interpreted to be 260 meters thick. At outcrop, in the eastern onshore portions of the Southern Carnarvon Basin, beach and tidal channel facies overlie a basal lag and pass up into very fine-grained shoreface sands (Dolan and Associates, 1991). The subsurface sections in Quail 1, Quobba 1 and Pendock 1 appear to show a more offshore shelf facies, with a generally coarsening-up profile in Quail 1 and an initially coarsening-up profile followed in the upper half by a generally fining upward profile in Quobba 1 and Pendock 1.

2.2.4. LATE DEVONIAN

GNUEDNA FORMATION

The Gnuedna Formation is an open marine carbonate to marginal mixed shelf facies, which gradationally overlies the Nannyarra Sandstone (Dolan and Associates, 1991) or onlaps the crystalline basement (Figure 2.6). The unit consists of interbedded carbonates, siltstones, and generally, fine-grained terrigenous clastics with minor evaporites. The carbonates reflect the marine transgression throughout the deposition of the Nannyarra to Gnuedna Formations. This formation was presumably deposited in a nearshore to restricted shallow-marine environment, and has a maximum known thickness of 1,092 meters (Mory et. al, 2003). Clastics usually occur at both the top and base with a carbonate section in between. The Gneudna Formation at Quobba 1is interpreted to occur at 462-1460 meters, with the clastic section below tentatively identified as the Nannyarra Formation. The Gneudna consists of an upper and lower carbonate dominated unit separated by a clastic interval. At Quail-1, the Gneudna consists of three members, an upper member of fine-grained limestones and dolostones, a middle member of calcarenites, lime mudstones and coarse and fine clastics, and a lower member of interbedded sandstones and carbonates (Pearson, 1964).

MUNABIA SANDSTONE

The Munabia Sandstone consists primarily of sandstone, locally highly argillaceous and pebbly (Dolan, 1991) that generally thicken eastward. The Munabia is up to 550 meters thick in outcrops to the eastern portions of the Merlinleigh Sub-basin, but is measured to be 31 meters thick at Quail 1. Bedding appears horizontal with small-scale bedding features such as herring-bone cross-bedding, flaser and lenticular bedding, bioturbation, and desiccation structures. Thicker bedded sandstones with larger scale trough and planar cross-bedded sandstones are also reported, with slump and de-watering structures which are interpreted as channelized braid-plain facies. The depositional environment is fluvial to distal braided fan plus tidal. The tidal sediments are apparently restricted to the lower parts of the formation (Hocking, 1987), in a transition zone from the underlying Gneudna Formation. In the upper part of the Munabia there are some conodont bearing dolostones which represent relatively minor marine incursions. The unit generally conformably overlies the Gnuedna Formation, but also locally is interfingered with the Gnuedna Formation (Iasky and Mory, 1999). This unit contains sandstone with minor claystones, conglomerates, and dolomites which is indicative of a coastal to nearshore environment (Hocking, 1990; Hocking, 2000).

2.2.5. EARLY CARBONIFEROUS

MOOGOOREE LIMESTONE

The coarser sediments within the Moogooree Limestone are a variety of limestone and dolostone predominantly composed of skeletal and algal material as encountered in Quail 1, between 2452-2710 meters. Shallow-marine, variable energy carbonate deposition was widespread in the area during the Early Carboniferous (Mory et. al, 2003). The Moogooree Limestone was deposited in a shallow marine to intertidal environment. The limestones range from mudstones to grainstones. Structures such as fenestrae imply that the limestone was deposited in shallow water conditions. A transgressive-regressive cycle is frequently recognized at outcrop, with an initial slight increase in water depth from high intertidal to uppermost subtidal representing a rise of sea level, followed by regressive conditions back to high intertidal mudstones at the top (Hocking, 1987).

QUAIL FORMATION

On the eastern margin of the Merlinleigh Sub-basin, the Quail Formation is equivalent to the Moogooree Limestone and consists primarily of siltstone and sandstone deposited in a high energy shoreface to a low energy marine-shelf environment (Mory et. al, 2003) that is sparsely fossiliferous. This unit becomes finer-grained to the west and to the north. Lower portions of the formation are dominated by a sandstone unit that is interpreted to be a shelf to shoreface facies, however, the lithofacies in this stratigraphic unit are quite varied that consist of poorly sorted, fine to medium-grained quartz and lithic wackes.

2.2.6. LATE CARBONIFEROUS

LYONS GROUP

The Lyons Group is inferred as a glacially influenced siliciclastic facies deposited in a marine environment. There are both massive unbedded and bedded diamictites, grey-green and dark grey siltstone, and shale with thin bands of pyrite and brown siltstone. These deposits are interpreted as continental margins and marine environments. Glacio-lacustrine sequences occur locally at the base of the sequence that represent glacial outwash braid-plains and associated fan-delta deposits into both lakes and sea. At outcrop, in the northeastern margin of the Merlinleigh Sub-Basin, the Lyons Group overlies the earlier Devonian and Carboniferous sequences with marked unconformity. During periods of folding, faulting, uplift, and erosion, the earlier sequences were removed from the more southerly parts of the basin (Hocking, 1987). In Quail-1, the sequence consists of a heterogeneous mixture of diamictites (Pearson, 1964) sandstones, greywackes, siltstones and mudstones with some minor limestones. Five glacial periods and four interglacials were suggested by Condon (1954), but Hocking et al., (1987) believe that this "simple" picture under-estimates the true complexities of the sequence, which represents a major glacial episode lasting over 20 million years.

CALLYTHARRA FORMATION

In contrast to the glacially influenced Lyons Group, the conformably overlying Callytharra Formation (Figure 2.7) has a rate of deposition of less than 2m/my (Mory and Backhouse, 1997). In the Merlinleigh Sub-basin, the Callytharra Formation is composed primarily of calcareous siltstones and calcarenites that are very fossiliferous and is indicative of a marine shelf environment, below the wave-base following a major sea-level rise after the close of the glacial period. The siltstones are often marked by bioturbation and also feature cross-bedding and cross-lamination and minor slumped horizons. The top of the formation is marked by Limestone that decreases in mud content and increases in grain size from silt to coarse-grained. The lime mudstones are frequently poorly sorted, with very coarse crinoid remains. Occasionally, thin upward-coarsening sequences are apparent in upper intervals. Some portions in the Southern Merlinleigh Sub-basin are composed of sandstone that indicates there was local deposition in a local fluviodeltaic incursion (Mory et al., 2003).

During a period of exposure, the calcarenite portion formed karsts prior to deposition of later Permian units.

2.2.7. EARLY PERMIAN

WOORAMEL GROUP

The Wooramel Group is a series of terrigenous clastics with occasional thin coaly intervals in the southern areas that were deposited disconformably over the older sequences. Unlike the later Permian strata (the Byro and Kennedy Groups), the Wooramel contains intervals of coarse-grained elastics. The Wooramel Group is recognized by four formations - the Billidee Formation, Moogooloo Sandstone, and the Cordalia Sandstone.

The Cordalia Sandstone conformably overlies the Callytharra Formation to the north and west. The boundary is marked by an abrupt change from fossiliferous packstone and wackestone of the Callytharra Formation to a siltstone minor interbedded with silty sandstones. There is little to no porosity within the sandstone and are display a coarsening-upward trend. The siltstones are fine to very finely sandy variants with increasing amounts of quartz grains. Bioturbation of the siltstone is observed at the base of the formation with an increase in shelly fragments. High organic productivity in a marine environment is seen by the rich

TOC values from Burna 1. Log-response of the sand-prone intervals are typically in the form of indistinctly upward-coarsening sequences.

In the east, the Moogooloo Sandstone rests directly on the Callytharra and represents fluvial deltaic and shallow marine sandstones. The sequence seems to have prograded in a generally northwesterly direction. and is almost entirely comprised of clean, well-sorted fine- to medium-grained quartz sandstone, with minor interbedded carbonaceous siltstones. In some portions the siltstones grades to coalified clasts. Porosity is poor to moderate and is considered that porosity reduction is a result of grain compaction.

The Billidee Formation lay at the top of the Wooramel Group. The sandstone is predominantly fine-grained, quartzose with calcite cement, minor pyrite, and traces of glauconite. Porosity is characterized as poor to very poor. This formation is a culmination of several upward coarsening sequences of micaceous siltstones with interbedded sandstones. The overlying Billidie Formation and the laterally equivalent and generally slightly shallower deposits of the Keogh Formation represent tidal and deltaic sediments deposited as sea-level rose further landward.

A complex and variable series of coarse and fine elastics were deposited in this last phase of the Wooramel Group (Dolan and Associates, 1991) in a wide variety of shallow to marginal marine to continental environments. In general, towards the north and west, the whole sequence of the Wooramel group appears to become more marine in nature. The lower half of the formation comprises an upward coarsening sequence, from siltstone to fine to medium-grained quartz sandstone. In Burna 1 (Figure 2.5), the Wooramel Group is moderately well-sorted, but exhibits little porosity. The tops of the units tend to be sharp and the Wooramel here appears to have been deposited in a shallow marine shelf setting. The Wooramel was considered the main play during the last exploration phase in the Merlinleigh Sub-Basin (Percival and Cooney, 1985).

BYRO GROUP

The Byro Group, which conformably overlies the Wooramel Group, is a thick sequence of terrigenous clastics that outcrops and has been subdivided into a number of formations on the basis of fauna and proportion of sand to silt to mudstone. This unit consists of alternating carbonaceous siltstone and mudstone, and fine-grained, bioturbated sandstones and is up to 1,500 meters thick at Kennedy Range 1 (Figure 2.5). Total organic carbon (TOC) ranges from 1.5 – 5.5%. The Byro Group was deposited under reducing conditions over a marine shelf (Bentley, 1998). Hocking et al., (1987) describe the Group as a repetition of facies associations ranging from anoxic black shales to various storm influenced marine sandstone facies

KENNEDY GROUP

The Kennedy group outcrops in the Merlinleigh Sub-basin and conformably overlies the Byro Group, which contains similar siliciclastic facies. This unit was deposited in a marine-shelf environment (Mory et. al, 2003). This unit caps the Permian section in the Southern Carnarvon Basin. However, it is restricted due to later erosion in the areas of the Merlinleigh Sub-basin (Dolan and Associates, 1991). Sediments of the Kennedy Group show a repetition of fine and coarser-grained facies ranging from offshore to shoreface as a result of accumulation on a marine shelf. Depositional energy appears to have been lower than during the accumulation of the Byro group along with slower subsidence rates (Hocking et al., 1987).

2.2.8. JURASSIC

WOODLEIGH FORMATION

The Woodleigh Formation is the only confirmed Jurassic sedimentary unit within the Southern Carnarvon Basin. This unit is an interbedded shale and sandstone unit of lacustrine origin (Mory et. al, 2003; Iasky et. al, 2001; Iasky and Mory, 1999) that is restricted to the Woodleigh impact structure (Figure 2.4). The unit is believed to have an original thickness of 1,100 meters. Uplift and erosion has removed roughly 700 meters (Gibson et al., 2000).

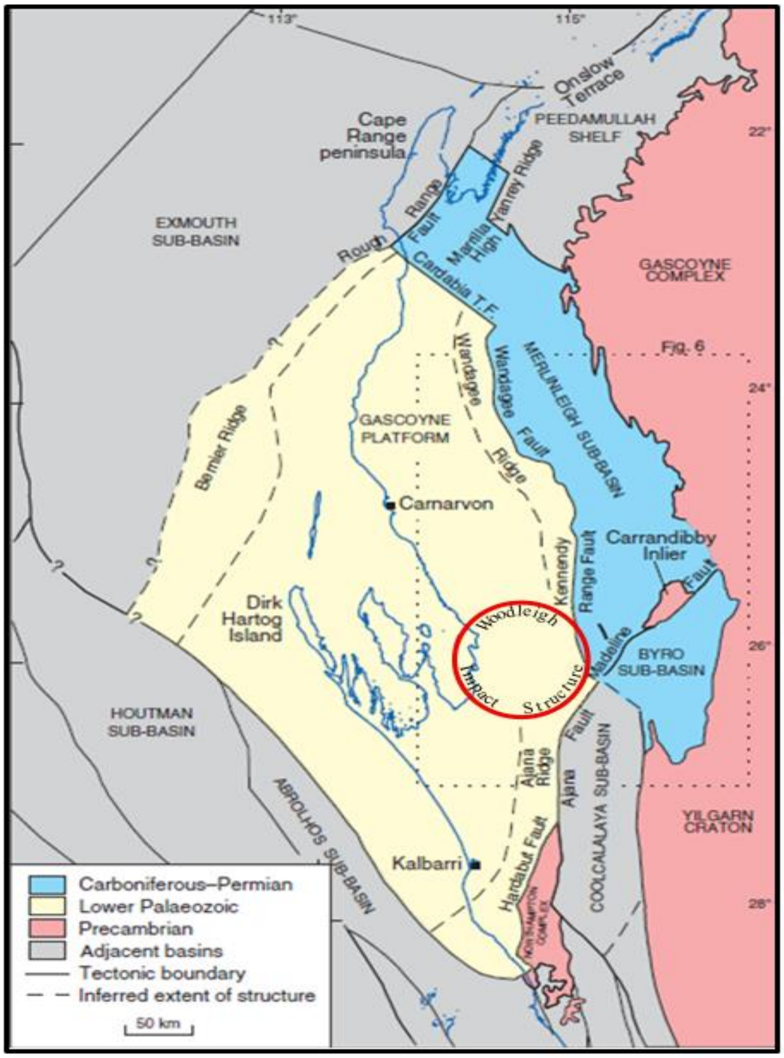


Figure 2.4 Tectonic Elements of the Southern Carnarvon Basin and adjoining sub-basins
The Woodleigh Impact Structure is located within the red circle

2.2.9. CRETACEOUS

BIRDRONG SANDSTONE

Following the breakup of the Greater India and Australia, basal transgressive sands were deposited over the entire Gascoyne Platform and along the western portions of the Permian depocenter, predominantly in coastal to inner-shelf environments. Overlying shallow-marine strata record progressively deeper waters across the platform. Fine to medium grained, friable, well-sorted quartz-rich sandstone. Regionally, there are thin lenses of massive pyrite, black shale and chips of torbanite which suggests deposition in a shallow marine to non-marine environments.

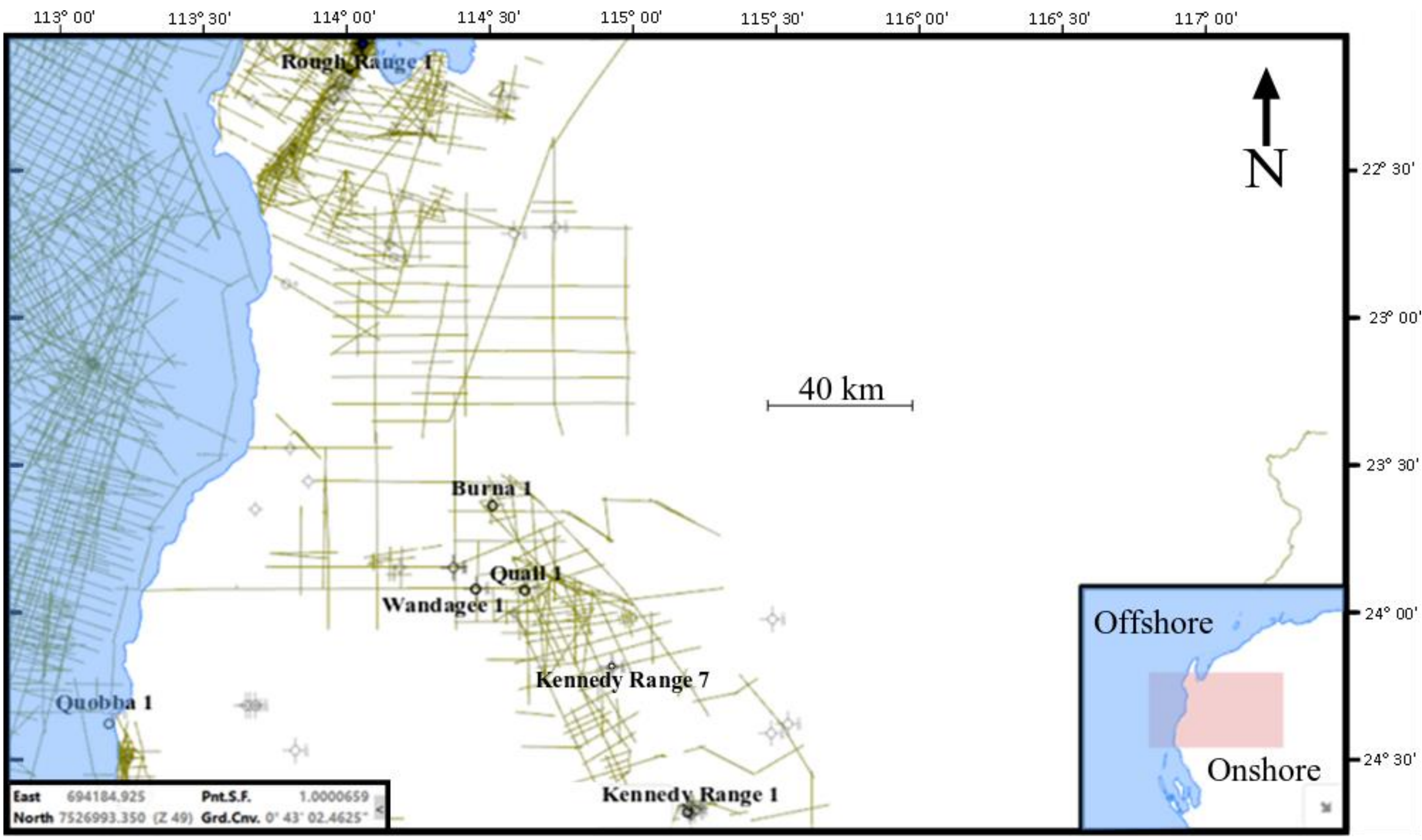
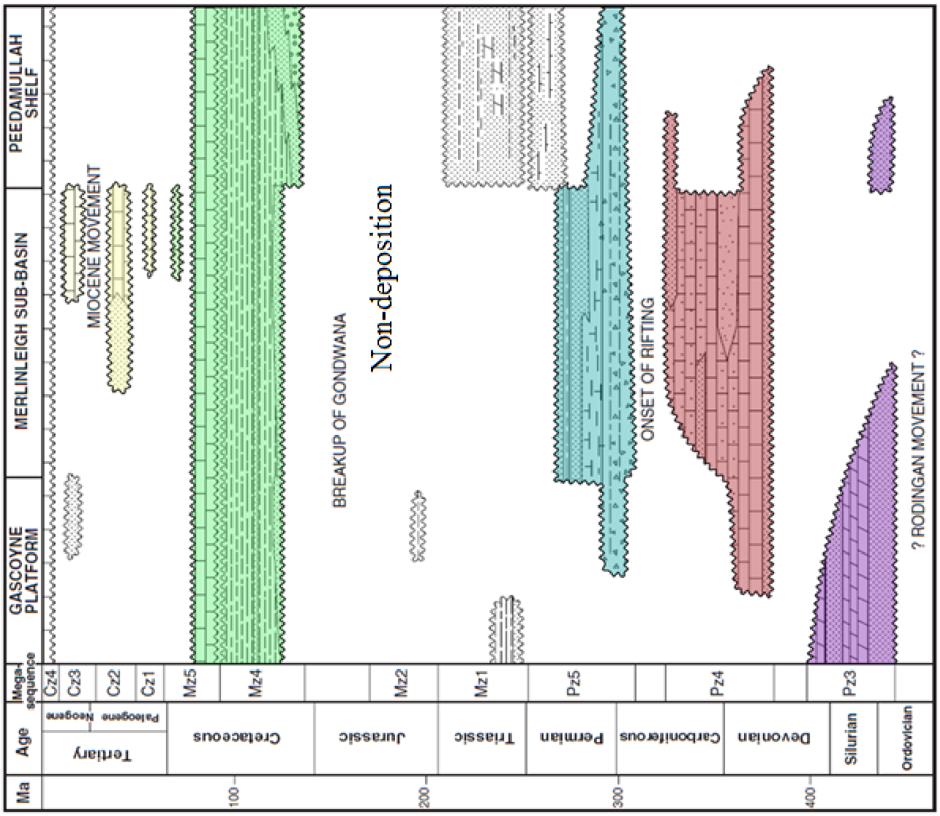


Figure 2.5 Basemap of the Southern Carnarvon Basin highlighting wells Quobba 1, Rough Range 1, Quail 1, Wandagee 1, Burna 1, and Kennedy Range 1 within study area.



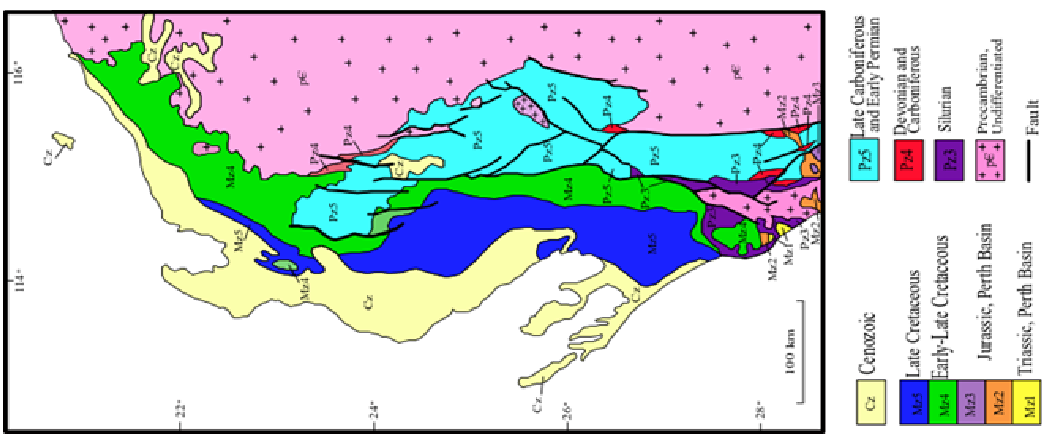


Figure 2.6 Generalized stratigraphy for the onshore Carnarvon Basin (modified from Nicoll et al., 1997)

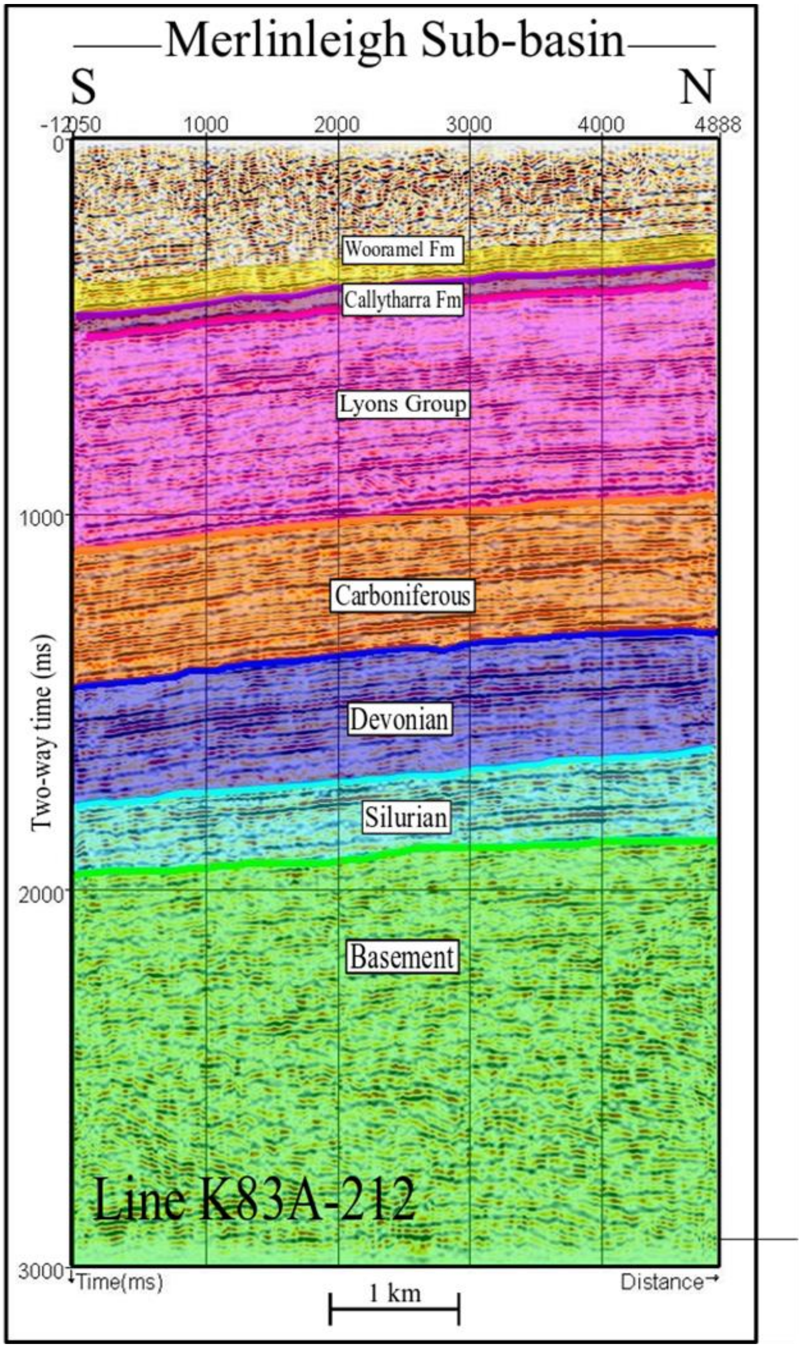


Figure 2.7 Seismic Line K83A-212 displaying typical stratigraphic layers within the study area of the Merlinleigh Sub-basin

2.3. GEOLOGIC STRUCTURES

2.3.1. GASCOYNE PLATFORM

The Gascoyne Platform is a diamond-shaped sub-basin that has been less deformed than the surrounding sub-basins, and contains a main northerly trending, elongate trough that shallows abruptly to the east and south, and gradually to the west and north (Iasky et al., 2003). The Late Jurassic rifting that led to the breakup of Australia from Greater India in the Early Cretaceous is easily recognizable in seismic data as the base of the Cretaceous unconformity. During the Miocene compressional events led to the reactivation of major faults and are associated with the formation of anticlines throughout the platform.

2.3.2. MERLINLEIGH SUB-BASIN

The Merlinleigh Sub-basin is an elongate asymmetric, en-echelon half graben formed by west-southwesterly extension (Eyles et al., 2002). The controlling fault in this sub-basin is the Wandagee-Kennedy Range fault along the western boundary. It is filled by Upper Carboniferous to Permian sedimentary fill that thickens westward towards the north-trending, en echelon Wandagee and Kennedy Range Fault Systems (Iasky et al., 1998). The basement rock rises eastward with a regional dip of 8 degrees and is unconformably overlain by sedimentary strata. Folds and faults are common in the strata. This is thought to be due to the Permian rifting and subsequent reactivation of faults (Mory et al., 2003).

Strata within the Merlinleigh Sub-basin generally have steeper dips than those of the Gascoyne Platform. Folding and faulting are also more common within this sub-basin. This is thought to be due to the basement fabric east of the Wandagee and Ajana Ridges, which acted as the loci for mid-Carboniferous – Permian rifting and subsequent reactivations of faults (Mory et al., 2003; Hocking et al, 1987).

Growth faults associated with rifting are seen in the geometry of the northerly trending Wandagee and Kennedy Range Fault Systems (Lowell, 1985). Late Carboniferous – Early Permian rift geometry probably controlled subsequent reactivation of major faults, most likely in the Early Cretaceous and Miocene (Mory et al., 2003; Crostella and Iasky, 1997; Hocking et al., 1987). This is evident by anticlinal features seen in wells Quail 1, Gascoyne 1, and Burna 1, and are believed to be post-Permian (Crostella, 1995a). The breakup of the Australian and the Greater Indian plate during the Cretaceous caused significant dextral strike-slip movement along the northerly trending faults (Mory and Iasky, 1996; Crostella and Iasky, 1997). Compression tectonics seen in the Miocene caused minor normal movements along these faults.

3. DATA AND METHODS

3.1. DATA

The Western Australia Department of Mines provided 1.3 TB of data for the project. The seismic dataset (Appendix A) used for this interpretation consists of 6,461 line kilometers of 2D conventional reflection reprocessed data, data from 111 wells (Appendix B), well logs, and gravity and magnetic surveys (Figure 4.14 & Figure 4.15). Coverage of the data is approximately 150,000km^2 with an average line spacing of 15km (Figure 3.1)

Mapping of the different reflectors and layers of varying depths was conducted on an area of roughly 23,000km^2 within the study area, in the highly faulted portion between the Merlinleigh Sub-basin and the Gascoyne Platform. All coordinates supplied in this study are referenced to the Geodetic Datum of Australia 1994 (GDA94).The datum for all seismic lines are set to 100 meters above sea level.

The seismic data for the study was acquired by a Common Depth Point (CDP) Stack process; traces for each depth point are summed to give one output trace for each depth point. Prior to the mix, first break energy plus the early portion of the traces where Normal Move Out (NMO) correction have caused severe stretching resulting in significant frequency changes can be suppressed.

The result of this is that the stacking multiplicity varies as a function of record time resulting in improvement of the continuity of shallow events.

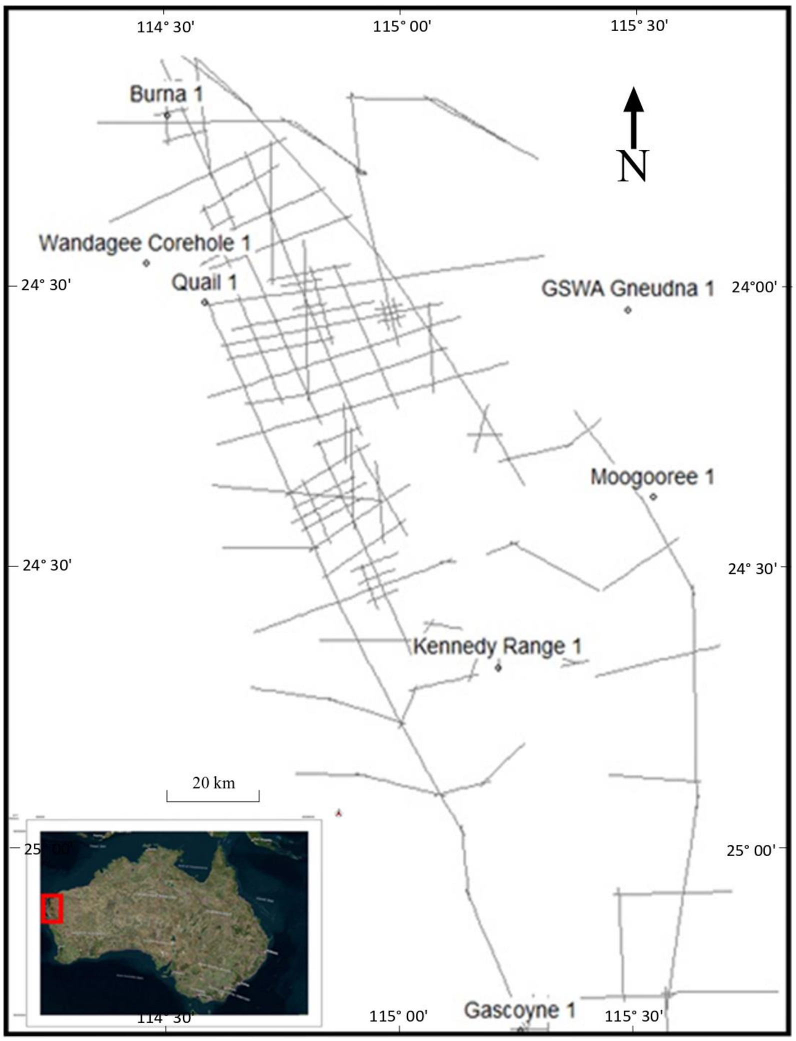


Figure 3.1 Basemap displaying seismic lines and wells within the study area of the Merlinleigh Sub-Basin

The final stack section is comprised of a series of common subsurface reflection points, which have been gathered, NMO corrected to a zero offset and then stacked together, and displayed in cross section form. The sections represent reflection data that would be obtained by recording zero offset traces at regular intervals, except the CDP method is used to improve the signal-to-noise ratio and to attenuate multiple reflections. However, the stack section does not show correct profiles of the subsurface layers due to -

- The CDP ray path model assumes flat, homogenous layers with constant velocities and constant surface conditions.

- The seismic energy is not constrained to ray paths, but is a spherical wave, which as it expands, is initially modified as it encounters each reflector.

- In a non-homogeneous situation, the reflection points generally are not directly below the surface location presumed to represent that reflection point.

The gravity dataset has traverses normally spaced at 3km intervals with stations spaced at 2 km intervals along the traverses. Data giving station locations, Bouguer gravity and station elevations for this survey were obtained from the Geological Survey of Western Australia.

The magnetic data covered the study area utilizing two grids. The first was a 500-meter grid which used for broad interpretation due to wide line spacings. The other grid used a line spacing of 500 meters and a ground clearance of 80 meters that allowed for the identification of fine magnetic details. Magnetic images and interpretations are based off the magnetic intensity reduced to the pole.

3.2. METHODS

3.2.1. SEGY VIEWER

The SEGY Viewer was used for the data loading and quality control. IHS Kingdom requirements for 2D data to be loaded, the data needs a survey name (line number), navigation data (shotpoints and XY coordinates), seismic traces, and shotpoint to trace relationships. This tool was used to extract the required information from the SEGY file. The SEGY file is composed of seismic traces, each of which is composed of trace headers and list of trace amplitudes. Trace headers identify the map location of the trace within the 2D seismic lines and the list of trace amplitude displays the lines as seismic traces. One or more trace numbers references each trace in a 2D seismic line. 2D seismic files are not uniformly documented, so the first step was to define the kind of numbers that may be needed to load the 2D seismic lines.

CDP Numbers are defined by the SEGY format standard as a simple integer trace counter with a defined position within the trace header. Usually, CDP numbers increment by one, but the CDP of the first trace is arbitrarily assigned by the data processor. Most of the SEGY files headers were of little assistance in identifying the byte number the CDP number were located. Determination of the shotpoint to trace relationship posed a challenge. Shotpoint numbers are the way traces are located on base maps and seismic sections that typically have to trace/CDP numbers per shot point. In order to determine the shotpoint to trace relationship, the text header was first examined (Figure 3.2).

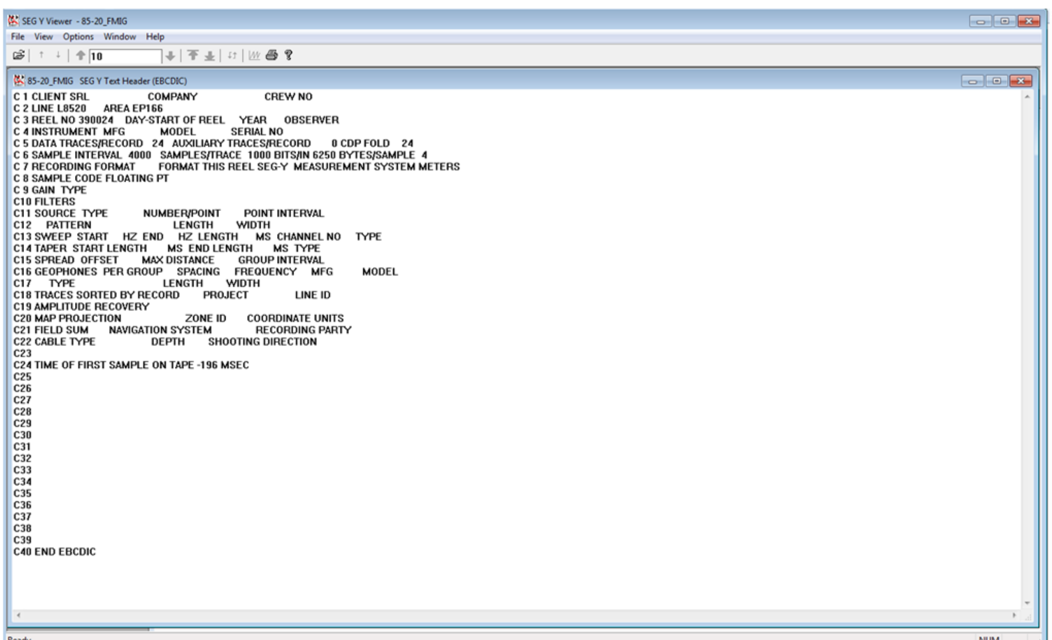


Figure 3.2 An example of a SEGY Text Header for seismic line 85-20 within the dataset

Most of the SEGY files within this project had little to no information contained within the text headers. Without information to delineate the byte numbers, the trace header (Figure 3.3) was then examined to determine the CDP number. In most formats, byte numbers 17-25 are typically where one would find the CDP numbers, but that was not always the case. To determine the relationship, a method of graphing the byte numbers was conducted. With the relationship of two CDP numbers per shotpoint the idea would be that it would create a stair-step like pattern (Figure 3.4A-C).

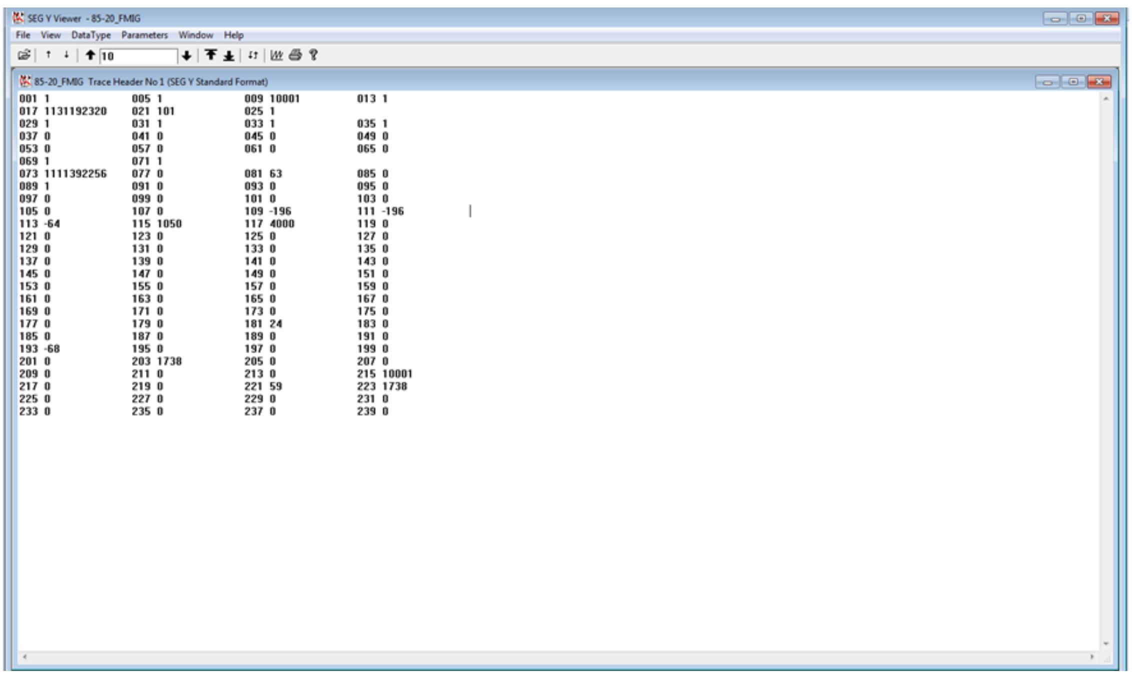
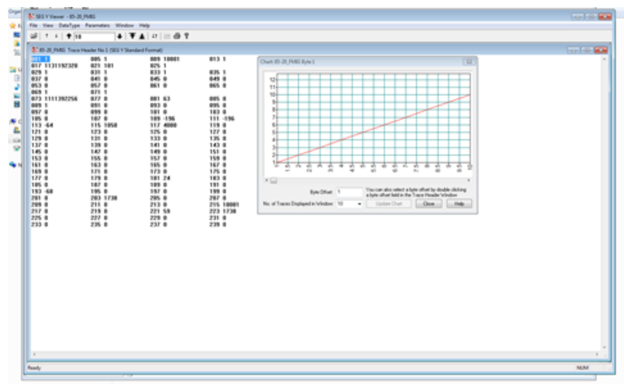
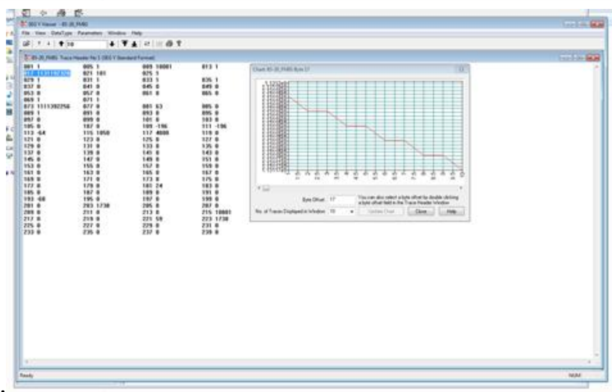


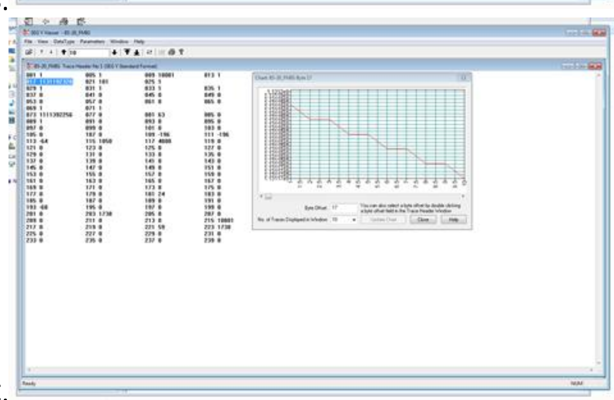
Figure 3.3 An example of the SEGY Trace Header for seismic line 85-20



A.



B.



C.

Figure 3.4 Graphical representation of the CDP-Shotpoint relationship from seismic line 85-20Trace Header displays A. the wrong byte number (Byte 001) for CDP due to the linear relationship B. and C. show the correct byte number (Byte 017) of the first and last Shotpoint numbers from their stair step pattern

3.2.2. IHS KINGDOM

The main software program used during the project was IHS Kingdom. Kingdom provides a geological, geophysical, and petrophysical interpretations for the 2D seismic data. The module used for interpretation was 2d/3dPak. The kingdom software program also allowed for various seismic attributes to be applied to seismic sections to enhance interpretation.

Loading the 2D seismic involved a process of importing SEGY files and assigning the corresponding shotpoint numbers from the byte numbers found within their trace headers (Figure 3.5). XY coordinates were not available in the SEGY files, but navigation files (UKOOA) for certain seismic surveys were available (Figure 3.6). The line numbers were then assigned an XY value for each shotpoint number in order to display on the map (Figure 3.7).

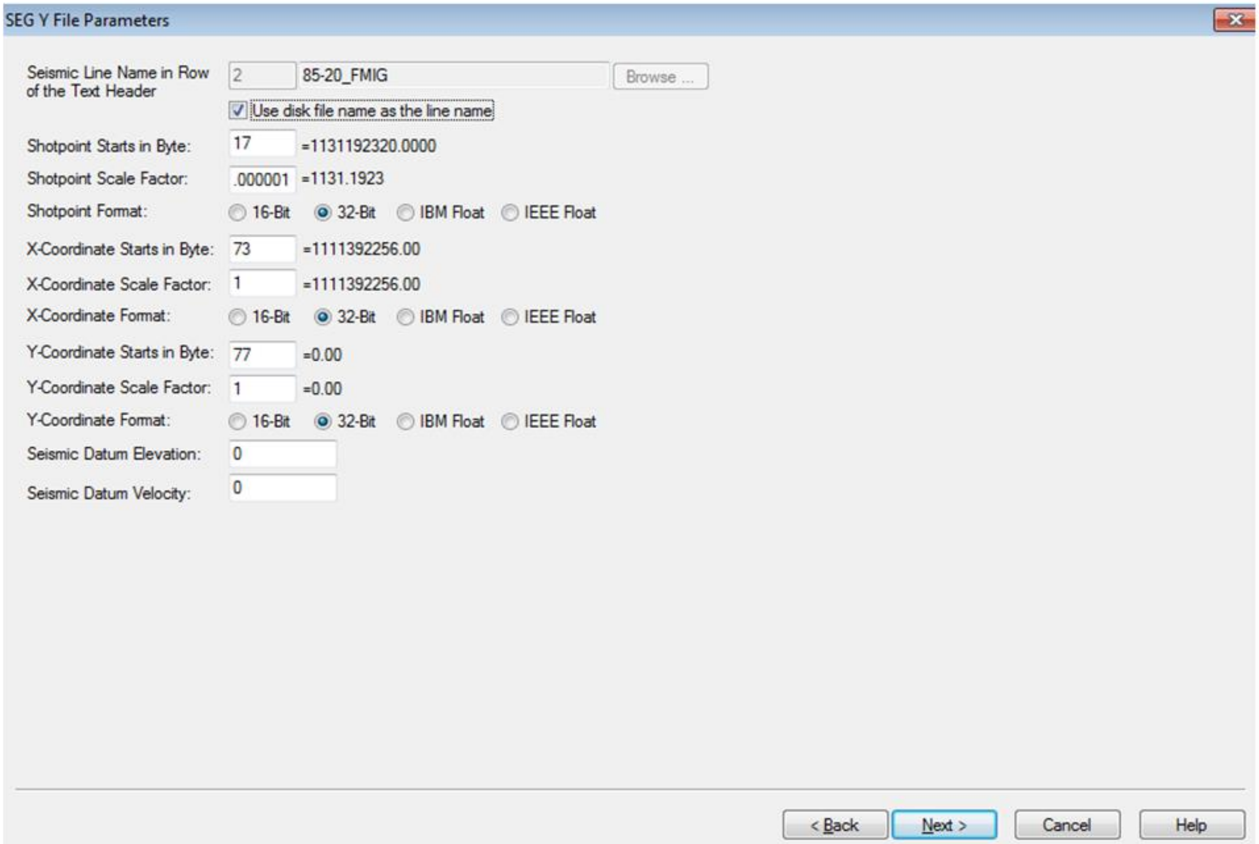


Figure 3.5 IHS Kingdom load screen for SEGY files and their corresponding parameters

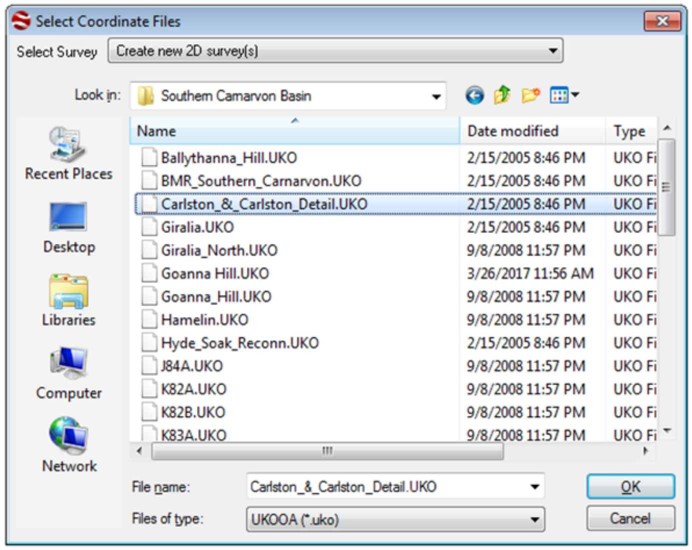


Figure 3.6 Navigation files for loading seismic lines onto basemap. Not all of the seismic data had corresponding navigation files and thus were unable to be used in the study

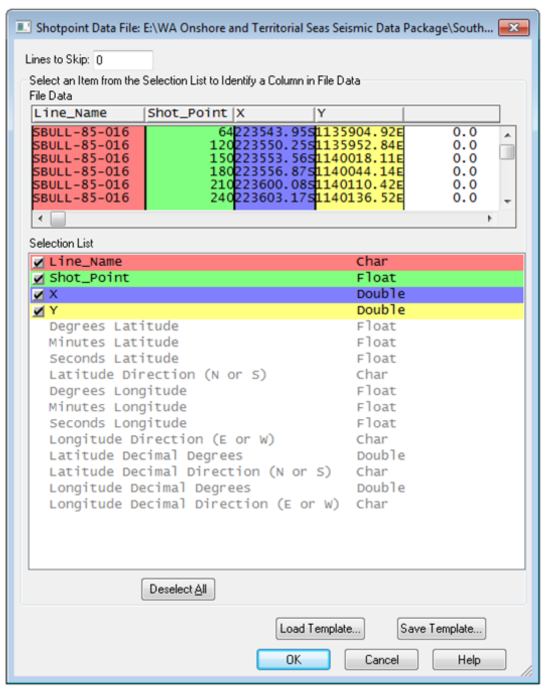


Figure 3.7 Process used for assigning XY values for the shotpoint numbers of the individual lines

4. GEOPHYSICAL INTERPRETATION AND MAPPING

4.1. SEISMIC

Seismic methods are increasingly being used in oil- and gas-field exploration. Seismic methods are applied to delineate the stratigraphic and lithologic characteristics of reservoirs (Table 2) with as much detail as possible in order to minimize the cost of development drilling and to support primary, secondary and tertiary recovery operations (Rice et al., 1981).

Bright spot detection is derived from the fact that high-amplitude reflections appear ‘brighter’ than lower amplitude reflections when observed on a seismic section. This is important in that high-amplitude events may indicate the presence of hydrocarbons, especially of gas.

Table 2 Frequently used geophysical methods for surface recording and their typical applications (from Lines and Newrick, 2009)

Geophysical method	Physical property measured	Typical Application	Comment of applicability
Seismology	Seismic wave velocity, seismic impedance contrast, attenuation, anisotropy	Delineation of stratigraphy and structures in petroleum exploration	Exploration seismology is the most widely used geophysical method in petroleum exploration
Gravity	Rock density contrast	Reconnaissance of large-scale density anomalies in petroleum and mineral exploration	Gravity surveys are generally less expensive, but have less resolving power than seismic exploration
Magnetics	Magnetic susceptibility or the rock's intrinsic magnetization	Reconnaissance of the crustal magnetic properties, especially for determination depth of basement features	Aeromagnetic surveys are widely used in both petroleum and mining applications for determining large, deep structures

Velocities and densities of sedimentary rocks vary according to mineral composition, degree of compaction, porosity, pressure, and fluid/gas content in the pores of the rock matrix. The change in acoustic impedance at an interface between two different rock types causes seismic energy to be reflected from the interface. Acoustic impedance is a convenient from of expressing the velocity-density relationship of an individual rock. The formula for acoustic impedance is

$$I = \rho \times \upsilon$$

where, I is acoustic impedance, p is density, and v is velocity.

On a fundamental level, seismic data can provide two major benefits. First, it can be acquired in frontier areas or over areas with sparse well control. An interpretation and generated maps can thus be extended with some confidence into areas that have little or no well control. The second benefit is that the seismic data can provide explicitly 2D and 3D data as opposed to the one-dimensional nature of a wellbore.

It is important to note when regarding seismic sections is that the section has the dimensions of space and time, and is not in the geologic realm of space and depth. A time section is simply a series of traces displayed next to one another on a computer screen or piece of paper. The distance along the line is a physical distance and represents a distance along the surface of the earth. Therefore, looking horizontally along a section requires the knowledge of the scale. The vertical scale should not be assumed to translate directly into a scalable physical distance. The vertical scale is displayed in two-way travel times. It represents the amount of time takes for a seismic signal or wave front to travel from the surface, down through the earth to the reflector, and back to the surface. Velocities change with depth. In general, the deeper the rock is, the higher its velocity.

Seismic data, well logs, and formation tops were interpreted to improve the general understanding of the regional geology in the Southern Carnarvon Basin. The target horizons were selected based on their lateral continuity, structural significance, and relevance to hydrocarbon prospectivity. Mapped horizons include the Top Basement, Top Devonian, Carboniferous, Base Lyons Group, Top Lyons Group, and Top Callytharra. Maximum sedimentary thickness of the study area is approximately 8,000 meters; therefore, mapped horizons lie within the four-second range displayed by the two-way travel time window in most seismic sections. Gravity and magnetic survey data were also integrated into the interpretation to help aid in the structural interpretation of the study area.

4.2. DATA QUALITY

The quality of data is highly variable, ranging from poor to very good (Appendix A). The majority of the lines were poor to fair quality. Some of the seismic surveys were reprocessed that improved the data quality minimally. The poor data can be attributed to near-surface geology, structural complexity, or abrupt changes in lithology. In seismic lines shot parallel to faults, horizon reflectors were impossible to distinguish (Figure 4.1) as seen in seismic line MM-007B. Even though some horizons were able to be picked, sparse seismic coverage, although reasonable for regional interpretations, did not allow for detailed mapping. Horizons picked across the less detailed seismic sections were based off general basin geology. Other seismic lines were of good quality (Figure 4.2) that led to a higher degree of confidence in identifying the appropriate horizons.

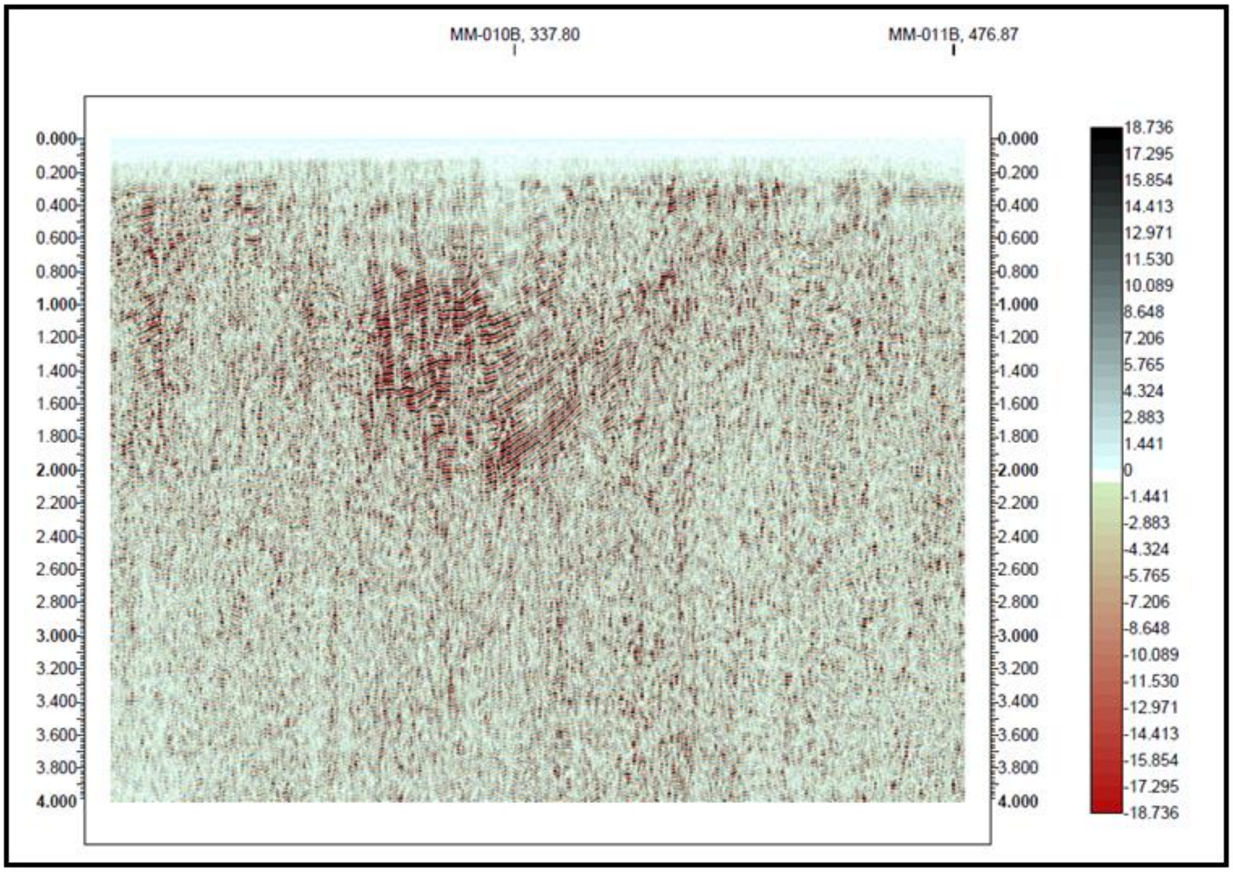


Figure 4.1 Seismic section displaying typical poor quality of data as seen in seimic line MM-007B

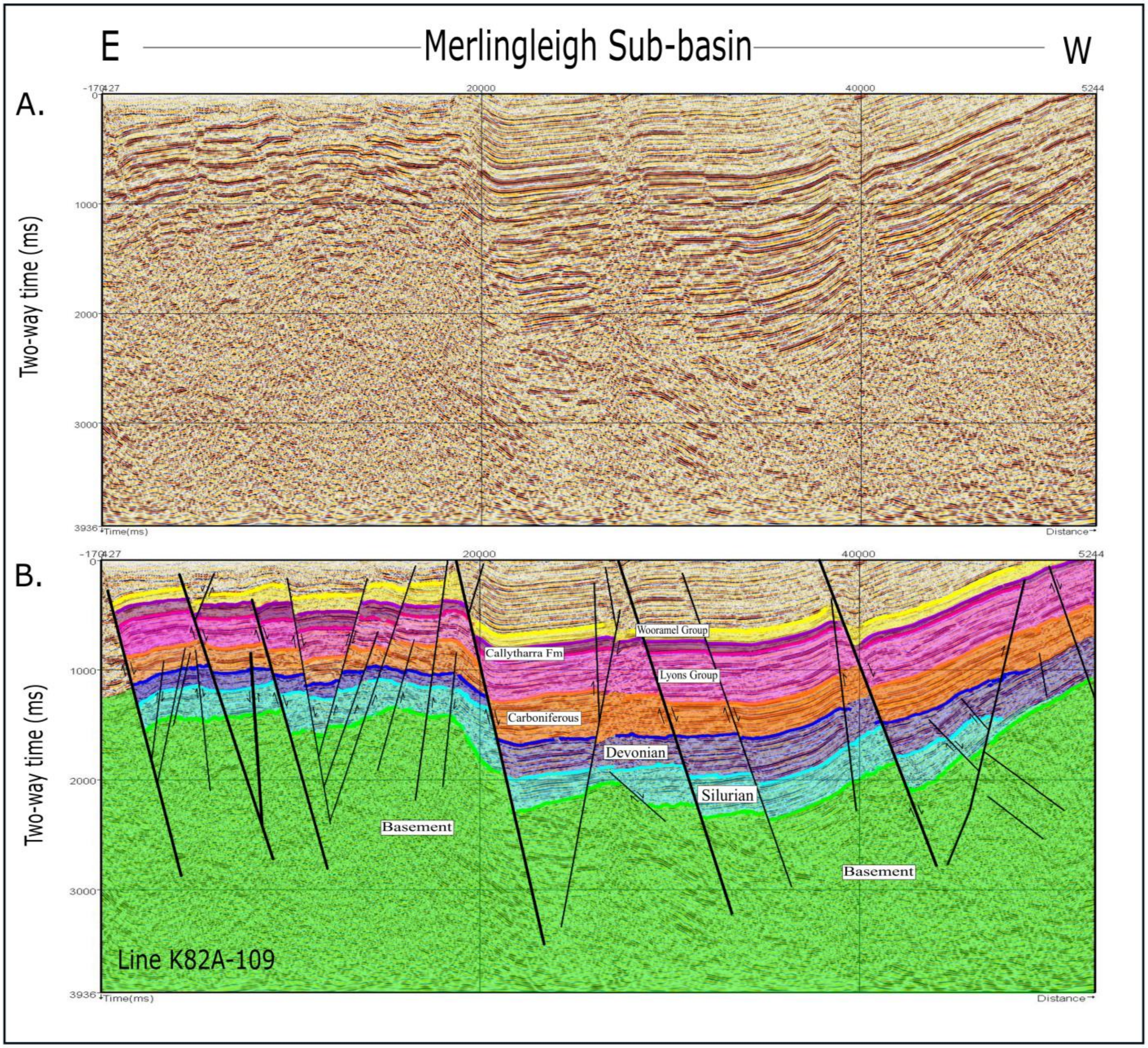
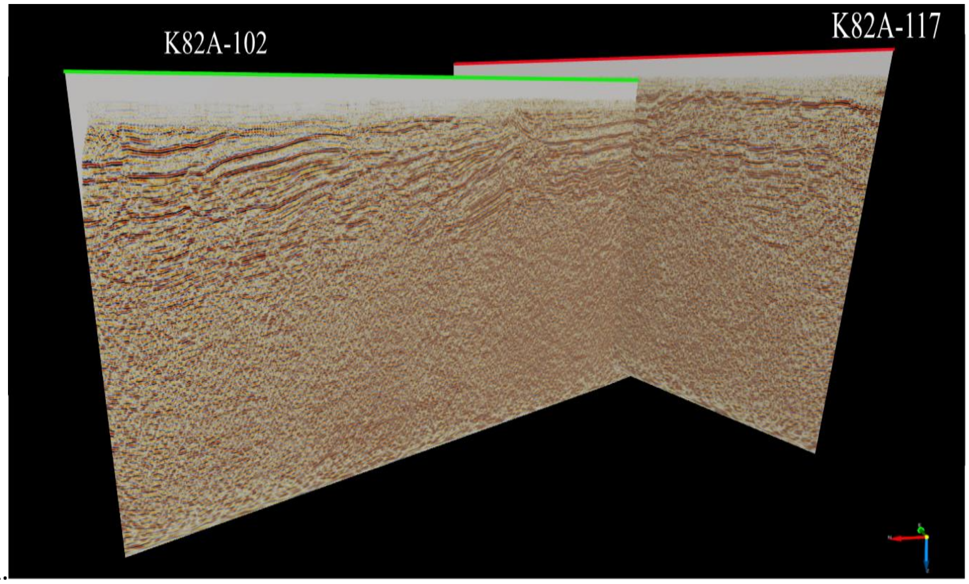


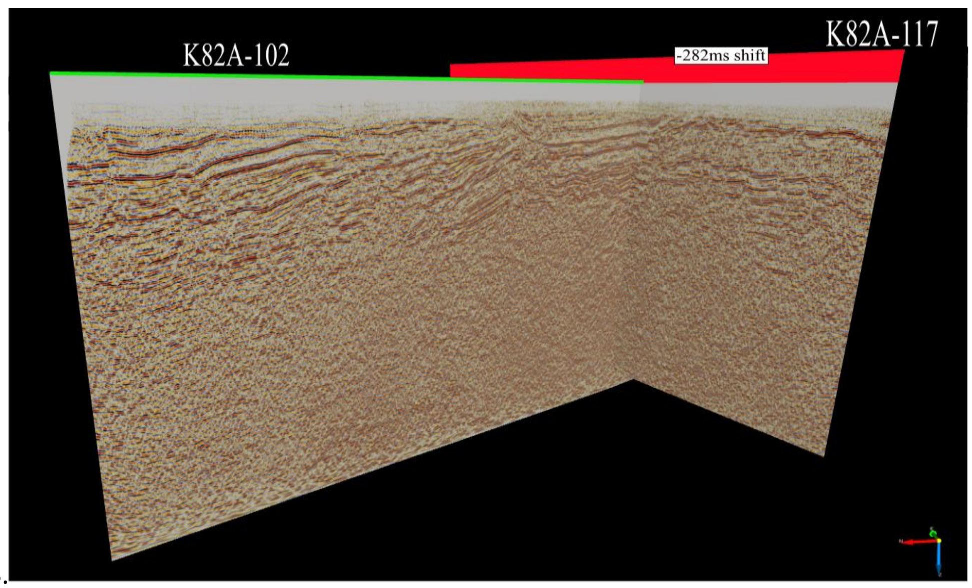
Figure 4.2 Representation of a good quality seismic line as seen with Seismic Line K82A-109 A. before interpretation B. after interpretation

4.3. MISTIES

Due to the seismic sections used in the interpretations being from different sources and times, bulk shifts were applied when interpreting horizons. By shifting the seismic traces, it establishes a relationship between the surfaces seen of the seismic sections. This assures that a given interpretation of a geologic surface on one line is the same surface as interpreted on an intersecting line. In doing so, it is possible to project horizons being mapped into areas where well control does not exist. All faults and horizons must be related and understood within the framework of a spatial grid of lines. The traces of geologic surfaces must intersect at the tie points. The misties between datasets typically range from 10 to 50 msec, and occasionally up to 300 msec, largest mistie anomaly, due to the static corrections applied by different processing contractors (Figure 4.3). Also, there were increasing time differences at varying depths. Therefore, seismic lines are only accurate to only about 30 msec for most of the study area.



A.



B.

Figure 4.3 Time shift of seismic line K82A-117 by -282ms using OpendTect

4.4. WELL CONTROL

The Southern Carnarvon Basin has very limited well control, with only two wells that were useful in tying the seismic data to well data. The distances between well ties were too far away to properly apply a general trend of the study area. Quail 1, in the north, and Gascoyne 1, in the south, were the two wells that were possible to tie a well to the seismic data (Figure 3.1), with Quail 1 being the only well that was drilled to a significant depth. Most wells were drilled as shallow stratigraphic tests. Frequent jump correlations over considerable distances were required along and between lines. In order to reduce the degree of uncertainty, stratigraphic correlations based on log signature and lithological descriptions, as well as all available velocity surveys, were used to assist in seismic interpretation.

4.5. SYNTHETIC GENERATION

A synthetic seismogram is a simulated seismic response computed from well data. The synthetic seismogram is obtained by convolving the sequence of acoustic impedances, p * v (where p denotes the rock density and v its velocity), with the seismic wavelet (Zimmerle, 1995). Both, p and v are obtained from borehole measurements. The process serves as a control to tie the well logs, which are in depth, to the seismic sections, which are in time. Synthetic seismograms were created for all wells that data was provided for that included density logs (RHOB), velocity logs (DT), and Time-Depth (TD) charts. The TD chart, RHOB and DT logs are used in the computation of the seismogram. A wavelet was extracted from the seismic traces surrounding the well. The processed wavelets on all interpreted seismic lines were minimum phase with normal polarity. Figure 4.4 illustrates all the components used in generating synthetic seismograms. Limitations of the use of synthetic seismograms are sometimes due to incomplete input data (velocity and density) from the well data.

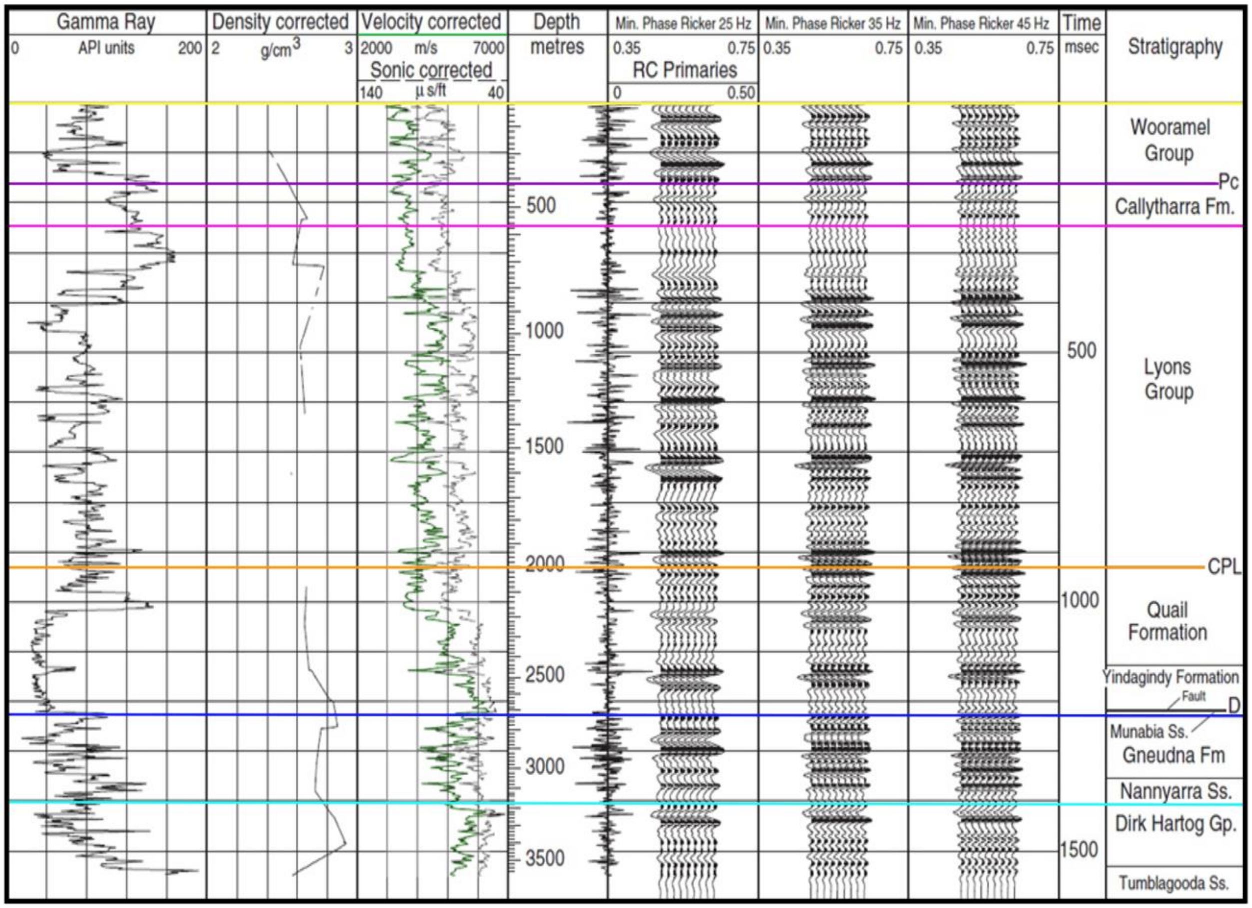


Figure 4.4 Synthetic seismogram generated for Quail 1 well. Illustrated is all components used in generating synthetic seismograms

4.6. SYNTHETIC MATCHING

Synthetic matching involves matching the synthetic seismogram to the actual seismic data. A wavelet is extracted from the closest trace from each well. This extracted trace is actual seismic data used to match the synthetic to. The synthetic trace can then be shifted, stretched, or squeezed to achieve the best matching between the synthetic and seismic trace. Figure 4.5 displays the synthetic seismogram on top of the seismic line K82A-105.

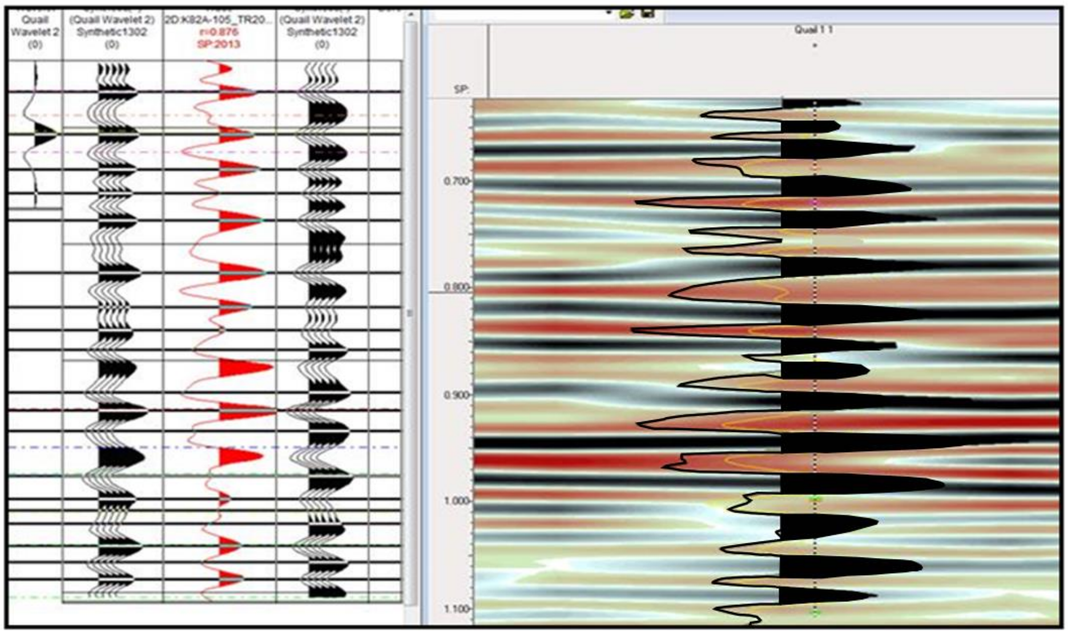
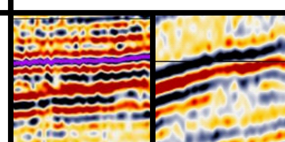
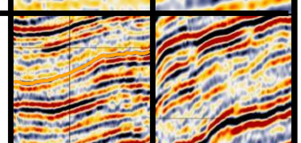
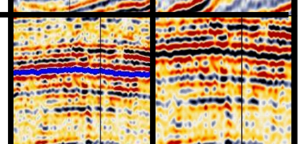
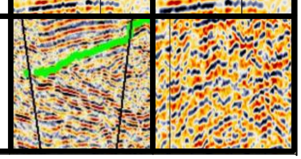


Figure 4.5 Seismic section K82A-105 with generated synthetic seismogram overlain atop the seismic data

4.7. MAPPED SEISMIC HORIZONS

Within the study area, four main seismic horizons were interpreted. The interpreted horizons are the Top Basement, Top Devonian, Base Lyons Group, and the Top Callytharra (Table 3). Each horizon was selected for their relevance to hydrocarbon prospectivity (Table 2). A two-way time (TWT) structure map was constructed for each horizon (Fig. 4.7, 4.9, 4.11). The maps of the horizons were not converted to depths due to insufficient velocity data control points to obtain accurate depth estimates.

Table 3 Seismic facies of the four major horizons picked within the study area

Horizon	Color	Acoustic Impedance Change	Boundary Type	Reflector	Seismic
Callytharra	Purple	High	Conformable	Peak	
Base Lyons	Orange	Low	Erosional, Disconformable	Peak	
Top Devonian	Blue	High	Conformable, Nonconformable (East)	Trough	
Top Basement	Green	Low	Erosional, Nonconformable	Peak	

Due to the lack of well control and quality of data, the interpretations are regional in scale with a moderate to good confidence level. Even with the lack of data coverage, the analysis provides valuable insights into prospective trends for future exploration efforts within the Southern Carnarvon Basin.

4.7.1. CALLYTHARRA SANDSTONE

The Early Permian Callytharra Sandstone (Fig. 4.6) was the uppermost horizon picked within the study area and was picked across the study area that was identified as a high amplitude peak. It may be recognized by the contrast between an underlying zone of very low amplitude reflections, which correspond to shales layers, and an overlying package of reflections from the Moogooloo Sandstone Member of the Permian Wooramel Group.

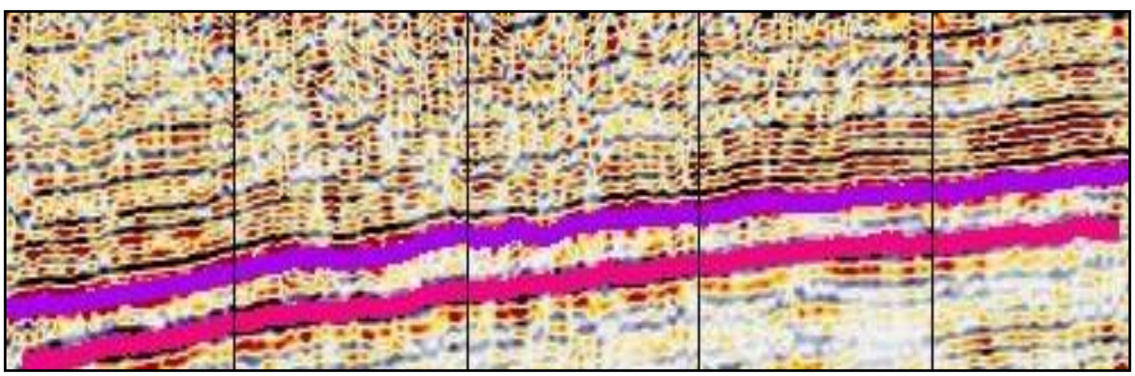


Figure 4.6 Top Callytharra formation (purple) displaying a series of low amplitude reflectors below the horizon and the over lying package of reflections from the Permian Wooramel Group.

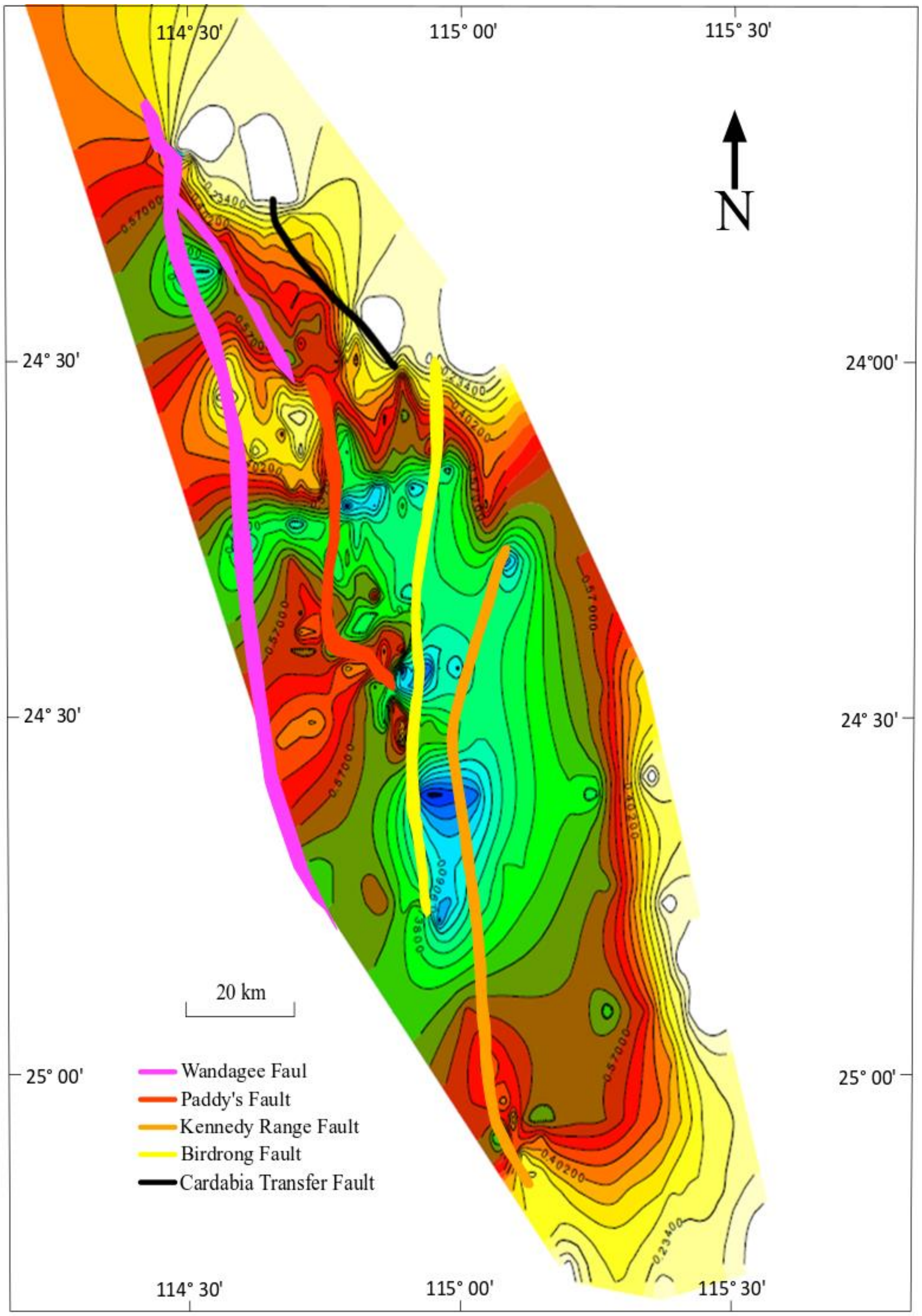


Figure 4.7 TWT structure map of the top Callytharra Formation

4.7.2.   BASE LYONS GROUP

These reflectors generated within the Late Carboniferous Lyons Group (Figure 4.8) can be recognized by its medium to low amplitude and often having strong continuity over large parts of the basin. The base of the Lyons Group is an erosional surface which helped in the identification of the horizon. Common with erosional surfaces, the horizon displays downlapping, while the underlying Carboniferous stratum displays toplapping. Another identifiable characteristic of the base Lyons Group was the termination of faults that were active before the deposition of the Lyons Group.

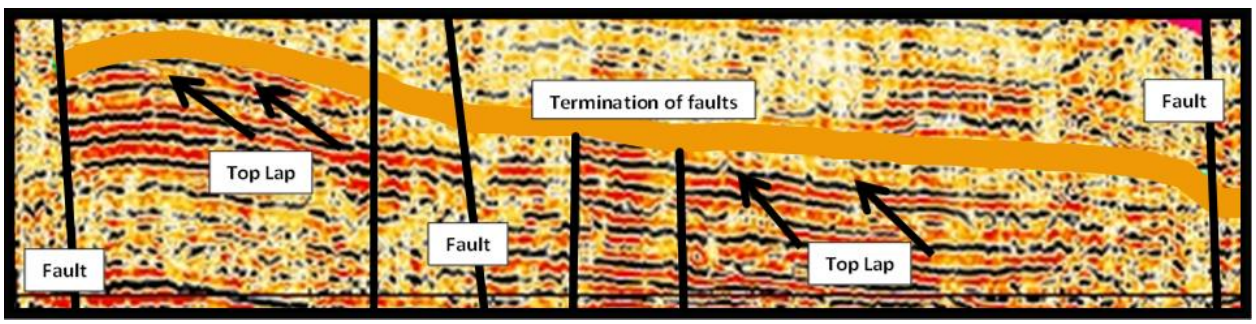


Figure 4.8 Seismic section showing the Base Lyons Group with toplapping from lower Carboniferous strata and termination of faults

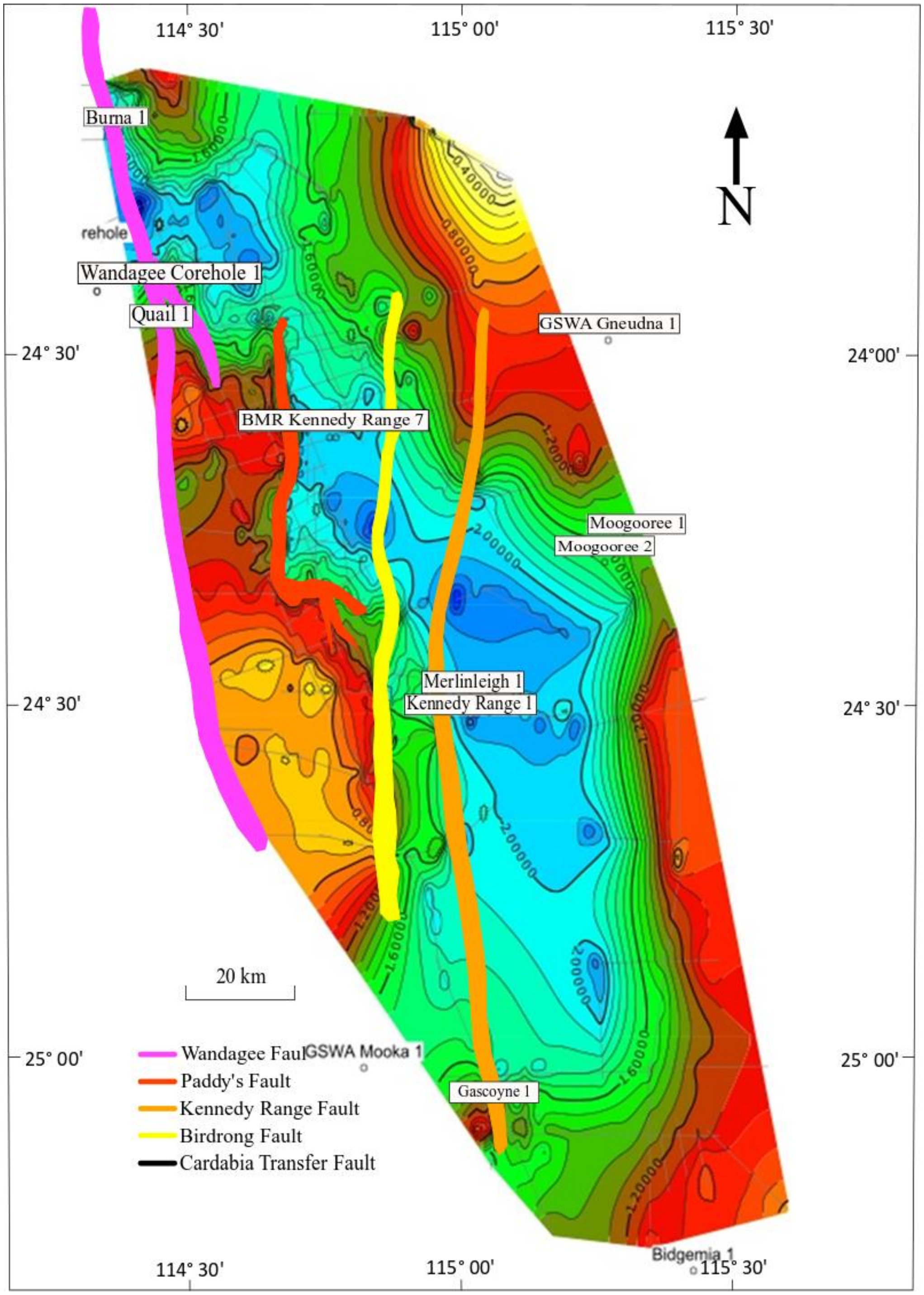


Figure 4.9 TWT structure map of the base Lyons Group

4.7.3. TOP DEVONIAN

Below the top Devonian horizon (Figure 4.10), the strata display a series of high-amplitude reflectors. The change in acoustic impedance at the base of the Moogooree Limestone, which overlies Devonian strata in some areas helped in the identification of the horizon. This horizon displays onlaping to the underlying Devonian and Silurian formations and Basement horizons and was absent from seismic sections in the southeastern-most portions of the study area. The base of the Devonian is an erosional surface that overlies synrift Silurian/Ordovician strata. The TWT structure map of the top Devonian horizon shows regional deepening towards the center of the basin with a north-northwest direction, with maximum depths near Kennedy Range 1 and is absent in portions of the southern-most areas of the study area.

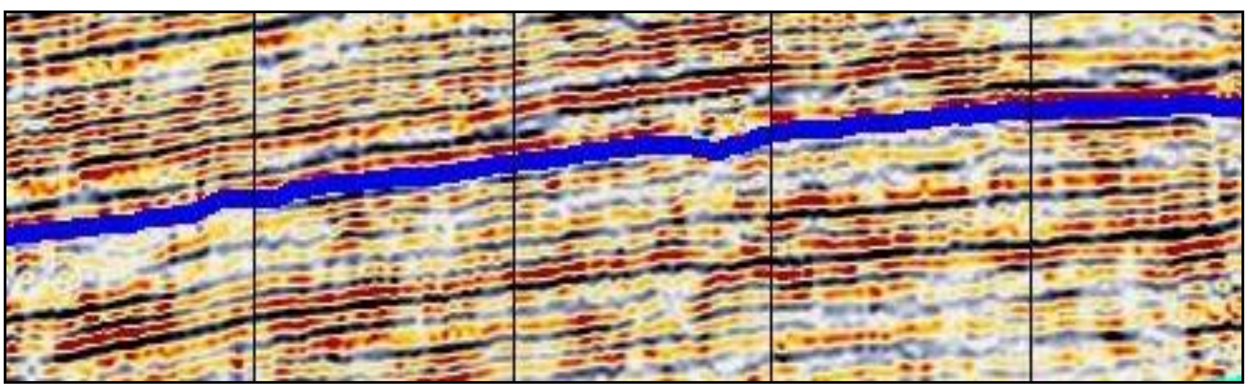


Figure 4.10 Typical response for Top Devonian horizon

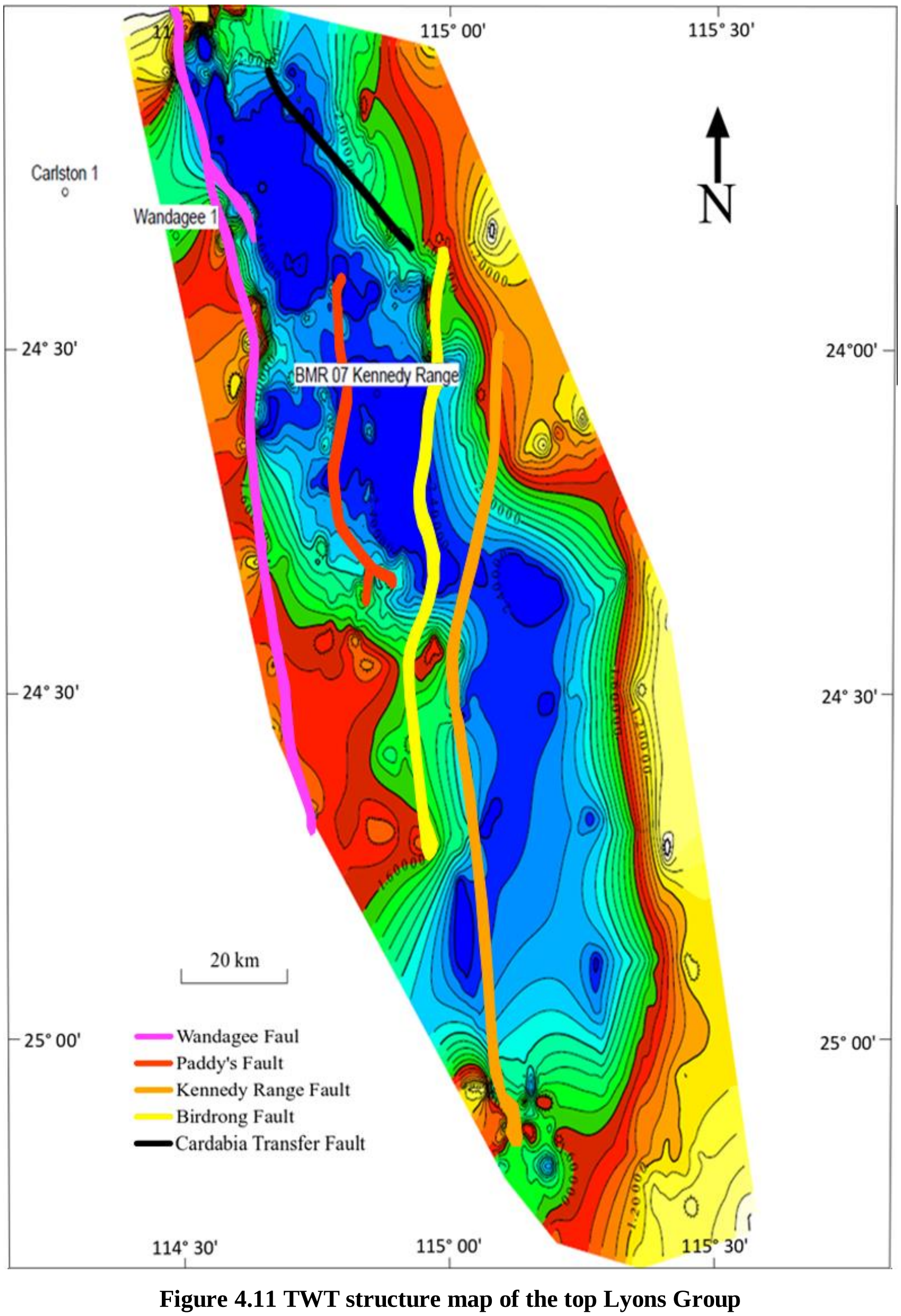


Figure 4.11 TWT structure map of the top Lyons Group

4.7.4. TOP BASEMENT

The Basement Top was picked fairly confidently throughout most of the study area and is expressed as a moderate- to high-amplitude, low-frequency event. The event was defined by seismic reflections due to none of the wells penetrating the basement. The Basement Top is an erosional surface, which was hard to map in many areas in the basin due to the low impedance. Reflectors were picked where there were intrabasement reflectors at a noticeable angularity to the overlying sedimentary rocks. This basal event indicates deepening to down to the center of the basin. Below the Basement Top, the characteristic of the reflectors were typically chaotic in nature defined by low amplitude and sub-parallel, discontinuous reflections (Figure 4.12) within the study area, faults at this level exhibit throws with normal movement that suggests there was an extensional regime before the deposition of the Merlinleigh Sub-basin.

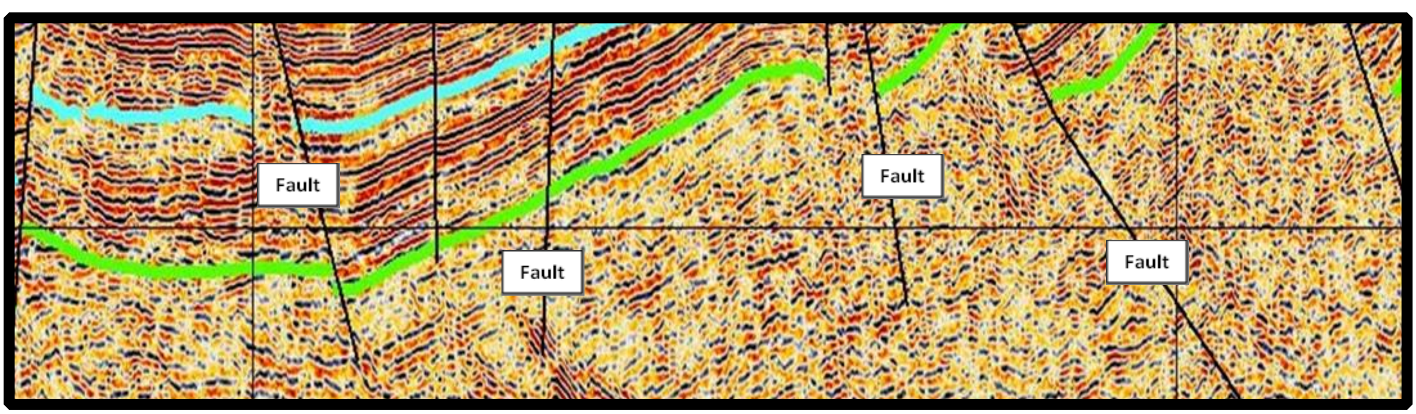


Figure 4.12 Basement horizon displaying low amplitude, chaotic reflections with high angle intrabasement refletors

4.8. STRUCTURAL INTERPRETATION

The procedure for subsurface mapping from seismic data began with data validation; i.e. analysis of what the seismic data represents. Does the seismic data actually have some relationship to the geology subsurface? The second step involved the actual interpretation of the seismic sections. The third step encompassed extracting the information from the seismic data and transferring it onto the map so that it could be used effectively. The 2D seismic workstation process collected data in relation to a base map. The final step was the construction of the subsurface geologic maps. This step represents the culmination of all previous work performed.

These mappings illustrate the study area as a north trending, Permo-Carboniferous depocenter that approximates a half graben. The depocenter appears to have shifted westward during active deposition. A series of north striking, mostly, but not entirely down to the east normal faults which define the structures. TWT structure maps (Figure 4.7, 4.8, and 4.10) show similar trends. Various major faults on the western side of the maps border large tilt block structures. The north plunging tilt-block ramps on the western side of the half graben and are bound on their eastern sides by the major north striking faults that include the Kennedy Range Fault, the Birdrong Fault, Paddy’s Fault, and the

Kennedy Range Fault. The faults appear to have behaved in a scissor type of movement that allowed for variable deepening of the basement under each horst block in a style that generally deepens the basement towards the north. The maps show the northwest striking Cardabia Transfer Fault, in the northern portion of the study area, traverse a zone where many of the north trending faults appear to terminate.

The western margin of the study area is an area where the basement is shallower. This structural high is the boundary that separates the Merlinleigh Sub-basin from the Gascoyne Platform and is identified as the Wandagee Fault. The fault appears to be east dipping and correlates interpretation of the area (Iasky et al., 1998). The eastern margins of the study area also display shallower basement depths indicating progressive downward faulting towards the center of the Merlinleigh Sub-basin.

4.9. GRAVITY AND MAGNETICS

In petroleum exploration, aeromagnetic surveys are more commonly conducted offshore than onshore because there is less interference from cultural features or near-surface noise. Under favorable conditions, magnetic data can provide structural information both within the sedimentary sequence and at basement level. Calculation of the depth to magnetic basement from aeromagnetic data is generally considered to correspond to the depth of crystalline basement. Depth solutions, however, may not correspond to the base of the sedimentary succession because discrete magnetic bodies deep within the basement or within the sedimentary succession may make depth solutions both ambiguous and inaccurate.

Gravity anomalies are the result of density contrasts between various sedimentary and basement lithologies. Unlike magnetic anomalies, surface cultural effects and/or surficial rocks and sediments do not affect gravity anomalies. Processed gravity images show lineaments that may either be faults within the sedimentary sections or intrabasement variations in density (Figure 4.14). By minimizing the effects of data aliasing, gravity surveys may be more advantageous over an evenly spaced grid rather than along roads and tracks.

Potential-field surveys can provide valuable evidence on the strike of and approximate depth to structures, and it is easier to interpret transcurrent movement on potential-field images than from 2D seismic data (Lines and Newrick, 2009). It is important to note that neither the gravity nor magnetic method can accurately establish the timing of structural events. Inferences may be made on the relative timing established by the spatial relationships of lineaments.

The interpretation of previously modeled gravity and magnetic datasets (Figure 4.14 & Figure 4.15) were used to help support structural interpretations and to identify anomalies that could be used in the identification of hydrocarbon-trapping features, especially in areas with limited to no seismic coverage. With areas that have seismic data, it was possible to integrate the gravity and magnetic data to help aid in subsurface interpretations. The use of gravity and magnetic survey data in conjunction with seismic data can have the potential to upgrade the Southern Carnarvon Basin prospectivity and help with future studies in the areas.

The gravity and magnetic datasets over the Merlinleigh Sub-basin offer similar regional structural information in that they illustrate the boundaries, alignment, and extent of thickest sedimentary infill similar to the structural interpretation. The north-striking discontinuities in the gravity data also correlate with the north-striking faults mapped. At the western margins, a gravity high is seen which is equivalent to the higher basement seen in the seismic data.

The aeromagnetic images were capable of delineating high-frequency anomalies that were produced by surface or near-surface magnetic sources. Most of the magnetic lineaments on the western side of the Sub-basin are seen as high-frequency anomalies, implying a shallower source, or have a low frequency, suggesting deeper bodies within the basement. Within the sedimentary sequences and at basement level, the depth to magnetic basement shows an absence of reliable magnetic sources. The Wandagee Fault’s east-dipping characteristics can be correlated with the zone of deepening magnetic sources on the western edge of the study area. Other various minor magnetic anomalies indicate shallow faults in the sediment section also consistent with faults mapped in seismic sections.

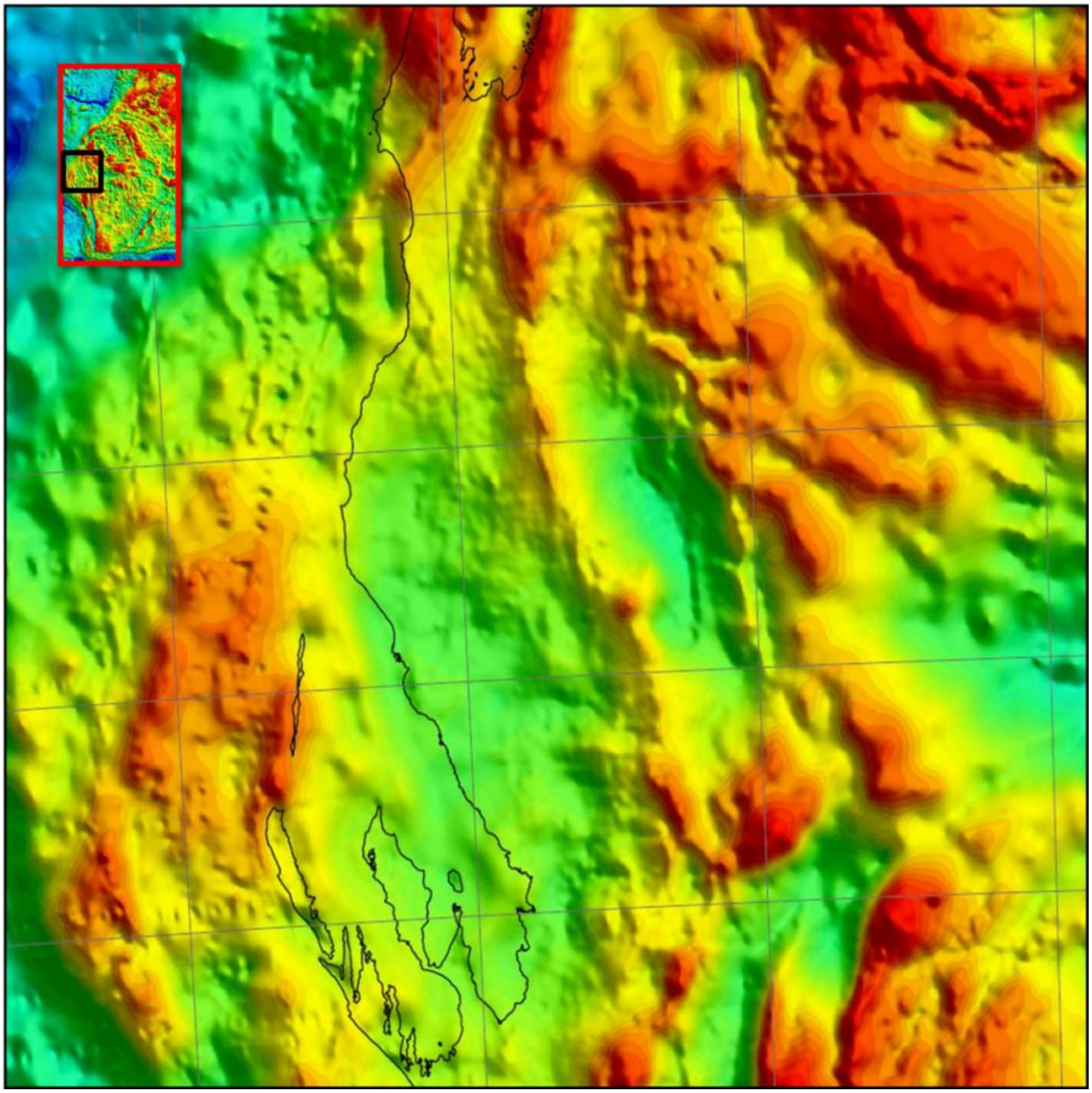


Figure 4.13 Isostatic Residual Gravity survey over Western Australia's Southern Carnarvon Basin (modified from GSWA 2004)

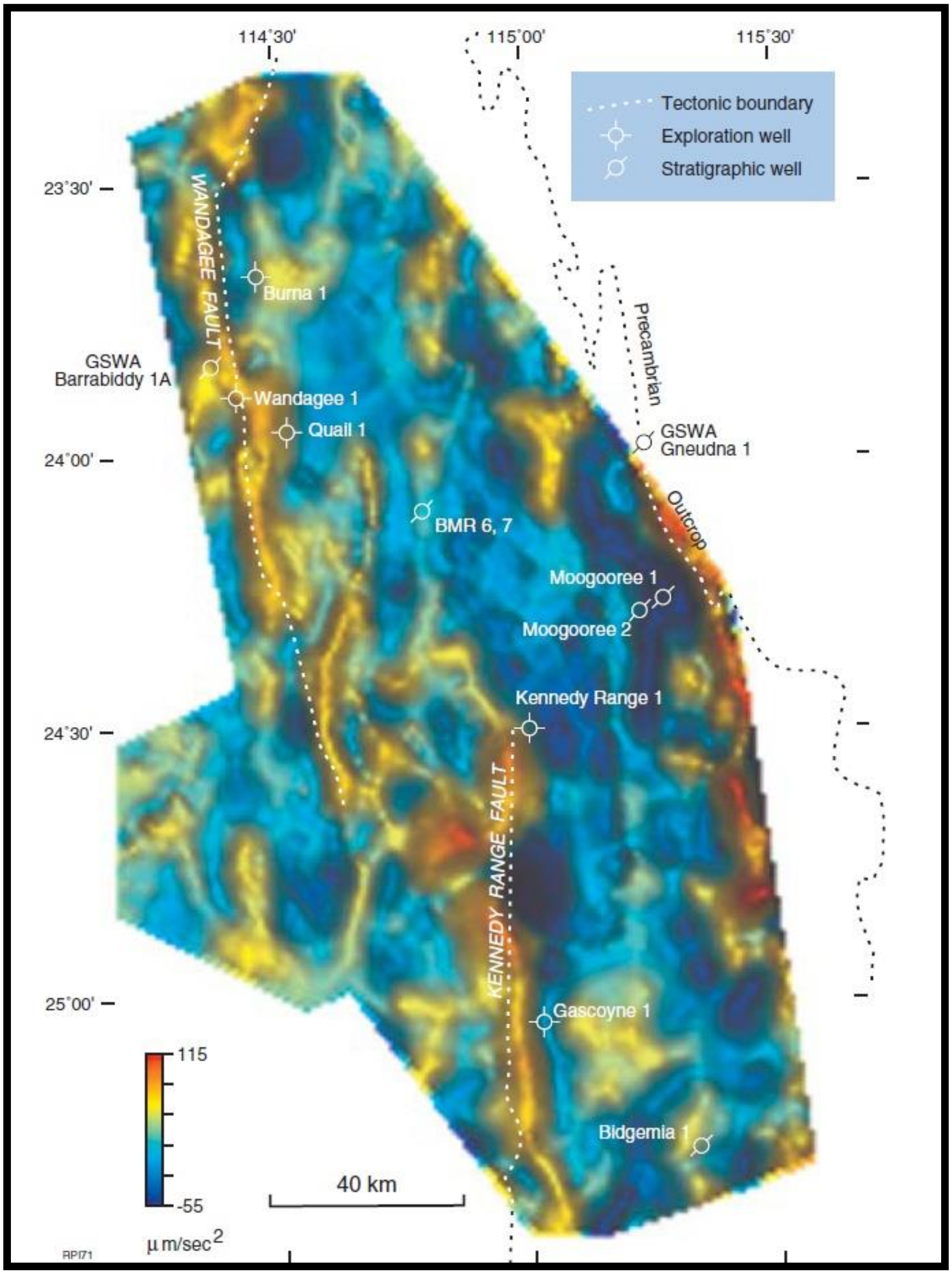


Figure 4.14 Image of the Residual Bourger Gravity (from Iasky et al., 1998)

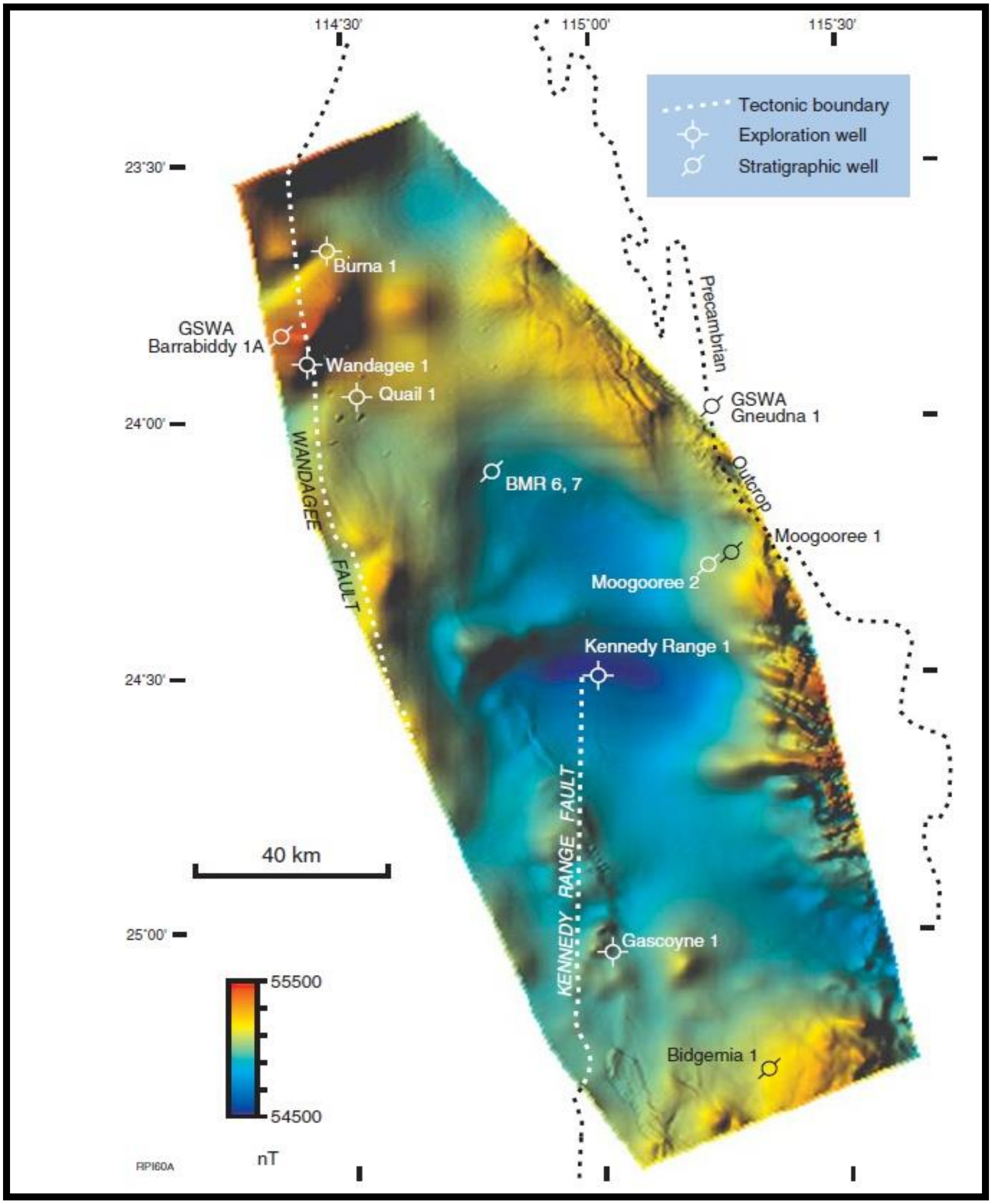


Figure 4.15 Image of the reduced-to-pole total magnetic intensity (from Iasky et al., 1998)

5. PETROLEUM SYSTEM ANALYSIS

5.1. INTRODUCTION

There are four crucial elements that define the petroleum system: (1) source and generation; (2) reservoir; (3) migration (pathways); (4) entrapment and preservation (Nanda, 2016). No hydrocarbon fields or accumulations have been discovered to date in the Southern Carnarvon Basin. However, there have been hydrocarbon shows in several wells in the area and it has been established that hydrocarbons are still being generated (Crostella, 1995; Fugro Douglas Geochemistry Pty Ltd, 1991; Dolan and Associates, 1991; Pervical and Cooney, 1985). Previous reports dealing with the Merlinleigh Sub-basin are constrained by the limited amount of available data, most of which is restricted to the western margin and conclusions reached have been subjective and varied at best. The main objectives in the Merlinleigh Sub-basin have primarily centered on structural plays identified as faulted anticlines immediately east of the Wandagee Fault and have been tested in wells Quail 1 and Burna 1. The majority of wells that have been drilled were spudded as stratigraphic wells and were not considered to be valid exploration tests.

Initial steps involved integrating all the hydrocarbon occurrence data such as source rock observations from well penetrations and outcrops, oil and gas in wells, core extracts, seeps, slicks, hydrates and direct hydrocarbon indicators from seismic data. An events chart (Figure 5.1) helps in identifying the critical moment when all elements of a variable petroleum system are first in place.

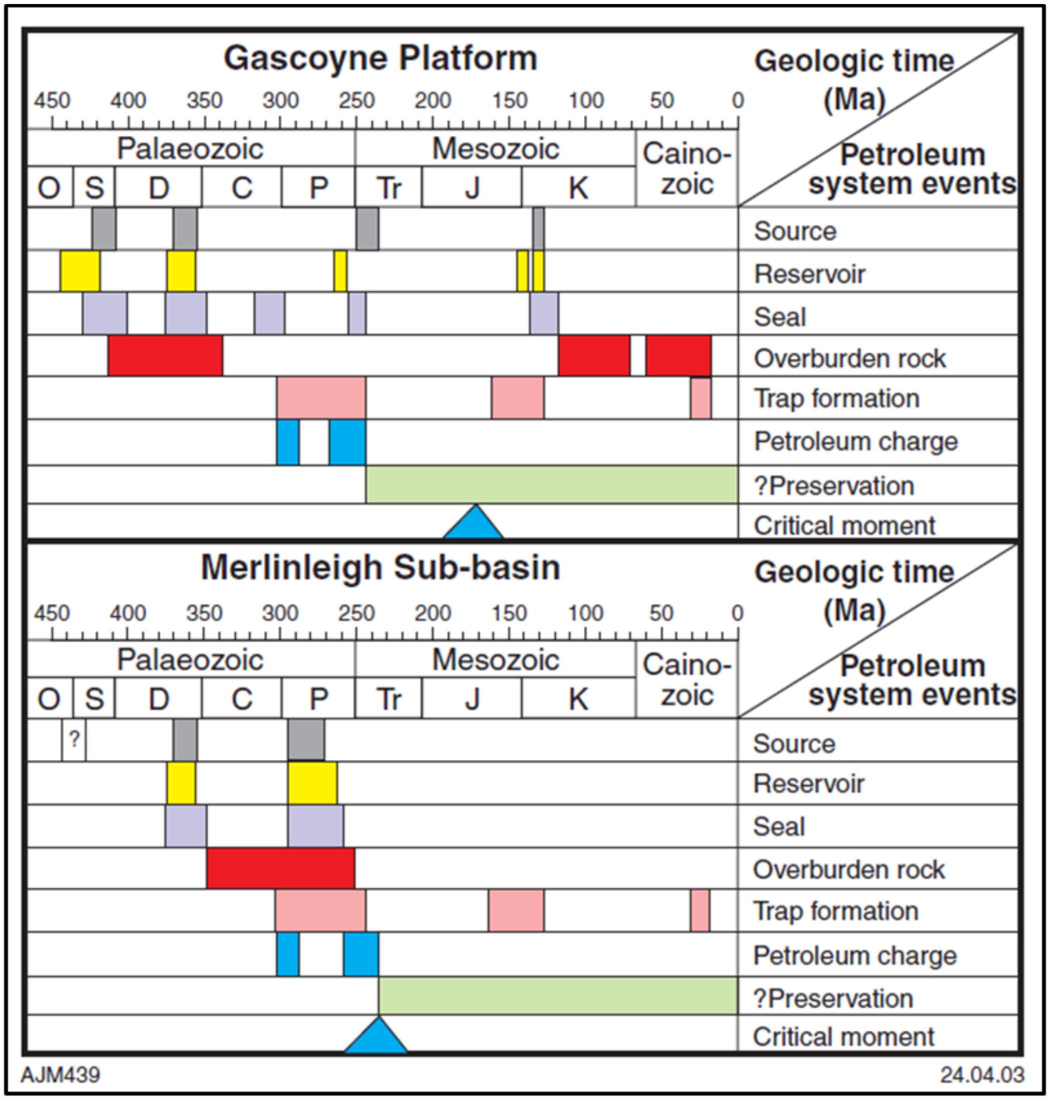
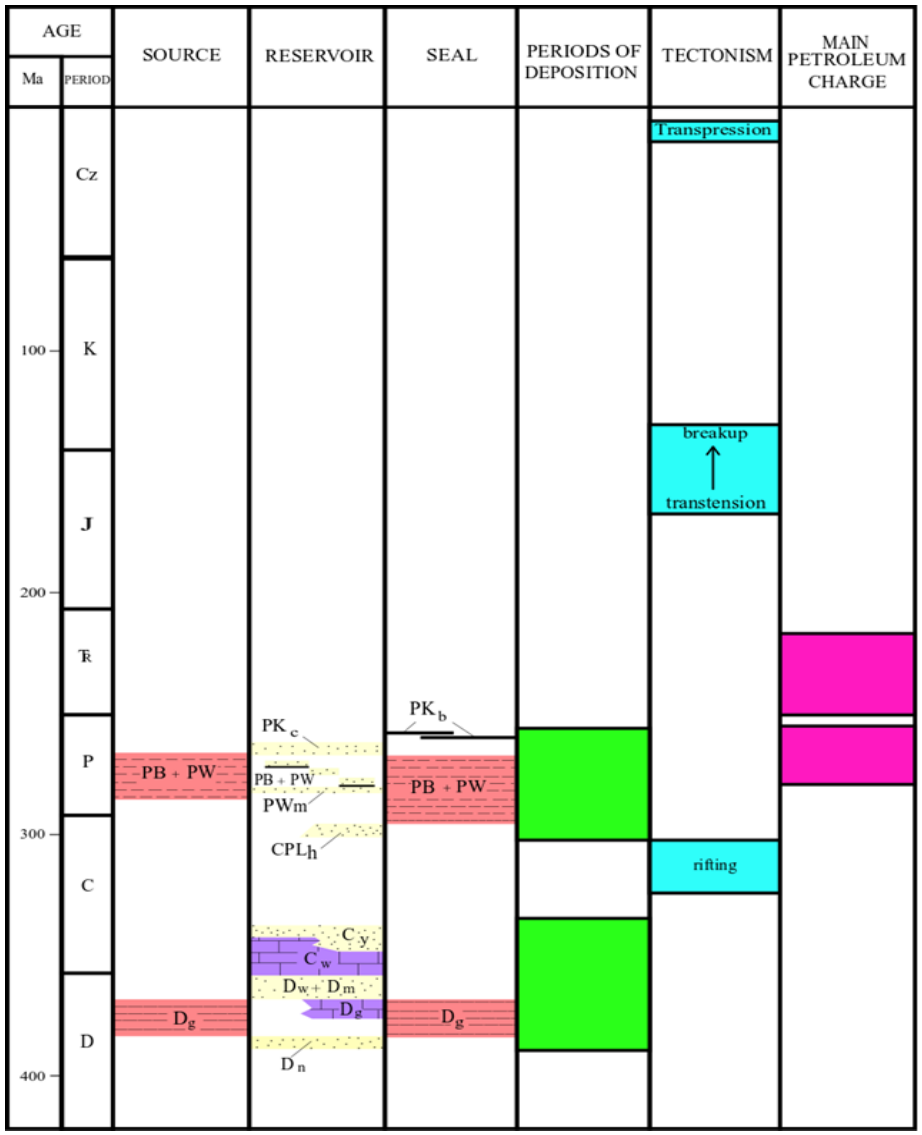


Figure 5.1 Petroleum systems event chart for the Merlinleigh Sub-basin and the Gascoyne Platform of the Southern Carnarvon Basin (from Mory et al., 2003)



PK_b = Binthalya Fm
PK_c = Coolkilya Ss
PB = Byro Group
PW = Wooramel Group

PW_m = Moogooloo Ss
CPL_h = Harris Ss
C_y = Yindagindy Fm
C_w = Williambury Fm

D_w = Willaraddie Fm
D_m = Munabia Ss
D_g = Gneudna Fm
D_n = Nannyarra Ss

Figure 5.2 Likely petroleum systems and their associated formations (adapted from Mory et al., 2003)

5.2. WELLS IN AREA

QUAIL 1

Quail 1 was well drilled by Oil Drilling and Exploration in 1964 to a total depth (TD) of 3,580m. The primary objective was to investigate the hydrocarbon potential of possible reservoir rocks in the anticipated Carboniferous and Devonian strata on the Quail Anticline (Figure 5.3). Other objectives included investigations of the stratigraphy of the Paleozoic strata beneath the Middle Permian outcrop sections.

The well intersects seismic line K82A-105 that was used to identify the optimal site for drilling which was determined to be the eastern side of the Wandagee Fault where more structures were present based on previous drilling data from Wandagee 1 to the west. A thermal history reconstruction using apatite fission track analysis and vitrinite reflectance (VR) test was performed on samples taken from Quail 1 commissioned by the Geological Survey of Western Australia. VR is a time-temperature indicator governed by a kinetic response in a similar manner to the annealing of fission tracks in apatite. This test included four samples to identify, characterize, and quantify the episodes of heating and cooling to determine the timing of major paleo-thermal episodes and VR data from five samples. The test concluded that there were at least two episodes of heating and cooling; Cooling from maximum paleotemperatures began sometime between 140 and 110 Ma Early Cretaceous) and between 20 and 5 Ma (Late Tertiary). From VR values of the samples from Quail 1 suggests that Devonian to Permian units were hotter than present temperature values.

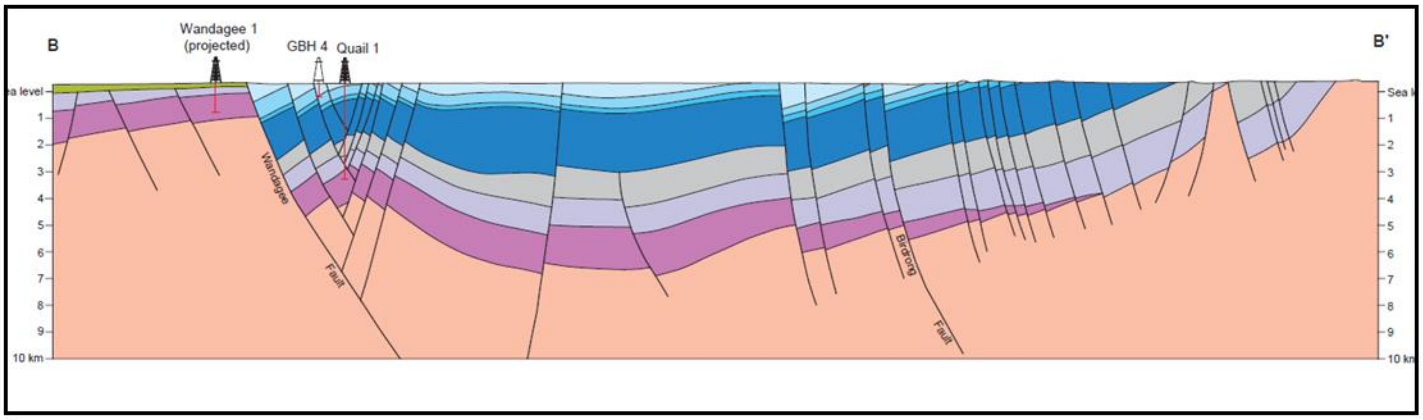


Figure 5.3 Idealized cross-section through Quail Anticline (from Iasky et al., 1998). Quail 1 was drilled east of the Wandgee Fault.

BURNA 1

Intairdril drilled Burna 1 to a depth of 767.7 meters in 1984 for Esso Exploration. It is located towards the northern end of the Merlinleigh Sub-basin. The purpose of the well was to test the hydrocarbon potential of Early Permian clastic sections of the Wooramel Group. Due to insignificant oil or gas detection, the well was plugged and abandoned as a dry hole.

KENNEDY RANGE 1

This well was drilled to a total depth of 2,204 meters by Oil Drilling & Exploration for West Australian Petroleum (WAPET). The Primary objective for the well was to test the sands of the Moogooloo Sandstone of the Wooramel Group, with possible secondary objectives in the Byro Group and Callytharra Formation. Kennedy Range 1 well is located in the Eastern portion of the Carnarvon Basin on the Merlinleigh Anticline, a surface feature developed on the eastern down-thrown side of the Kennedy Range Fault. The Merlinleigh Anticline and associated features were formed as reverse drag folds during tectonism in the Jurassic. Reverse movement along the Kennedy Range Fault in the late Tertiary resulted in the eastern downthrown block being elevated an estimated thirty to sixty meters.

WANDAGEE 1

The objective of Wandagee 1 was to investigate the stratigraphy and oil potential of the Devonian and older rocks on a shallow part of the Wandagee Ridge and drilled in 1962 by Oil Drilling & Exploration for WAPET. Wandagee 1 was drilled to a total depth of 1,073 meters and it was used as a water well after drilling was completed.

GASCOYNE 1

Gascoyne 1, located towards the southern end of the Merlinleigh Sub-basin, was spudded in October, 1983 and reached a maximum depth of 527 meters that penetrated into the Early Permian portions of the Lyons Group. Due to the absence of hydrocarbons, the well was plugged and abandoned as a dry hole and left as a potential water well.

The Moogooloo Sandstone was a primary objective along a faulted anticline. According to the well completion report, the structure was to be drilled up is on the downthrown side of the fault and the up-thrown side of a smaller down-to-the-west antithetic fault. A small proportion of the resultant structural closure is independent of faulting, but the majority was fault dependent. However, no hydrocarbon shows were detected anywhere in the sections penetrated. The well was designed to test hydrocarbon bearing potential was classified as a Wildcat before drilling. It is believed that failure of this fault to seal the Moogooloo Sandstone from the downthrown block to the west was the primary reason for lack hydrocarbons. However, gravity and magnetic surveys show that the well was drilled off structure to west by about 10 meters (Figure 5.4)

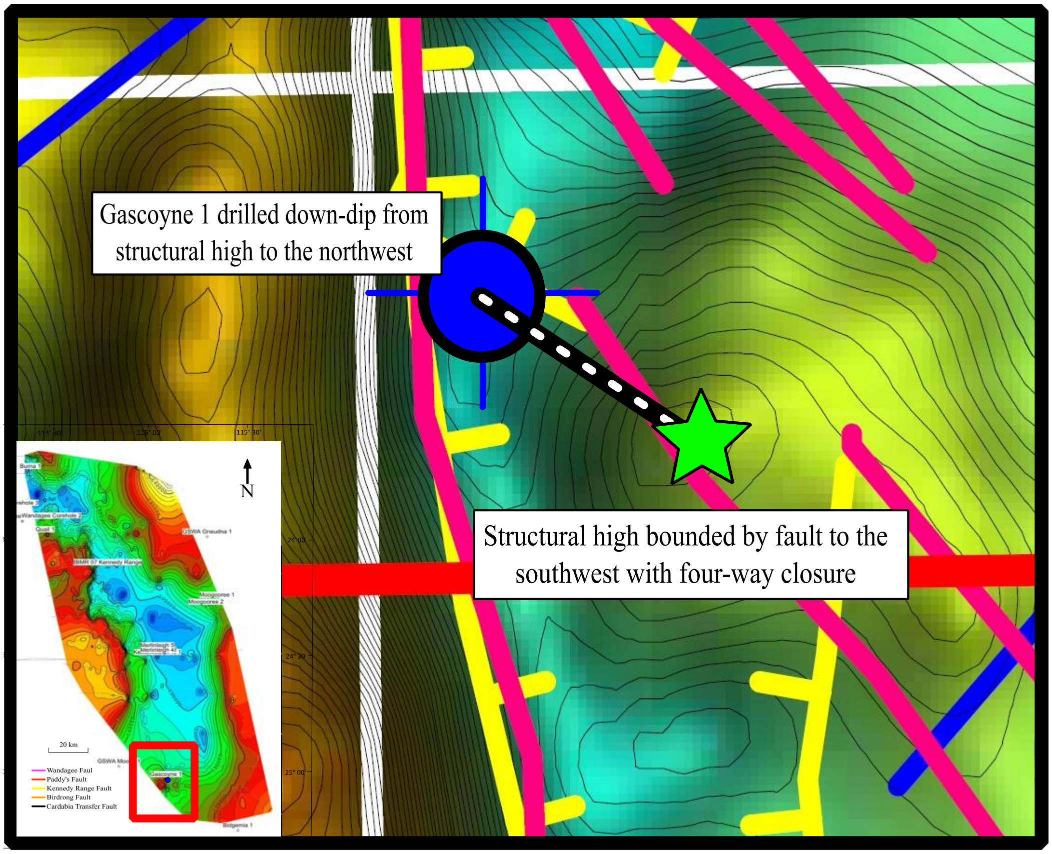


Figure 5.4 Gravity survey map highlighting Gascoyne 1 (blue circle) appears to have been drilled downdip to the northwest from the structural high (green star) identified to the southeast. The pink linaments represent intrasedimentary faults while the yellow lineaments represent normal faults from the gravity survey.

GNUEDNA 1

Gnuedna 1 was drilled as a stratigraphic test to investigate the source rock potential of the Gnuedna Formation in the Merlinleigh Sub-basin. The well was drilled by Mt. Magnet Drilling in 1995 for the Geological Survey of Western Australia. A total depth of 492.1 meters that terminated in the Precambrian granite basement rock.

5.3. SOURCE AND MATURATION

Source rocks are sedimentary rocks, usually shales or limestones, in which organic matter was transformed to liquid or gaseous hydrocarbons under the influence of pressure heat, and time. Source rock parameters are (1) the amount organic matter, (2) type of organic matter, and (3) maturity of the organic matter. An active source rock can be defined as a rock containing a sufficient amount of organic matter of a proper type and of sufficient maturity. A potential source rock is an immature source rock.

Generation of hydrocarbons from source beds is related to temperature and, to a lesser extent, to pressure and geologic time (Zimmerle, 1995). Generation and primary migration occur when the source rocks attain an optimum temperature range. The term ‘oil window’ has been applied to the temperature range in which hydrocarbons are generated. Present depth of burial may be markedly less than in previous geological epochs because of erosion of large volumes of overburden since oil generation took place.

Hydrocarbon source rocks of marine origin are widespread and well-studied. However, oil has also been produced from non-marine strata, e.g. in the Uinta basin of Utah, U.S.A (Vandeen et al., 2013). Previously, it was believed that these occurrences were a result of migration from marine source rocks.

Specific environments favorable for the deposition of organic-rich sediments are:

1. Shelves of open oceans and silled seas and deltas and estuaries on shelves of open oceans and silled in the marine realm with nutrient supply and preservation as controlling factors.
2. Peat bogs and freshwater lakes

Hydrocarbons migrate from the source to the porous reservoir rock (primary migration) and then through the porous reservoir rock into a suitable hydrocarbon trap (secondary migration) where the hydrocarbons accumulate.

Three factors influence secondary migration: (1) the tendency for buoyant rise of oil and gas in water-saturated rock pores, (2) capillary pressure that determines multiphase flow, and (3) the hydrodynamics of pore-fluid flow (Tissot and Welte, 1984).

The direction of hydrocarbon movement is determined largely by local or regional pressure gradients; upward, lateral, downward migrations are all possible depending on local conditions. Hydrocarbon migration will continue as long as driving forces are active.

The Paleozoic of both the onshore and offshore Carnarvon Basin contains, or may be expected to contain, significant source rocks at a number of stratigraphic horizons. Iasky et al. (1999) suggests the horizons seem to be more widespread stratigraphically in other basins than the Carnarvon Basin. This again, could be an artifact of sparse well testing in the area. There are several numbers of potential reservoirs within the study area that include the Silurian Dirk Hartog Formation and the shaly intervals of the Devonian Gnuedna and the Permian Wooramel Formations. All show considerable local variations in richness and type and their detailed occurrence is not predictable on the currently available data.

In the Southern Carnarvon Basin, shows within the Silurian sequence match geochemically with surface occurrences, which indicate viable source rocks are present. However, the extent of such source rock is still unknown.

Devonian aged source rocks such as the Nannyarra Sandstone and Gneudna Formation (Figure 5.) may have some source potential (Dolan, 1991). In the lower shale-prone portions from the Gneudna Formation (Figure 5.) at Quobba 1, the samples had TOC content in excess of 0.5%, with the best yield-potential reaching 3.62 mg/g. The upper carbonate samples, however, failed to reveal any source rock potential (Blake et al., 1984). This trend is also seen in Quail 1 (Crostella, 1995). Mitchell (1992) identified an anomaly at Pendock 1, where the Gneudna Formation’s carbonate sequence had oil shows and is believed to have come from a clastic source. This suggests that the Gneudna Formation source potential depends on the presence of terrigenous material, with a high content of organic matter. The deposition of terrigenous material is in turn related not only to the basinal position of the sedimentary rocks, but also the local presence of paleolows.

Permian source rocks are believed to have the greatest potential for producing hydrocarbons. These source rocks are both gas type II) and oil and gas (type III) prone (Figure 5.). Of the Permian, the Wooramel Group (Figure 5.6) is rated as good, especially in the northern parts on the Merlinleigh Sub-basin. The organic richness is very good and the hydrocarbon-generating potential is fair to good (Crostella, 1995). However, at Kennedy Range 1 and Gascoyne 1, the source-rock potential of the Wooramel Group is rated low. This may be related to the depositional environment of the lithostratigraphic unit (Hocking et al., 1987) at Quail 1 and igneous intrusions at Kennedy Range 1 (Gunn, 2003).

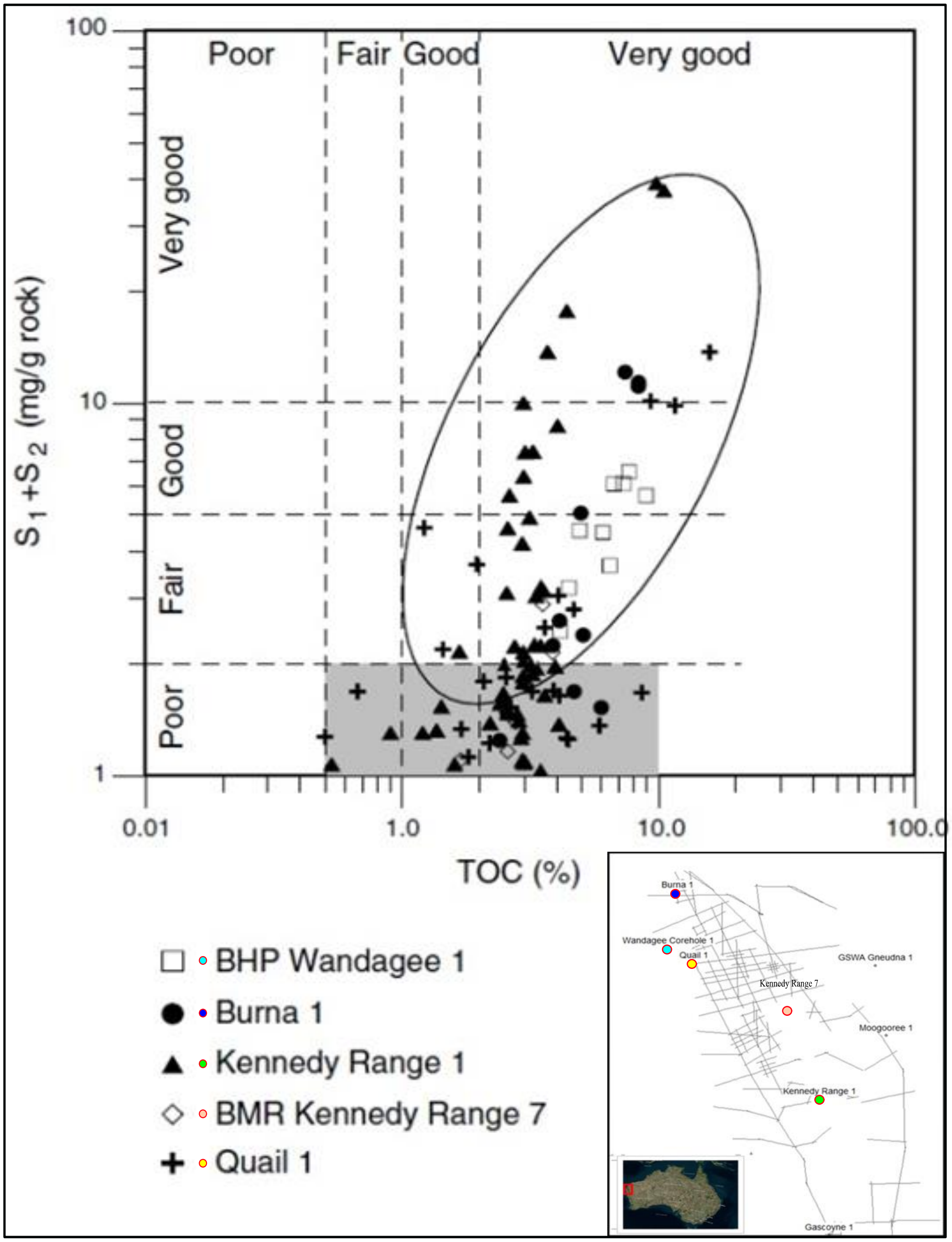


Figure 5.5 Hydrocarbon-generating potential of the Permian Wooramel source rocks from the Merlinleigh Sub-basin (from Iasky et al., 1998)

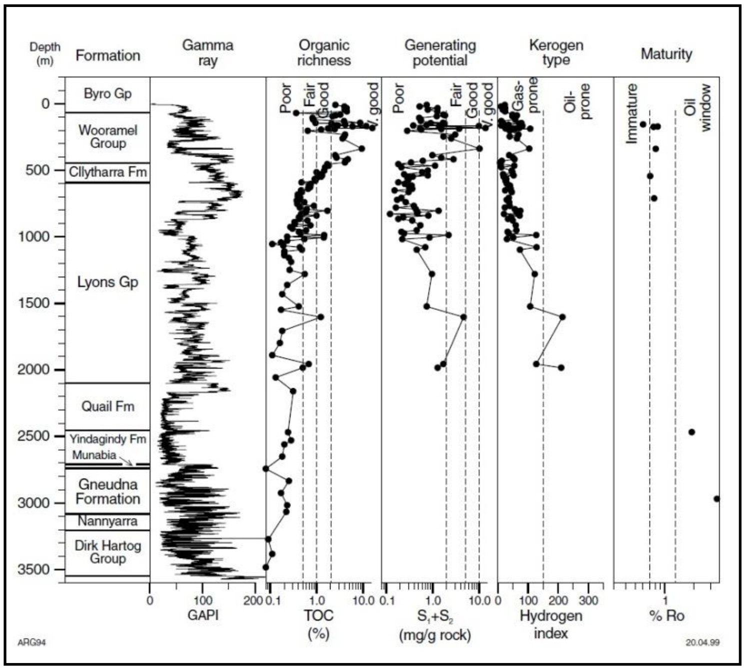


Figure 5.6 Source rock analysis geochemical log from Quail 1 showing potential in the Permian aged Wooramel Group

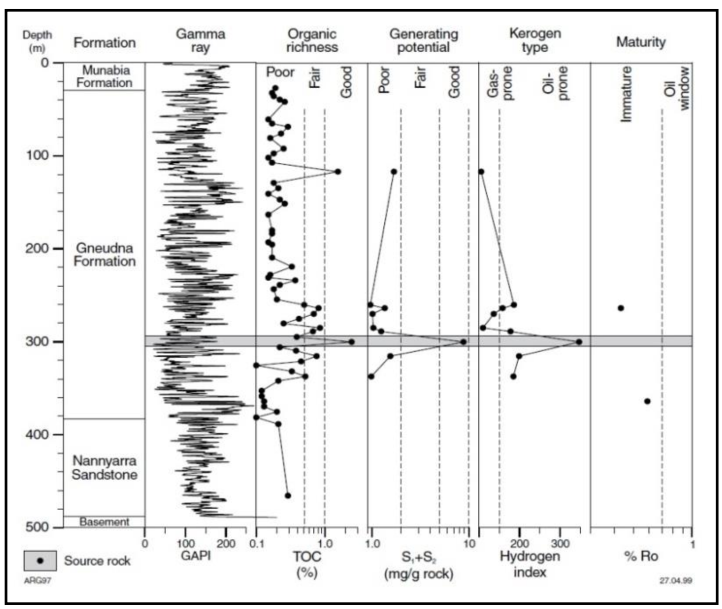


Figure 5.7 Source rock analysis geochemical log at Gneudna 1 showing potential in the Devonian aged Gnuedna Formation

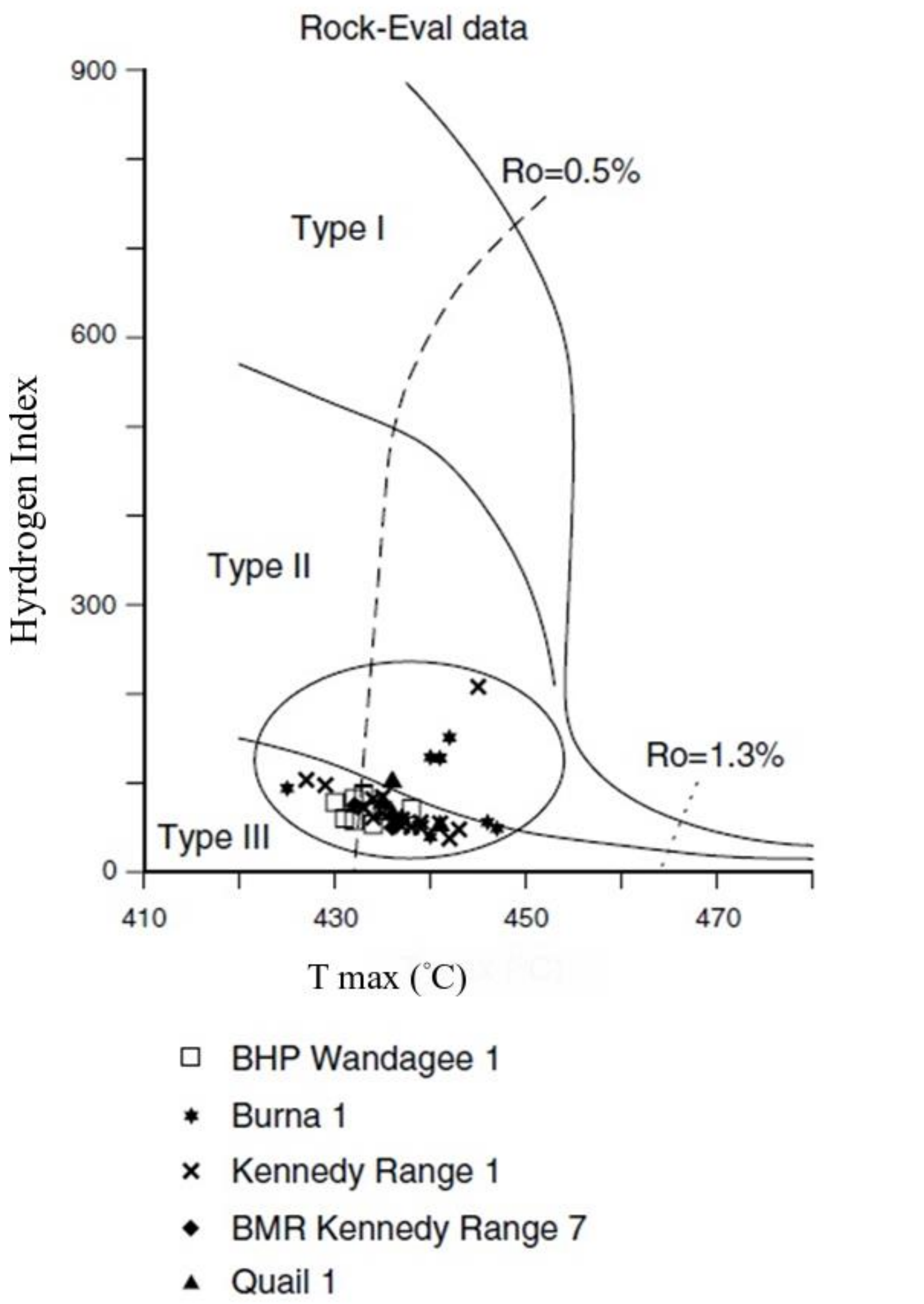


Figure 5.8 Kerogen type of Lower Permian source rock from the Merlinleigh Sub-basin from Rock Eval pyrolysis (from Iasky et al., 1998)

The maturity of the relevant formation must be taken into consideration in assessing the present source-rock potential (Figure 5. and Figure 5.). Maturation is a function of the temperature reached, which in turn, depends on the heat flow in the region. According to Percival and Clooney (1985), overmaturity of the Devonian source-rock at Quail 1 was related to rifting during the Late Carboniferous that subjected this section to high heat flows. Temperature gradients along the western margins of the rift in the Merlinleigh Sub-basin range from 35 to 40°C per kilometer (Moors, 1980). Due to Quail 1 being located in such close proximity to the rift, maturity data from this well cannot be extrapolated across the basin.

The Permian Wooramel Group sections near Burna 1 in the northern portion and at Gascoyne 1 in southern portion of the Sub-basin are in the early mature zone of the oil window. Both of the wells are east of the Wandagee Fault Zone, whereas at Wandagee 1, west of the fault, the Wooramel Group is still immature. Wooramel source rocks at Kennedy Range 1 appear to be over mature for oil generation by a sharp increase in paleotemperature. The higher paleotemperatures are thought to be cause by intrusions and should not be considered to be representative of the entire basin.

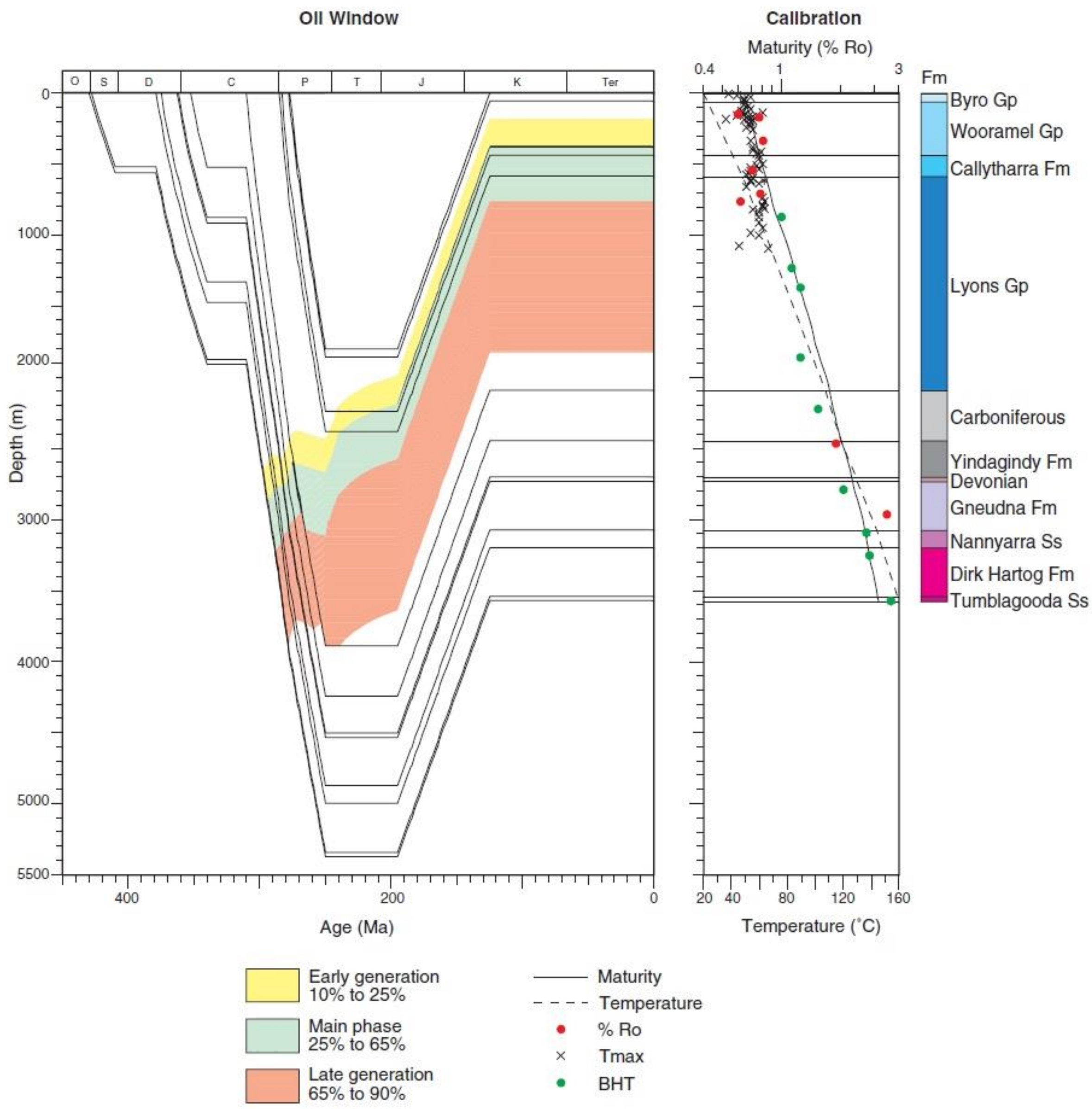


Figure 5.9 Burial history and maturity calibration for well Quail 1 (from Iasky et al., 1998)

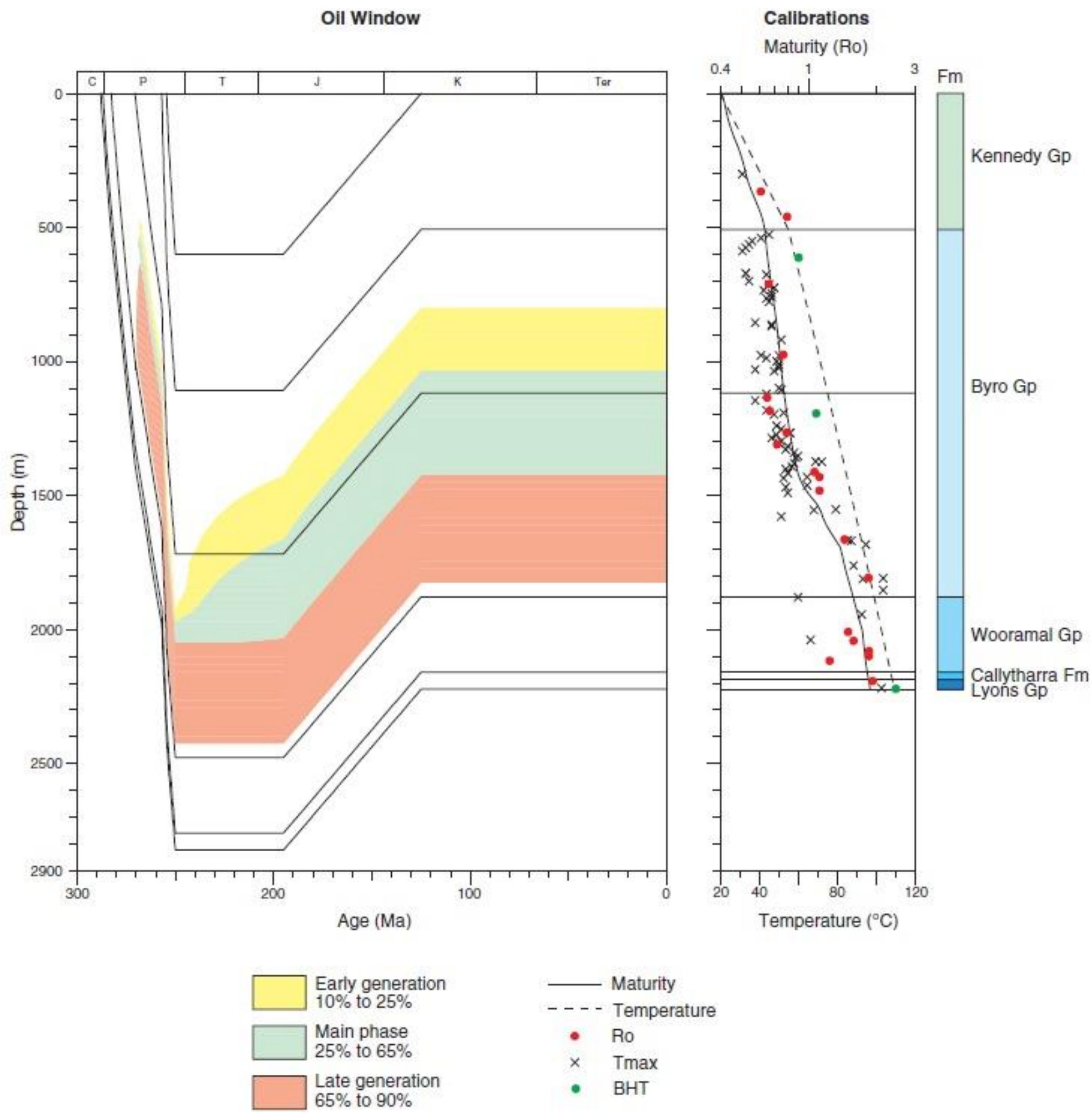


Figure 5.10 Burial history and maturity calibration from for well Kennedy Range 1 (from Iasky et al., 1998)

5.4. RESERVOIRS

Hydrocarbon reservoirs are rocks that have sufficient porosity and permeability to permit the accumulation of oil or gas under adequate trapping conditions. In most instances, the rock is a sediment, generally sandstone or a carbonate rock; exceptionally, shales, pyroclastics, tuffs, or fractured igneous rocks serve as reservoir rocks.

Porosity of a rock is the ratio of its total pore space to its total volume, expressed as the given equation:

$$porosity = \frac{volume\ of\ total\ pore\ space}{volume\ of\ rock\ sample} \times 100$$

Porosities in sedimentary rocks commonly range between 5-25%. Porosities of > 25% are regarded as excellent, 15-25% as good, 5-15% as fair, and <5% as low. It is important to note that total porosity of a rock is not the same as effective porosity (the amount of interconnected pore space present in a rock). The effective porosity gives a rock the property of permeability. Permeability is the capacity of a porous rock for transmitting gas or fluids and is a measure of the relative ease of flow under unequal pressure.

Permeability is determined conventionally based on Darcy's law using the equation:

$$Q = \frac{K \Delta A}{\mu \cdot L}$$

where, Q = rate of flow in cm^3/s, Δ = pressure gradient in Pa, A = cross-sectional area in cm^2, μ = fluid viscosity in Pa.s, L = length in cm, and K = permeability.

The conventional units of measurements are darcy (D) or millidarcy (mD). One darcy is equivalent to the passage of one cubic centimeter of fluid of one centipoise viscosity flowing in once second under a pressure differential of one atmosphere through a porous medium have a cross-sectional area of 1 cm^2 and a length of 1cm.

Reservoir potential was based primarily on released core porosity and permeability data. Wireline porosity logs and other available data were also utilized where present. Sandstones present in the Devonian of the Carnarvon Basin are noted as having moderate porosities and Permian sandstones of having highly porous sections down to depths of 1,500 meters. The other main porous horizons are the Devonian and Ordovician carbonates. Potential reservoirs include the Silurian Tumblagooda Sandstone, the Devonian Nannyarra Sandstone, the Munabia Sandstone, and the Permian Moogooloo Sandstone of the Wooramel

Group. Permian sandstones within the Lyons, Byro and Kennedy Groups may be considered secondary reservoirs (Baker et al., 2000).

The Silurian Tumblagooda Sandstone has good porosity preserved at depth. The characteristic hematite-clay staining of the sandstone has inhibited quarts overgrowths and allowed primary porosity to be preserved. Lack of porosity at depth in the Carnarvon Basin may be related to the sparse drilling of deep wells in the study area rather than absence of reservoirs.

The base of the Wooramel Group is marked by generally fine-grained and calcareous clastics of the Cordalia Sandstone (Figure 5.121). Cleaner, medium to coarse-grained quartzarenite and quartzwacke characterize the overlying Moogooloo Sandstone unit. The top portion of the group is marked by silty clays and sandstones to coarse sandstones and conglomerates. The Moogooloo portion indicates fairly good reservoir characteristics at shallow depths to around 610 meters with porosities of 15-22% and permeabilities commonly up to around 200-500mD. Kennedy Range 1 gives porosity readings between 10-18%. The loss of porosity and permeability is thought to deteriorate with depth due to pressure solution and quartz overgrowth.

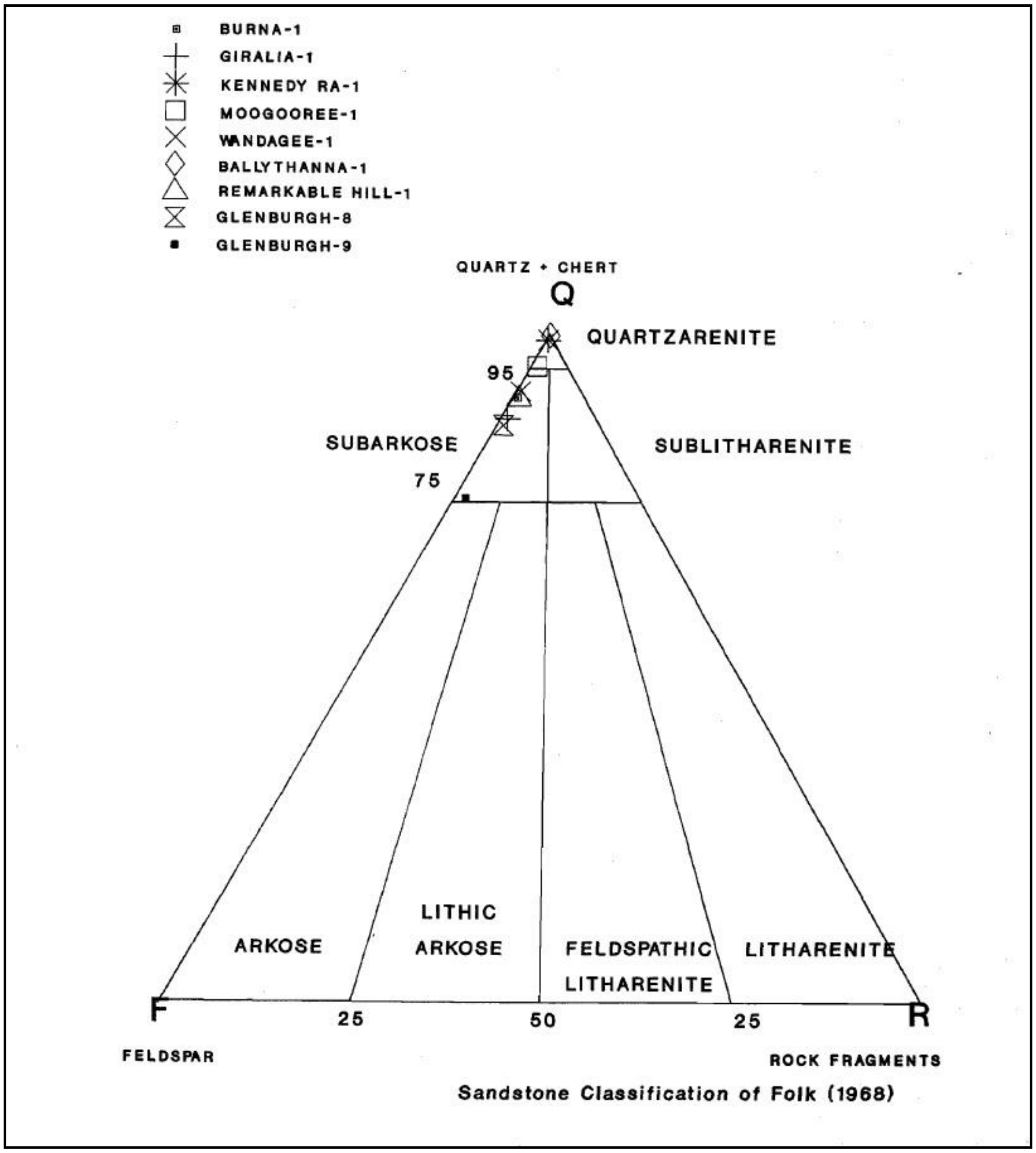


Figure 5.12 Sandstone classification scheme of the Cordalia Sandstone from multiple well locations

5.5. TRAPS

Traps that formed during Late Carboniferous – Early Permian tectonism are more likely to be charged with oil from Devonian and Permian source rocks that underwent maximum oil expulsion during the Late Permian – Early Triassic. Traps formed during breakup and Miocene tectonism, however, may be charged from sources maturing in marginal areas if there were sufficient increases in heat flow. Numerous anticlinal features have been identified (Pearson, 1964; Moory et al., 1993; Iasky, 1998; Gunn, 2003; Hocking, 1987,1999) from seismic, gravity/magnetic, and outcrop data. An example is seen at Burna 1 in Figure 5.12 using seismic sections K83A-273 and K83A-270 and the use of gravity surveys. The extent of their depths, however, remains unclear. It appears that the Quail Anticline that plunges gently to the north in which Quail 1 was drilled downdip from the highest portion of the structure. The southern limit of the structure is poorly defined, and additional control is needed to define an optimal location (Moory et al., 1993).

Structural, fault-dependent traps and should be focused on the eastern and western portions of the sub-basin. Along the eastern margin, the Devonian aged source rocks are presently in the oil generation window. Farther west, such traps may be prospective for gas exploration.

In the carbonate sections of the Gneudna Formation, if lenticular, the possibility of stratigraphic traps, charged from intraformational shales, could be one possibility. The underlying Nannyarra Sandstone may also possess potential in fault traps; it is more likely to be of economic interest away from the eastern margin of the sub-basin, where the Devonian source rocks are within the oil-maturation window. Possible truncation traps may be present below the Lyons Group if basal shales seal the unconformably underlying Lower Carboniferous sandstone charged from Devonian or older source rocks.

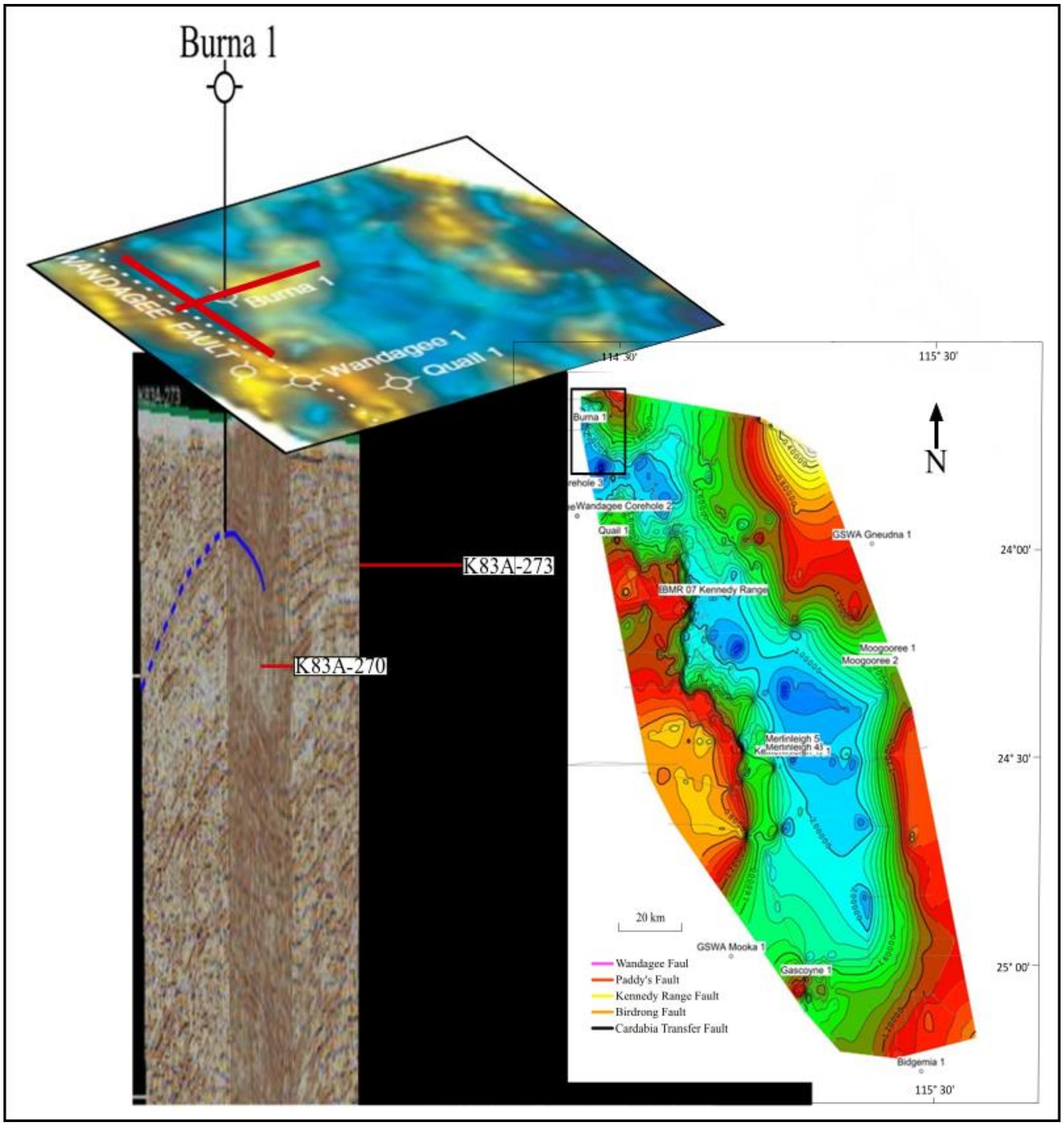


Figure 5.32 Pseudo-3D view of an anticline structural trap that was located near Burna 1 using a gravity survey and seismic lines K83A-270 and K83A-273

5.6. SEALS

Seals, often referred to as Cap Rocks, are the layer of impervious strata that overlays any oil- or gas-bearing reservoir rock. The seal prevents further upward migration of the oil and gas. Comparatively, impervious sedimentary rocks can be of different lithology; they occur in most stratigraphic sections.

Shales are the most common cap rocks. The majority of sandstone and limestone reservoirs are capped by shales. Even moderately compacted shales are normally impermeable to gas and oil. It is necessary to reach the displacement pressure to force the droplets of oil or gas through the pores of the shales. Other seals include dense limestone and tight sandstones. Sandstones may be impervious due to mineral cementation and/or because of the presence of a fine clay or silt matrix.

Seals in the area include intraformational shales of the Gnuedna and Lyons Group, the Moogooree Limestone, the Coyrie Formation of the Kennedy Group.

5.7. PLAYS

In the Southern Carnarvon Basin, structural, stratigraphic, and combined traps have been identified. However, most of these traps remain poorly tested or untested. These conventional plays are seen in Figure 5.43 and are recognized with in the Gascoyne Platform and Merlinleigh Sub-basin:

Tertiary Anticline Play: Late tertiary inversion has resulted in the development of some very large anticlinal structures, which have the potential for four-way dip closures. These large structures could form very large traps for re-migrated oil that was spilled during the inversion event. The primary reservoir target is the base Cretaceous Birdrong Sandstone, which would be sealed by the Cretaceous Muderong Shale. Secondary reservoir potential exists within the Devonian carbonates.

Devonian Topography Play: Karstic reservoirs in the Devonian carbonates are likely to be the best developed over the crest of the topographic highs where they may be directly overlain by the Muderong Shale.

Devonian Reef Play: There is some evidence to suggest that carbonate build-ups may be present in the Carnarvon Basin. If present, then these features may be preferentially located over structural features such as Silurian horst block or in the footwall crests of faults that were active during the Devonian.

Silurian Fault-Block Play: The Silurian sequence in the Carnarvon Basin is thought to have source potential and is known to contain effective seals. If suitable reservoirs are present then could be numerous fault block structures within the Silurian section, which might form the basis of an early Paleozoic play in the basin.

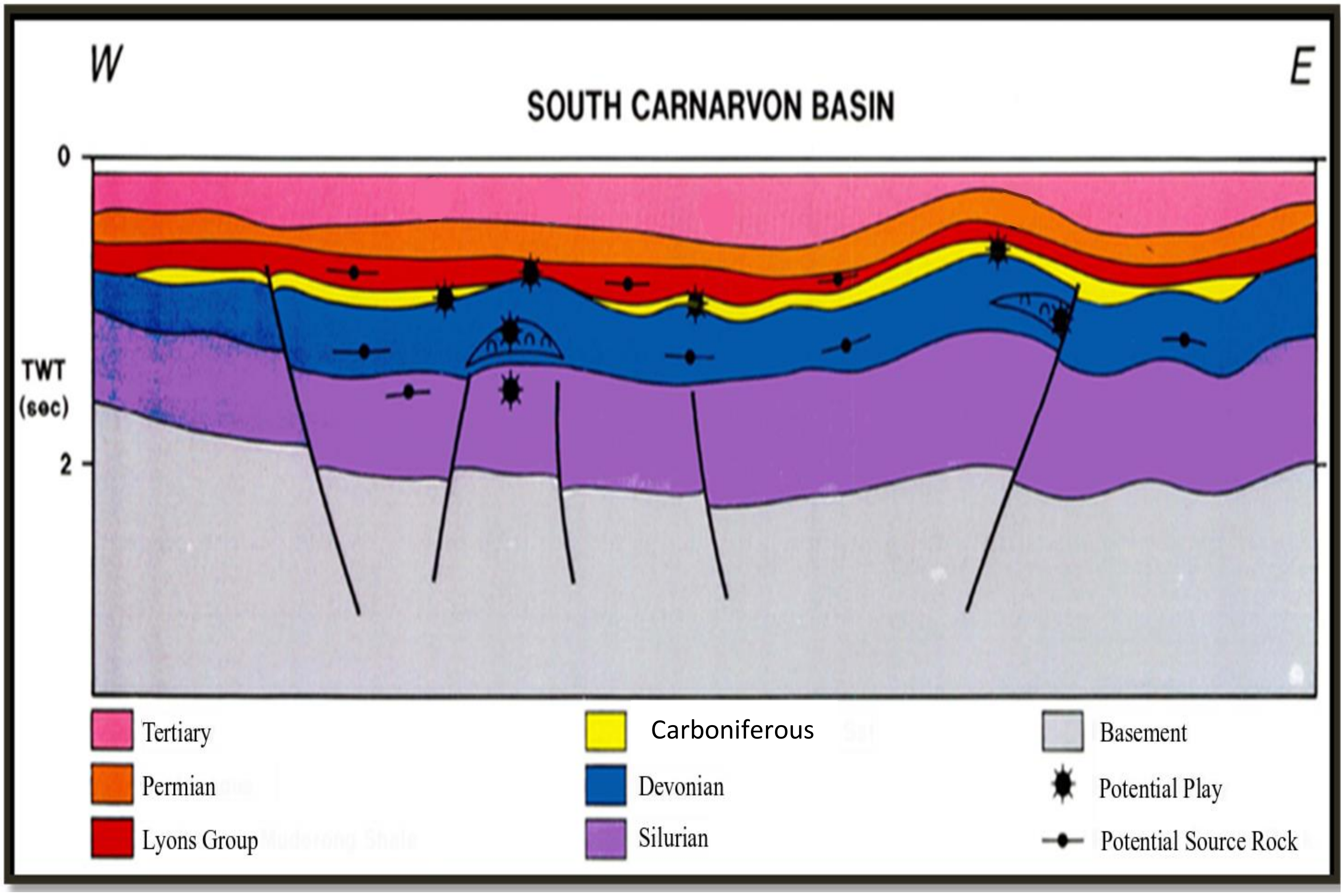


Figure 5.43 Likely plays to found within the Southern Carnarvon Basin (modified from Dolan and Associates, 1991)

5.8. PROSPECTS AND LEADS

5.8.1. PREVIOUS INVESTIGATIONS

In a previous report, Gunn (2003) identified several prospective areas using only gravity and magnetic data. To test these structures identified, a number of seismic sections were interpreted to help identify, seismically, the extent of the features and further the understanding of the basin. The two areas included the northern portion of the Merlinleigh Sub-basin (Figure 5.54) and the area east of the Kennedy Range Anticline (Figure 5.65).

The gravity data indicates an oval shaped gravity high approximately, 8km in length and 3.5 km wide located about 5 km west of the location of Quail 1. Seismic line K82A-105 (Figure 5.76) intersects the anomaly suggesting that it could be due to a tilted fault block present with significant back-dip and has the potential for fault closure. It also indicates that the well was drilled off-center and down-dip from the apex of the anticline feature.

Seismic line K82A-127B crosses the southernmost and smallest of the residual gravity high denoting K3 (Figure 5.65). The line was previously classified as of poor quality and their mappings were too broad to detail any structure over the anomaly, however, Figure 5.87 shows associated structures from the magnetic and gravity surveys. Using a 3D viewer, it was also possible to delineate, what seems to be, an anticlinal feature on the eastern edge of the study area associated with K5 and K6 from Gunn's (2003) report by using seismic lines K82A-121, K82A-117, and K82A-102 (Figure 5.98 & Figure 5.109).

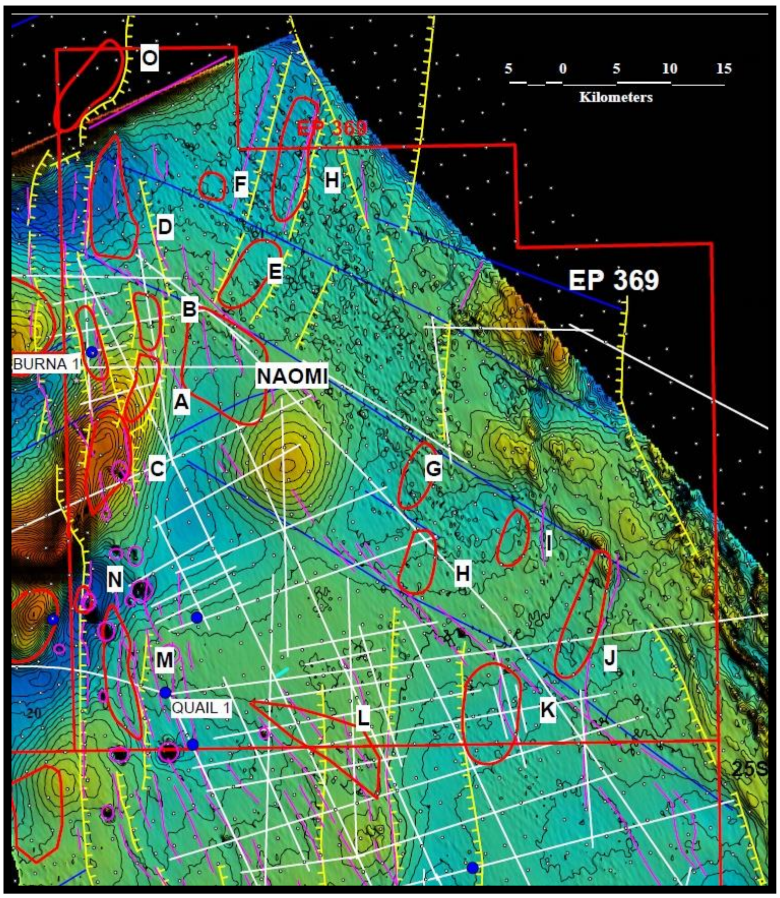


Figure 5.54 Residual magnetic intensity map from Gunn (2003) report outlining prospective leads in the northern portion of the Merlinleigh Sub-basin outlined in red with seismic lines in white

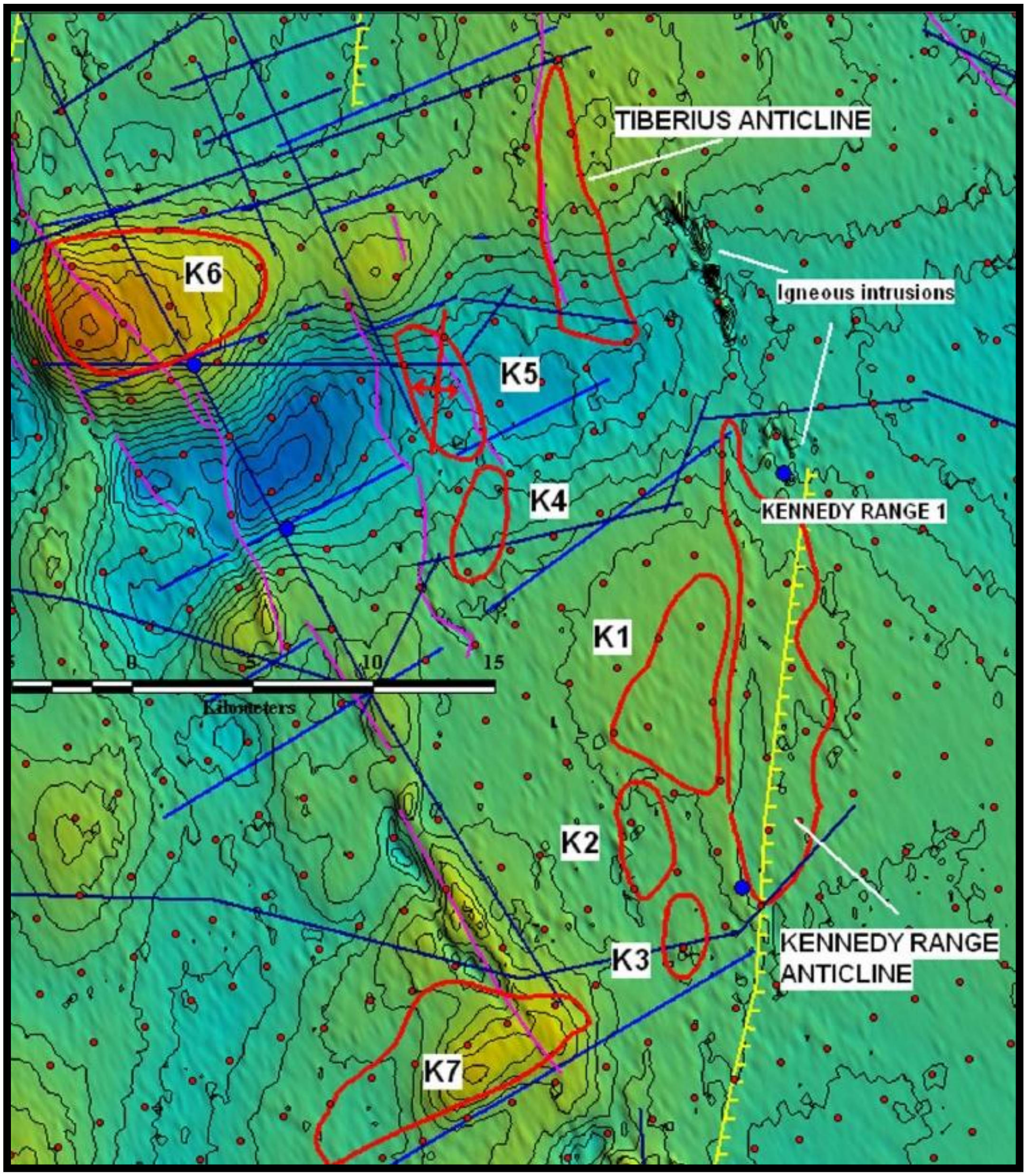


Figure 5.65 Resdiual magnetic intensity map from the Gunn (2003) report outlining prospective leads to the east of the Kennedy Range Anticline in red with seismic lines in blue

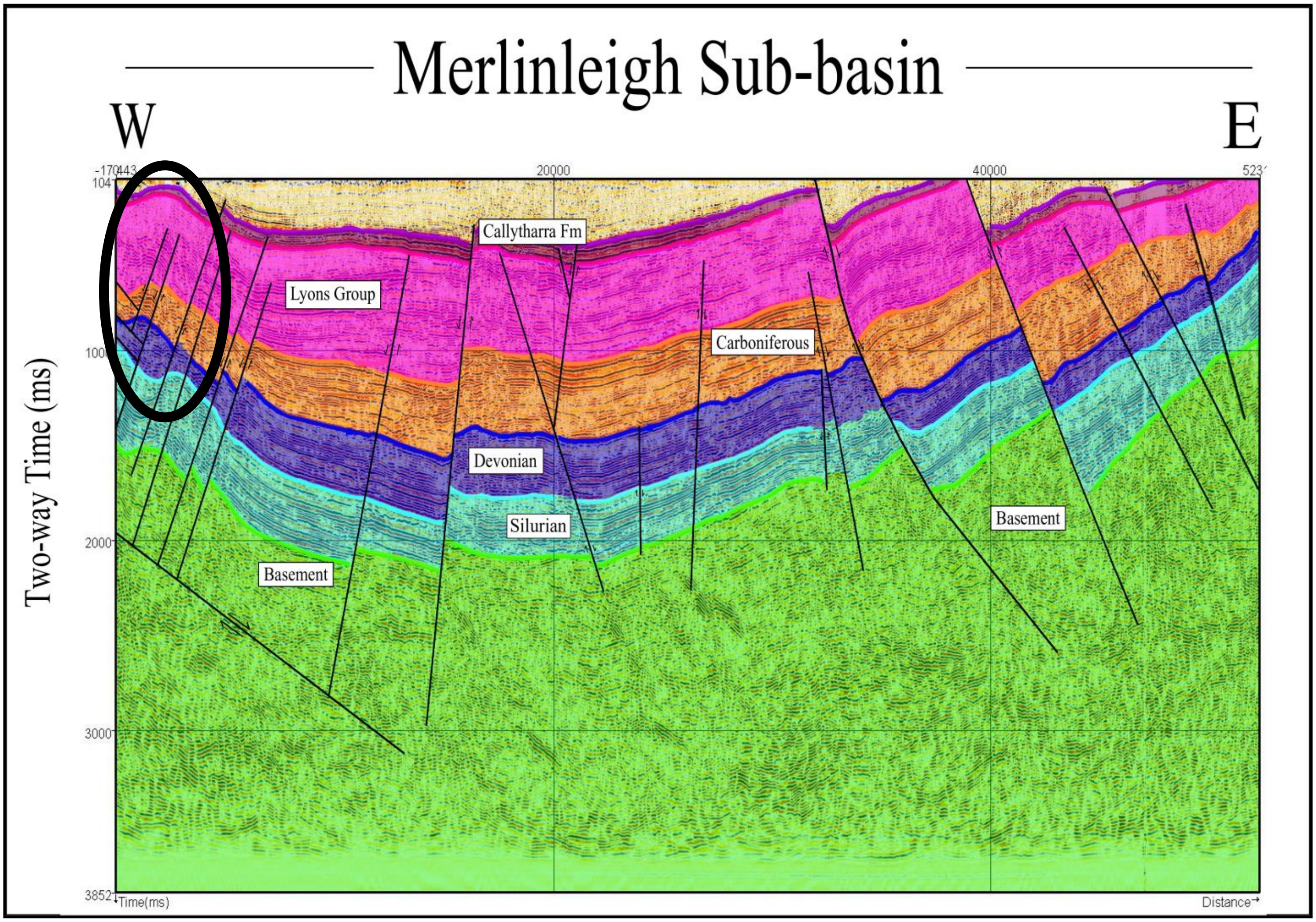


Figure 5.76 Seismic Line K82A-105 crossed the magnetic anomaly associated with the Quail Anticline on the western side of the Merlinleigh Sub-basin oulined by the black circle

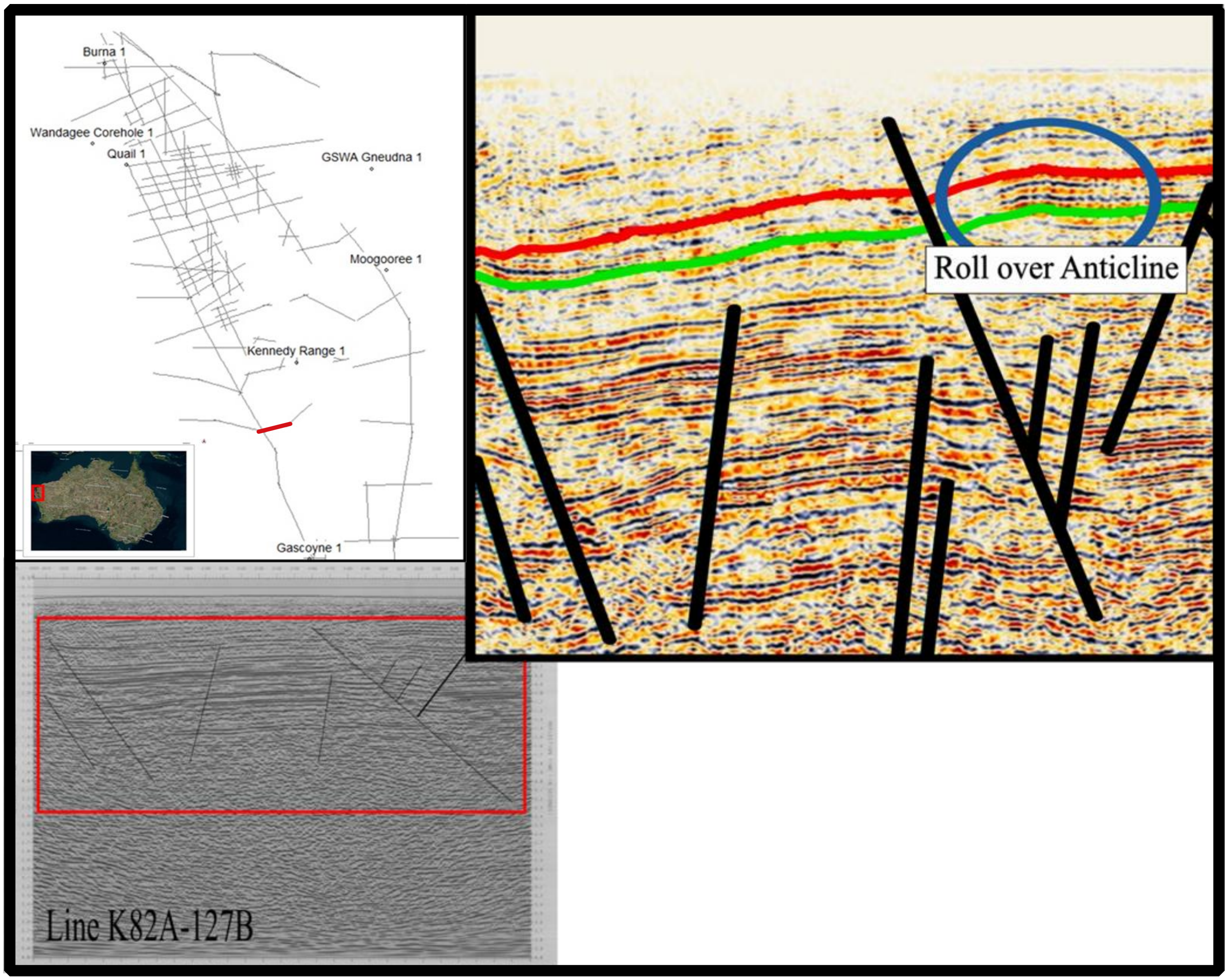


Figure 5.87 Seismic Line K82A-127B, red line on basemap, displaying arbitrary lines forming a roll over anticlinal feature on the down thrown side of the mapped fault

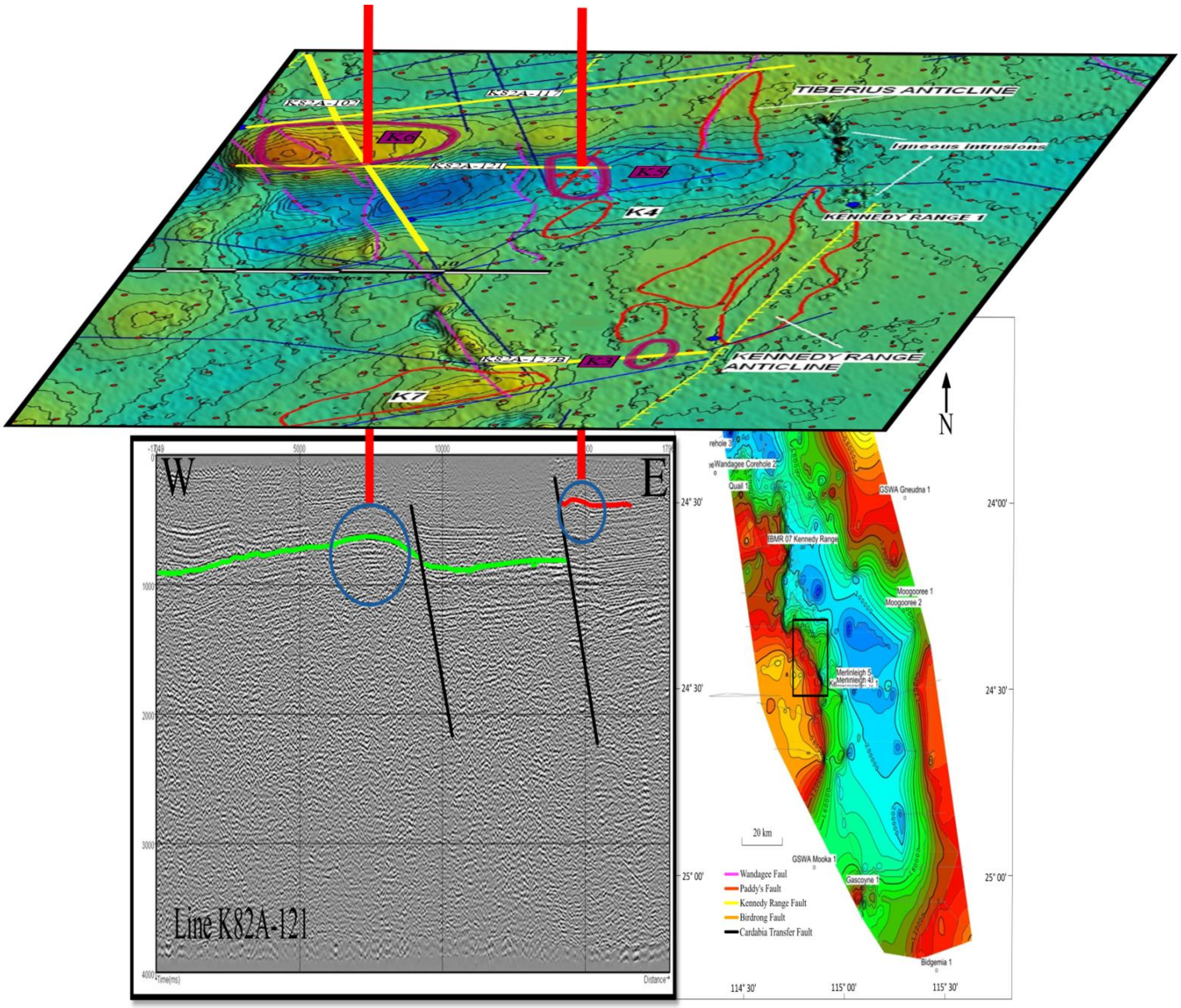


Figure 5.98 Seismic Line K82A-121 displaying magnetic anomalies associated with K6 (west) and K5 (east) structures identified by Gunn (2003)

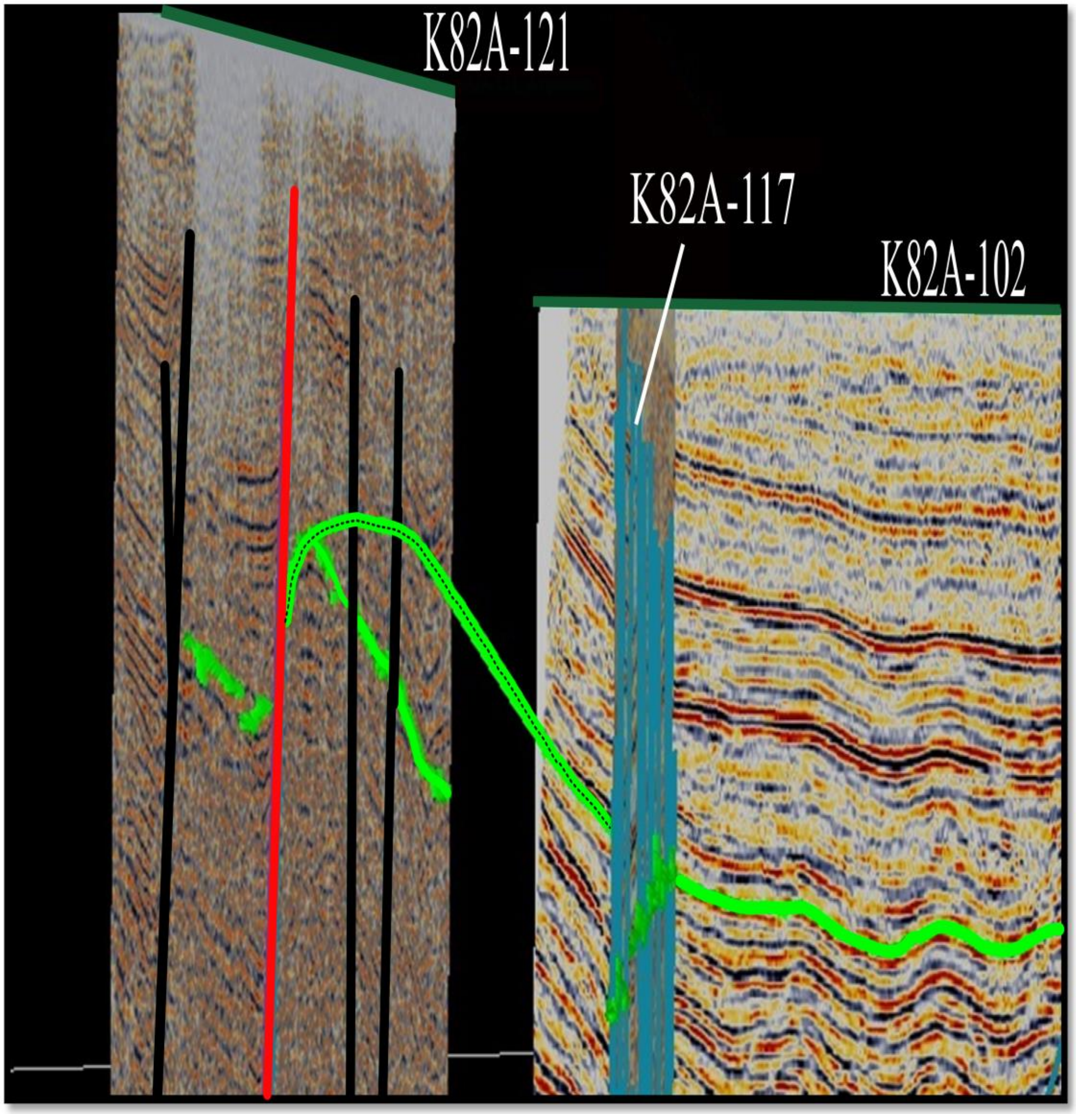


Figure 5.109 Anticlinal feature associated with Gunn's (2003) K6 using seismic lines K82A-121, K82A-102 and K82A-117 bounded by fault (red). The dotted black line represents correlation interpretation

5.8.2. PROSPECTS

Within the study area the potential for oil and gas generation and accumulations is offered by Devonian and Permian aged rocks that have reached peak maturity in the Early to Late Permian – Early Triassic respectively. Both have good potential for gas generation, which is still being generated, especially in the deeper, central portions of the Merlinleigh Sub-basin.

Ghoris (1996) showed that the best source rocks in the Merlinleigh Sub-basin are within the Permian Wooramel Group and the Devonian Gnuedna Formation. There have been small gas shows at the top of the Moogooloo Sandstone (Wooramel Group) at Kennedy Range 1, fluorescing oil-inclusions from the Moogooloo Sandstone, sandstone samples containing small inclusions of oil from wells in the Merlinleigh Sub-basin (Eadington, 1997), interpreted hydrocarbon plumes from soil samples (Furgo Douglas Geochemistry Pty Ltd, 1991), and a sample of oil recovered from the Gneudna Formation at Pendock 1, 160 kilometers west of the study area. The Devonian succession represents an objective for oil along the eastern edge where the strata is not deeply buried and along the western flanks of the up-dip areas from the relay ramps within the study area. The Permian successions are prime objectives for exploration due to it currently being in the oil-generative window over great portions of the study area. Anticline and fault traps are likely to provide the main trapping mechanism (Iasky et al., 1998). Devonian carbonate and truncation plays below the unconformity at the base of the Lyons Group could be considered secondary objectives (Figure 5.146 and Figure 5.157).

Upon further examination of the seismic lines (Figure 5.2020), there were some direct hydrocarbon indicators on both the eastern and western edges of the study area. Seismic Line K82A-113 (Figure 5.21) showed two potential plays. Displayed on the western side of the Merlinleigh Sub-basin, distinct flat spots (Figure 5.113, 5.24, 5.25) with apparent closure bounded by faults on either side was identified. Figure 5.122 might be associated with another carbonate mound and possible pinchouts onlapping the mound.

Seismic line K82A-102 (Figure 5.26) intersects line K82A-113 perpendicularly. There were five potential plays identified that included stratigraphic and structural trapping mechanisms. Figure 2.7 highlights potential channel fill facies within the Devonian strata and a stratigraphic pinchout play between the Devonian horizon and the overlying Carboniferous strata. Anticline structures were seen in Figure 5.28 that displayed flatspots and were highlighted with potential hydrocarbon accumulation.

On the eastern side of the study area, the line spacings were spread further apart, but there were still some single line indications of possible hydrocarbon generation. Seismic line K83A-116A displayed bright spots and flat spots (Figure

5.2). From the figure, lead1 highlights possible accumulation within the Permian strata with the possible trapping mechanism being an anticlinal structure bounded by a fault. Lead 2 indicates the possibility of an intraformational play. Figure 5.31 displays the possibility of a stratigraphic pinchout play on the western margin of seismic line K82A-116A

Seismic line K82A-108 shows the possibility of a carbonate buildup (Figure 5.29) and a possible indication of a gas chimney updip from the carbonate mound, however, with the lack of well control, there was no way of determining the formation and further investigation should be considered.

Within the central portion of the Merlinleigh Sub-basin, seismic line K83A-211(Figure 5.33) shows potential in the anticline structure on the eastern margins of the basin (Figure 5.34). The anticlines should provide for accumulation of gas from the overmature Devonian source rock (Figure 5.35). The anticline appears to be bounded by the Birdrong Fault to the east. The seismic line correlates to the structural highs evident by each of thecorresponding horizon’s TWT structure map (Figure 5.36).

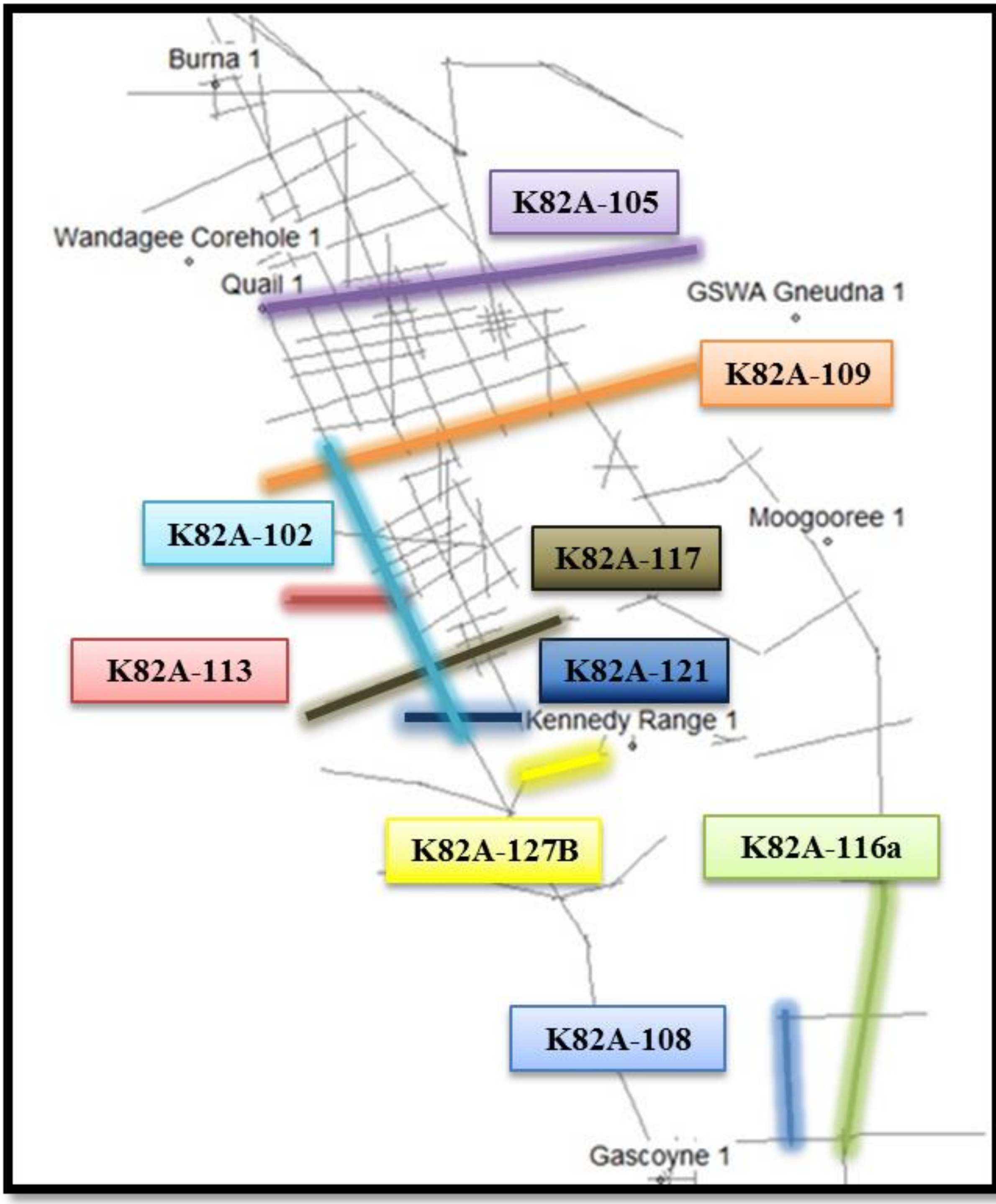


Figure 5.20 Basemap displaying seismic lines for prospects and leads within the study area

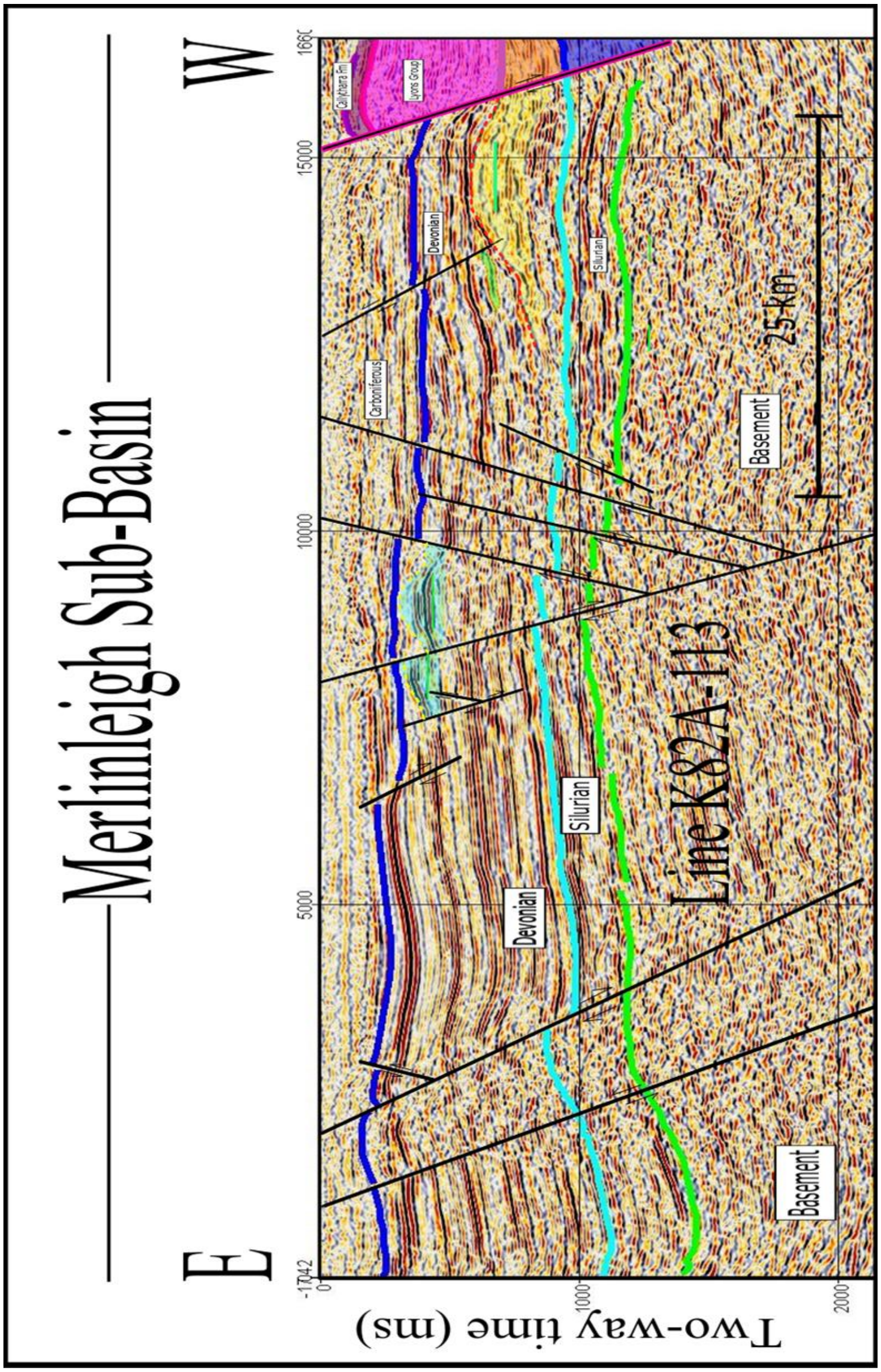


Figure 5.21 Seismic Line K82A-113 highlighting two potential plays (Blue and Yellow)

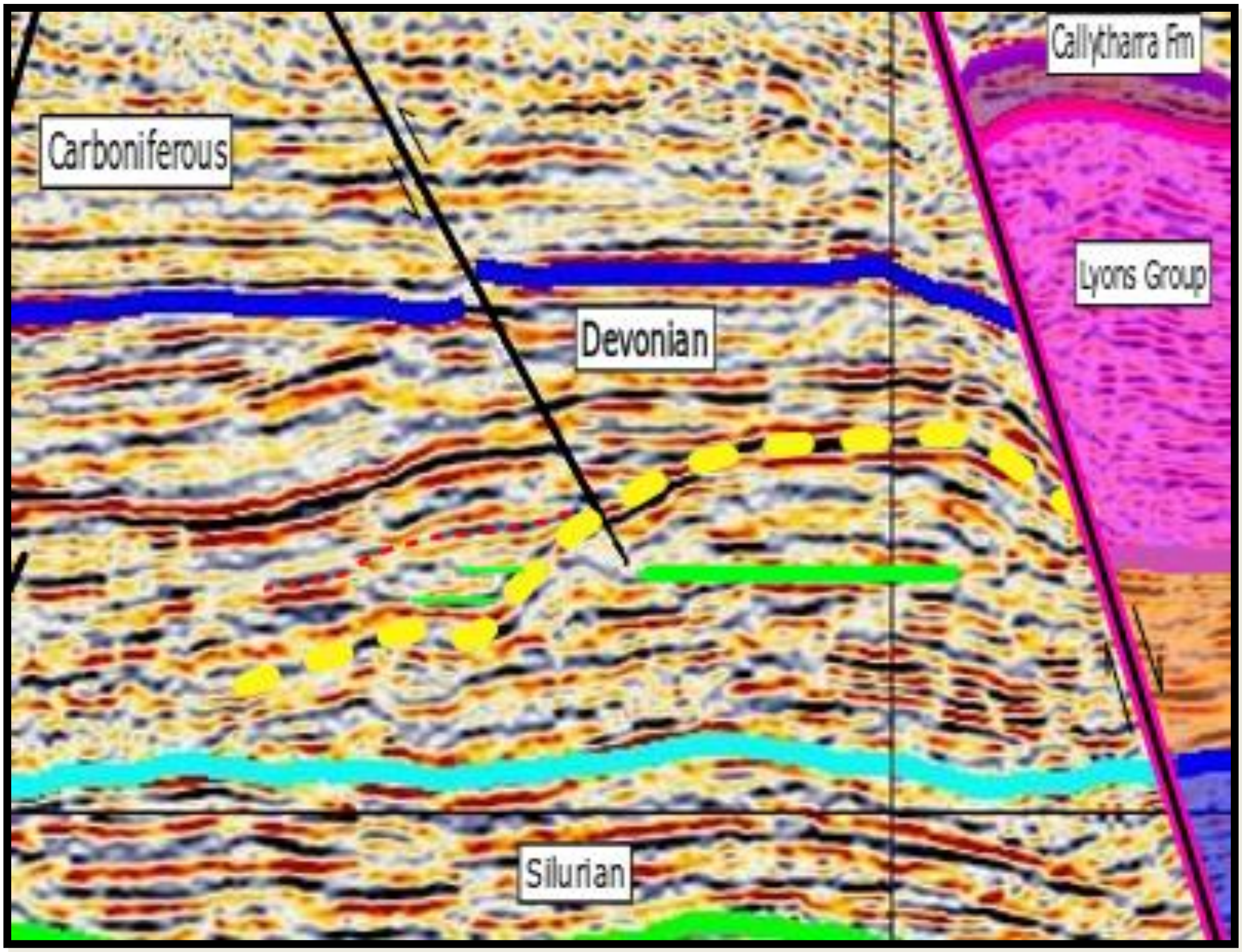


Figure 5.22 Seismic Line K82A-113 highlighting the potential carbonate mound along with pinchout plays

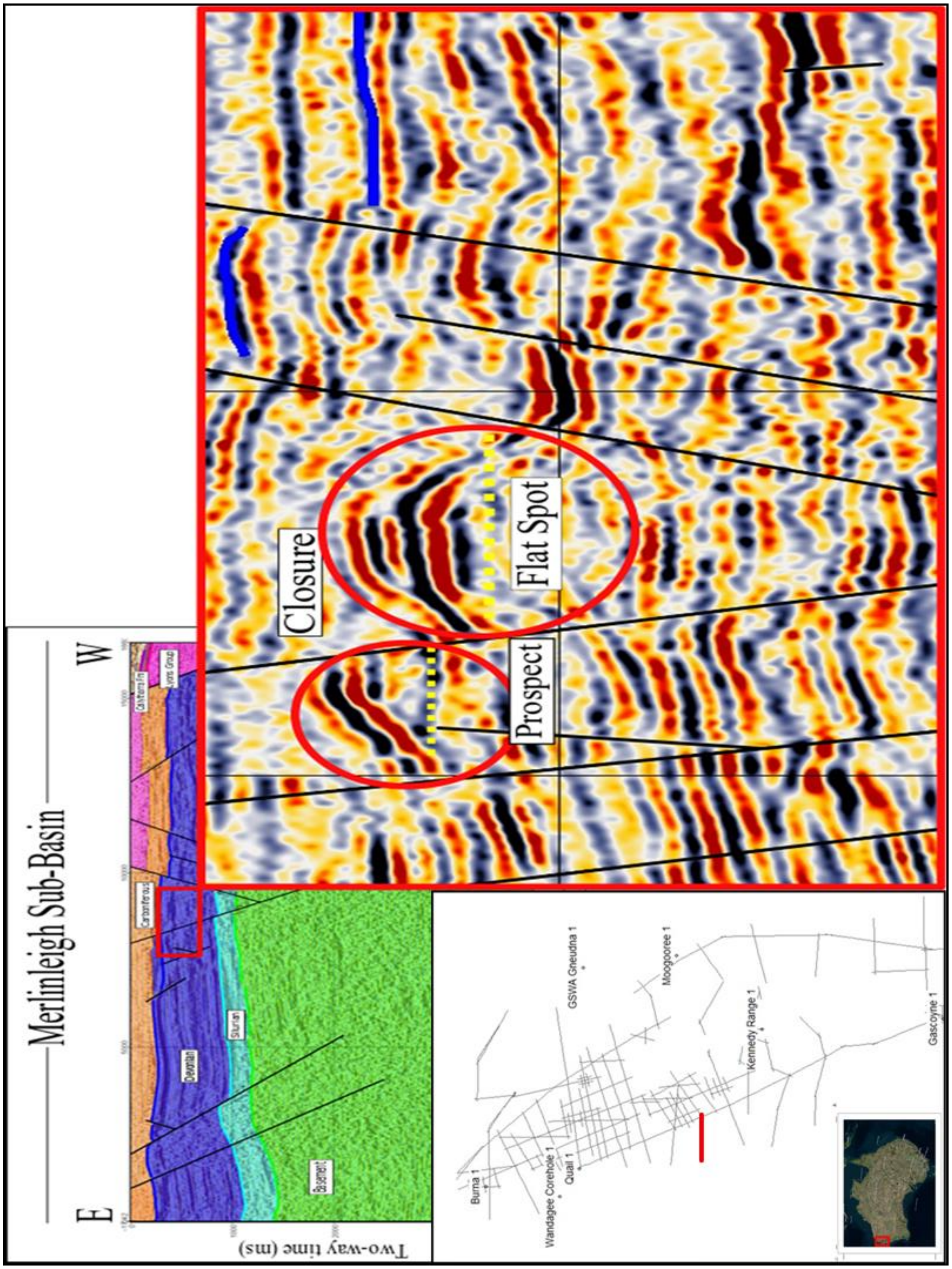


Figure 5.113 Seismic Line K82A-113 displaying direct hydrocarbon indicators with flat spots.

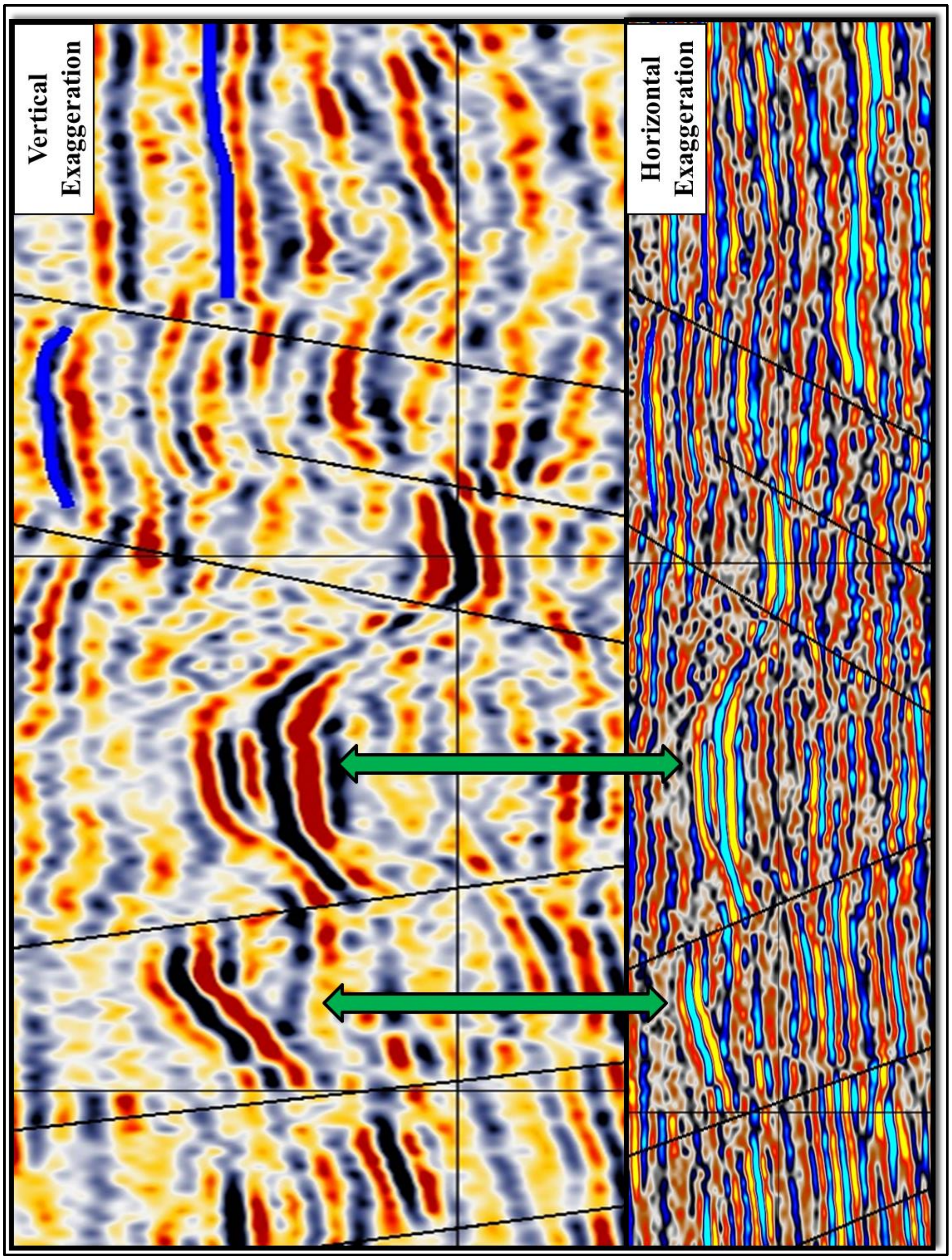


Figure 5.124 Seismic Line K82A-113 displaying veritcal and horizonata exargeration. The horizontal exargeration had the OpendTect Magic attribute applied, which displayed DHI bright spots.

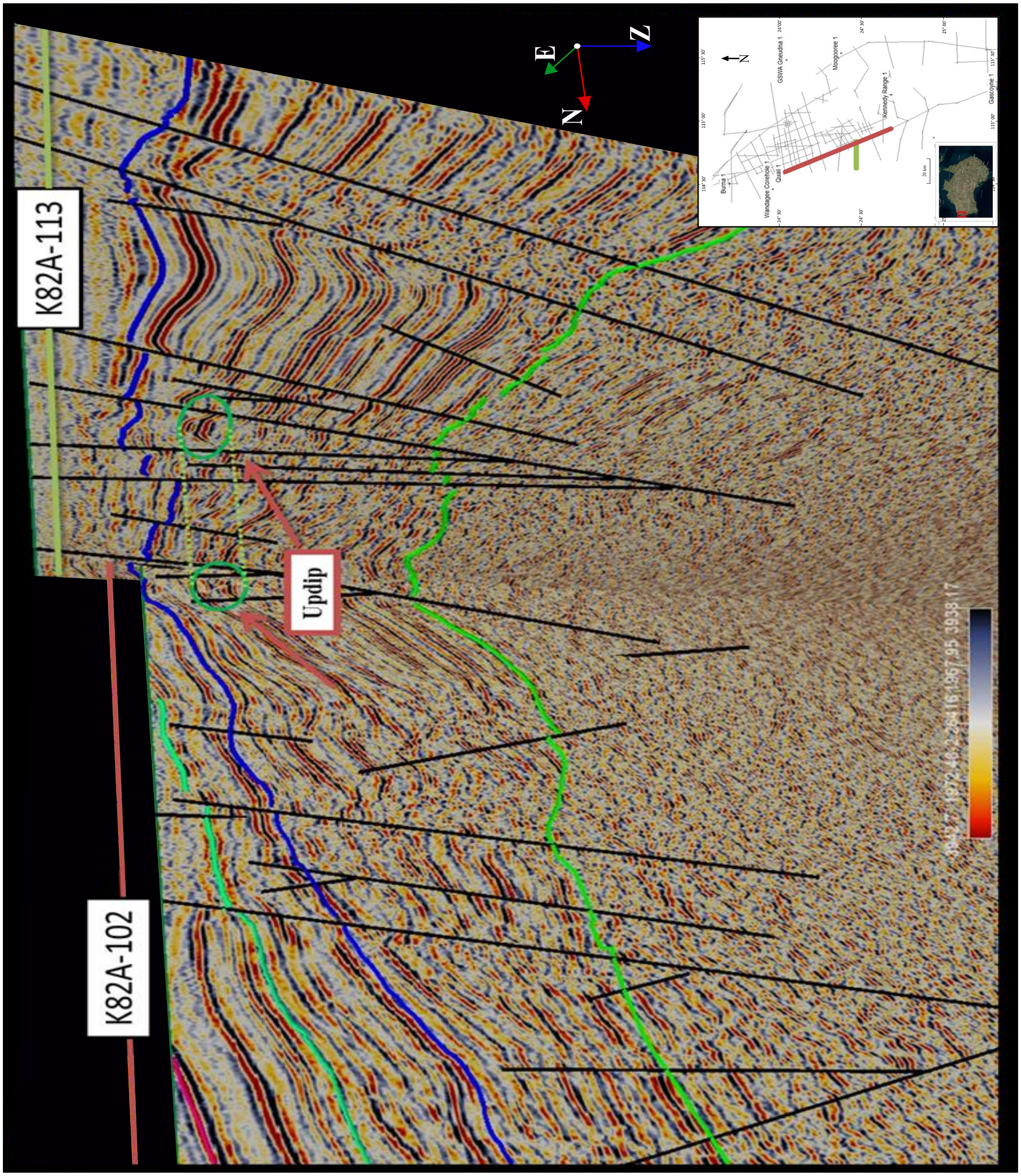
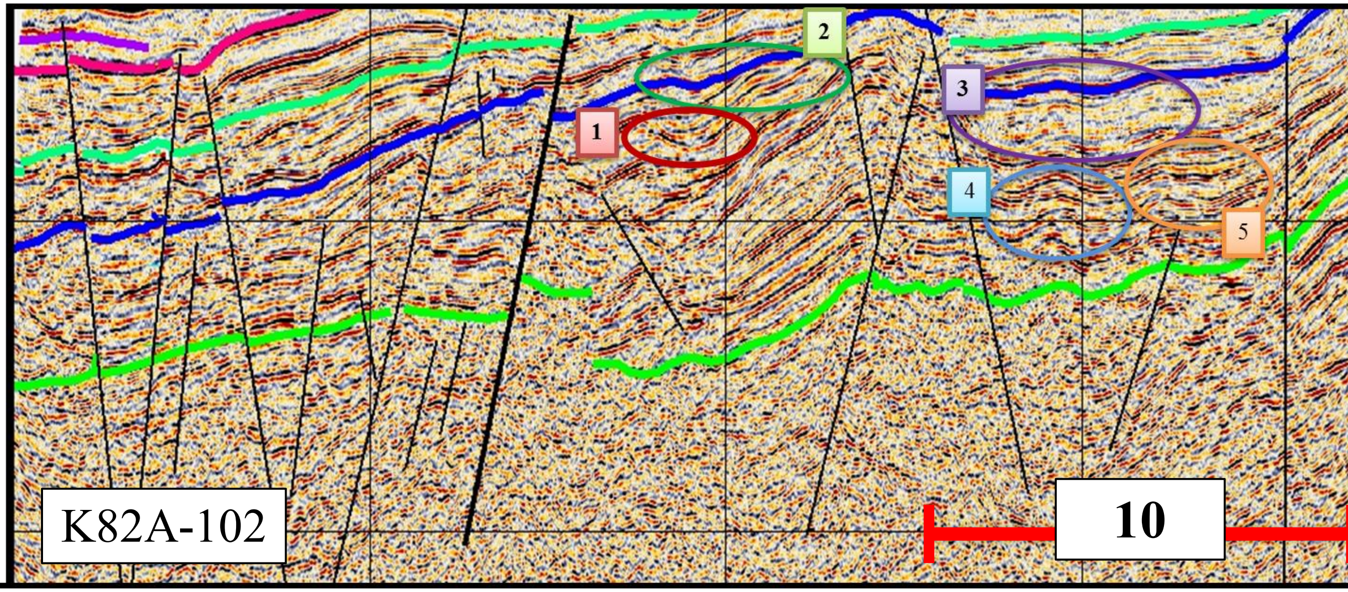


Figure 5.135 Seismic Lines K82A-113 and K82A-102 displayed in a 3D viewer showing the correlation of lead. K82A-113 is updip from K82A-102.



Blue – Devonian Top; Light Green – Base Lyons Group; Pink – Top Lyons Group; Purple – Callytharra Formation

1 – Possible source for Intraformational Gneudna Formation, Nannyarra Sandstone Reservoir, Gneudna Formation Seal, Stratigraphic trap, possible channel fill (Figure 5.24)

2 - Sourced from lower Gnuedna Formation or Silurian, Munabia Sandstone Reservoir, and possibly sealed by overlying Carboniferous Moogooree Limestone, Stratigraphic Pinchout Trap

3 – Possible Carbonate Play Source and Sealed Intraformational Gneudna Formation

4 & 5 – Anticlinal Structures Silurian Dirk Hartog or Devonian Gneudna Formation source, Reservoir Nannyarra or possibly Silurian Tumblagooda Sandstone sealed by Gneudna Shales (Figure 5.25)

Figure 5.146 Displaying potential plays for seismic line K82A-102A

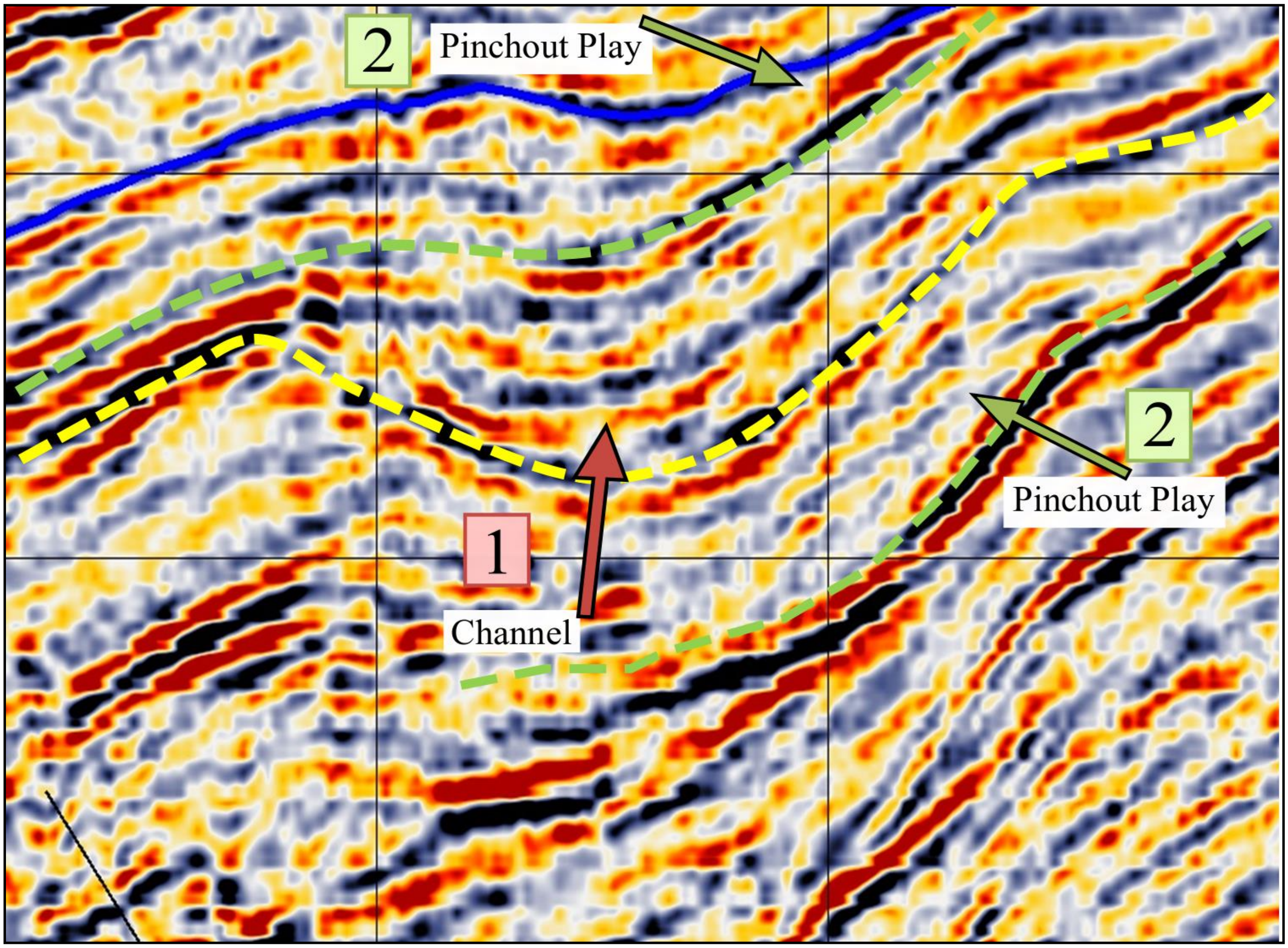


Figure 5.157 Possible Devonian stratigraphic plays. Close up display of 1 and 2 from potential leads from Figure 5.19. 1. Possible incised channel fill and 2. Pinchout play

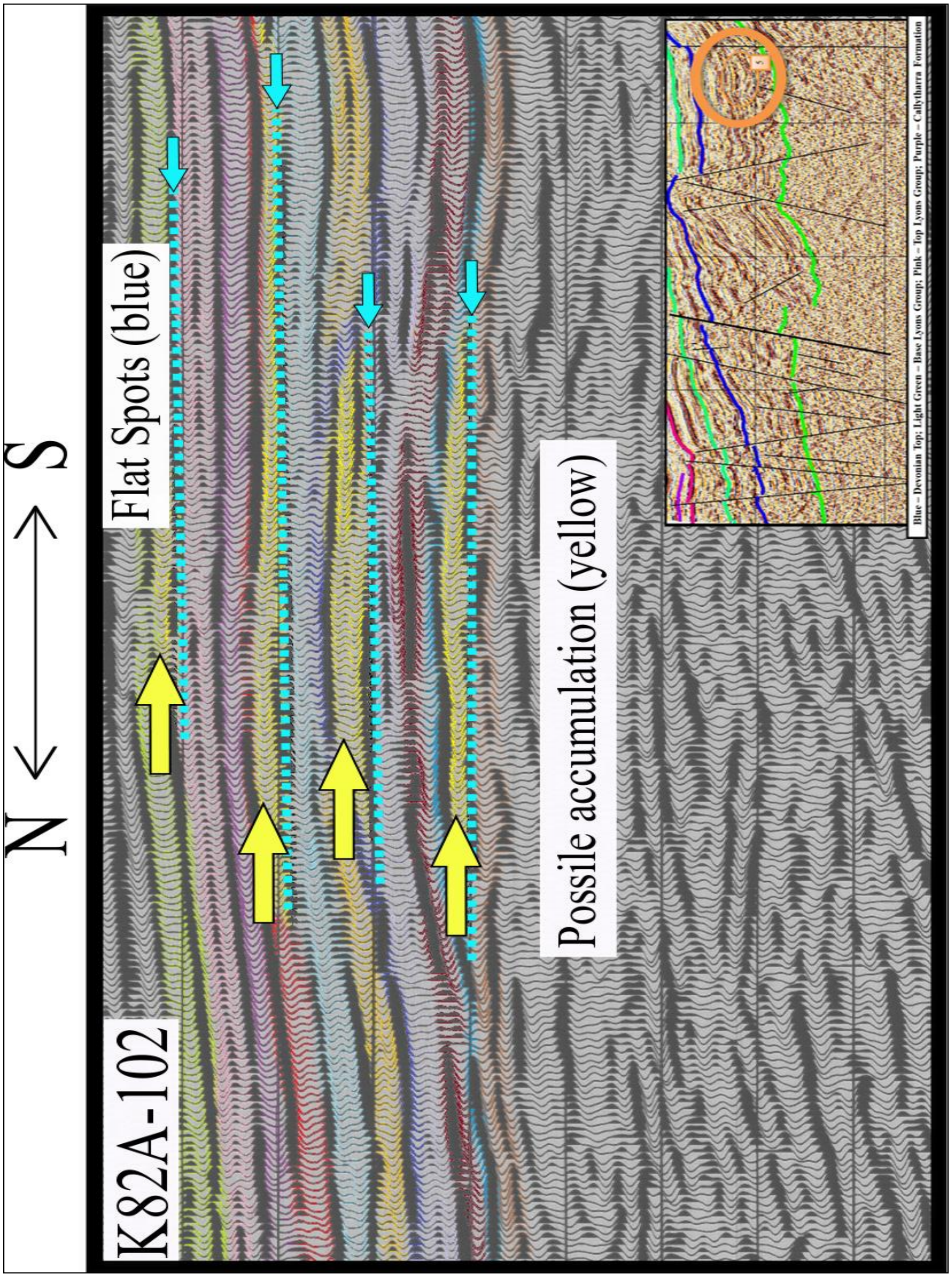


Figure 5.168 Zoomed in section displaying flat spots and possible hydrocarbon accumulations (yellow) from Seismic Line K82A-102

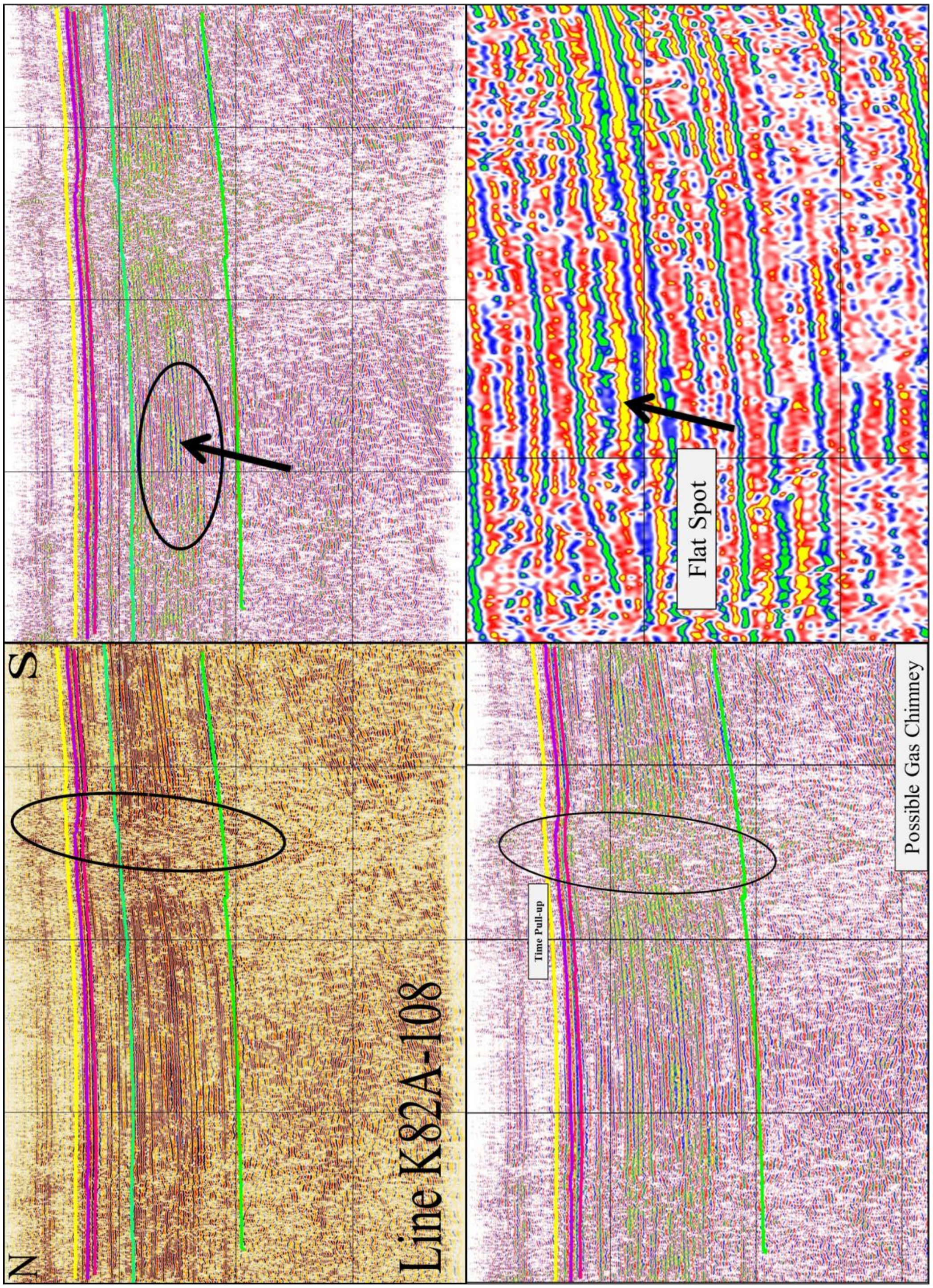


Figure 5.179 Seismic Line K82A-108 Displaying direct hycarbon indicators (DHI) using OpendTect's Extreme Attribute

Figure 5.30 Seismic Line K82A-116A displaying potential hydrocarbon generation in the eastern portion of the Merlinleigh Sub-basin 1. Anticline structure with bounding fault to the south. Extreme attribute was applied using OpendTect

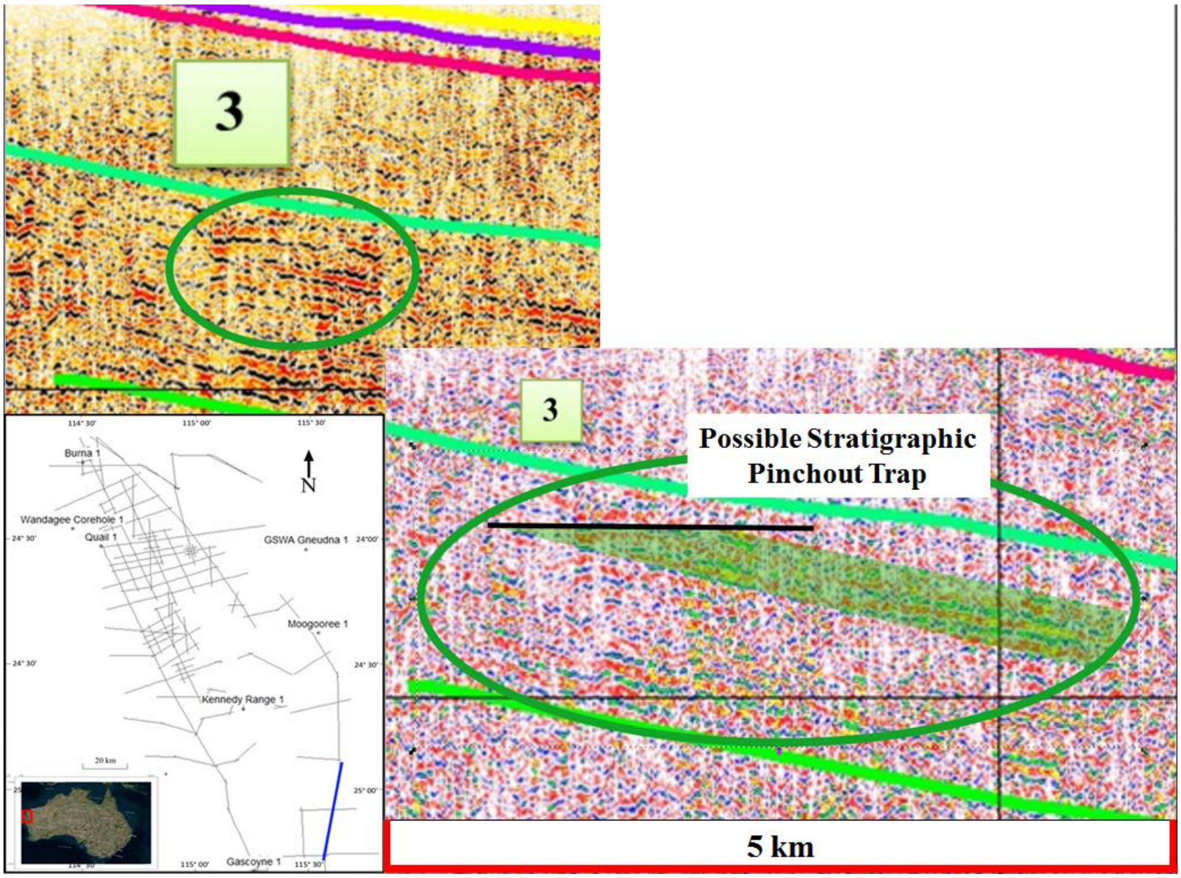


Figure 5.31 Seismic line K82A-116A prospect 3 displaying a possible stratigraphic pinchout play

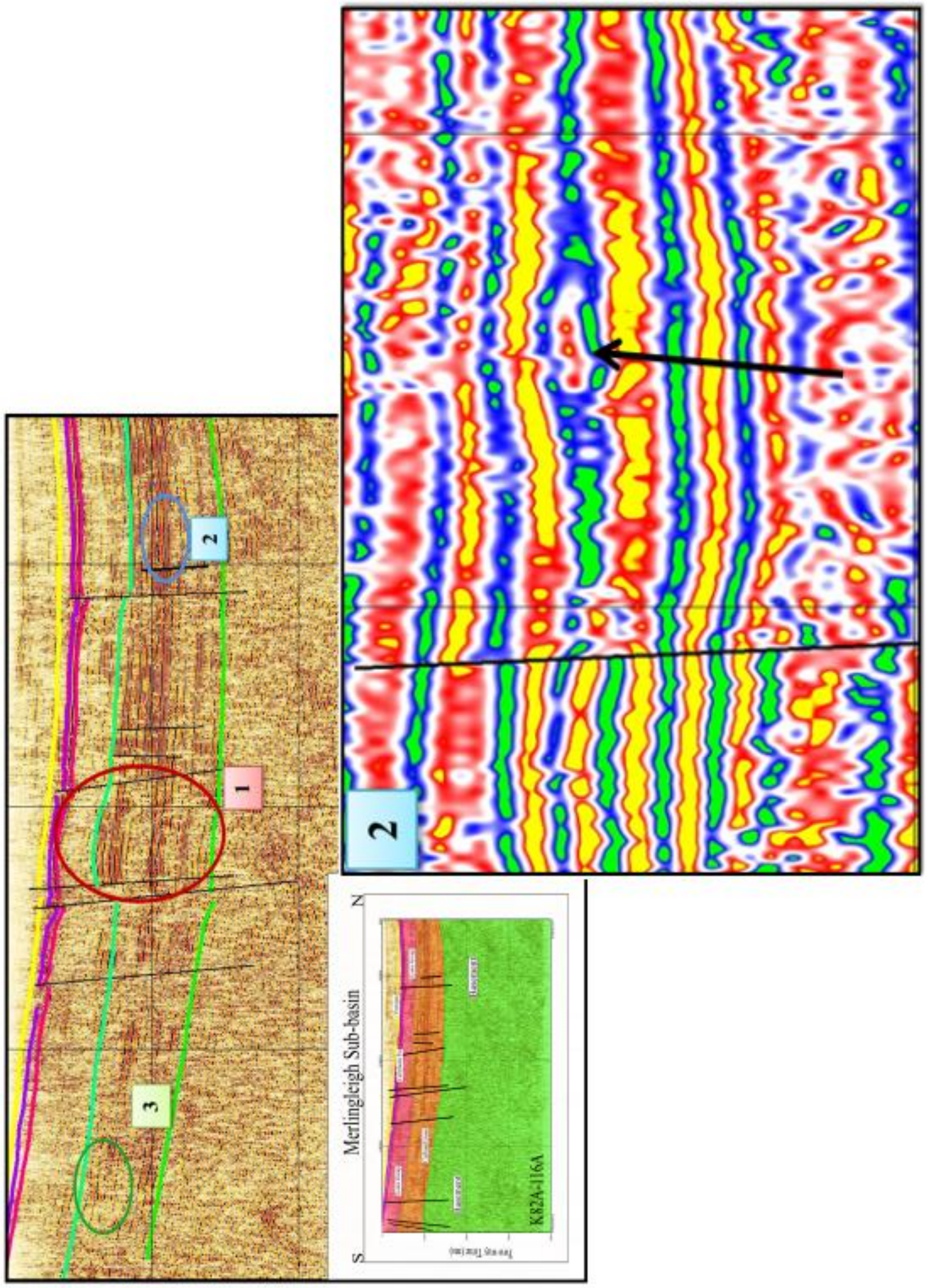


Figure 5.32 Seismic Line K82A-116A displaying potential hydrocarbon generation in the eastern portion of the Merlingleigh Sub-basin 2. Intraformational structure with bright spot highlighted with OpendTect Extreme attribute

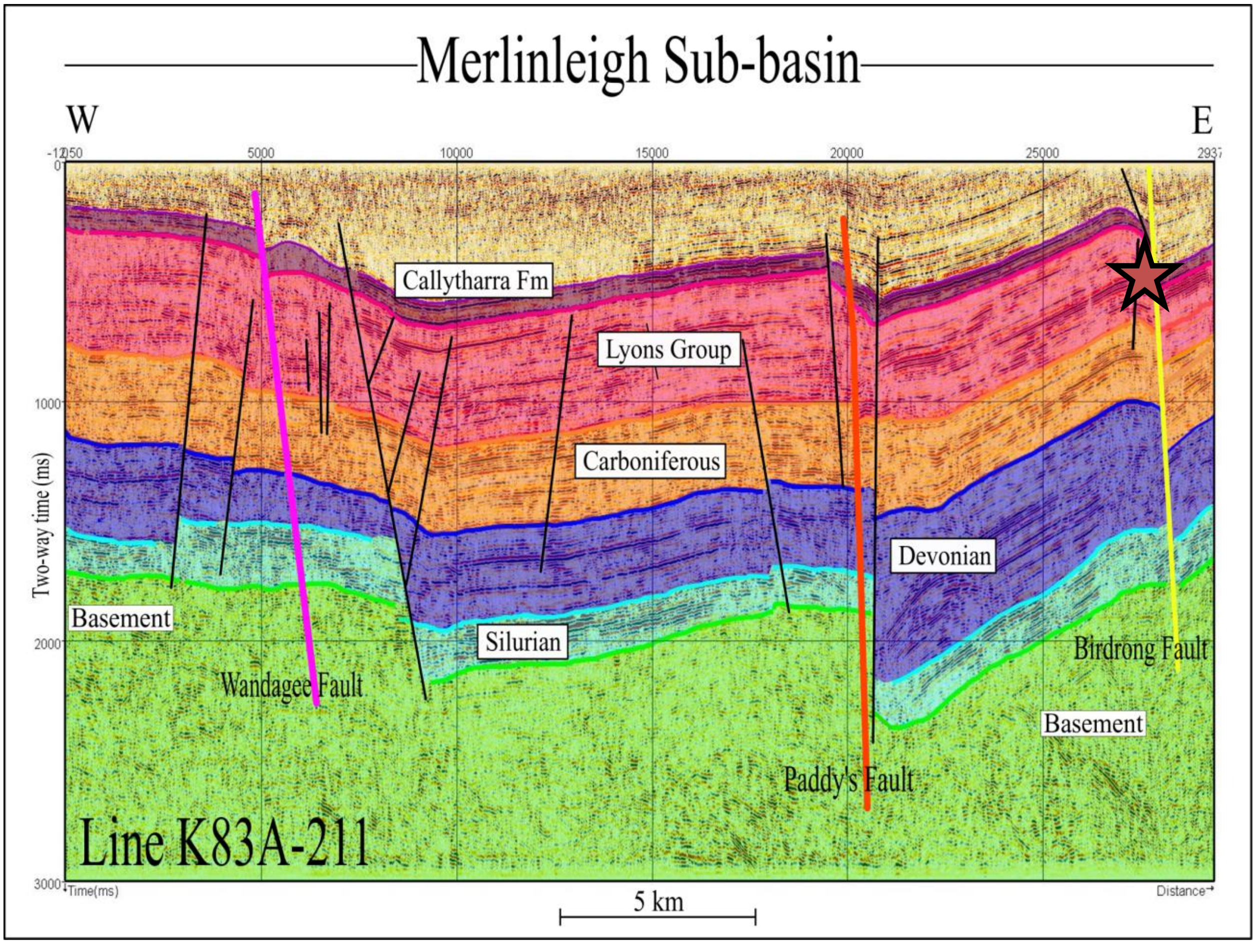


Figure 5.33 Seismic Line K83A-211 displays the horizons fillied in to easily identify the strata

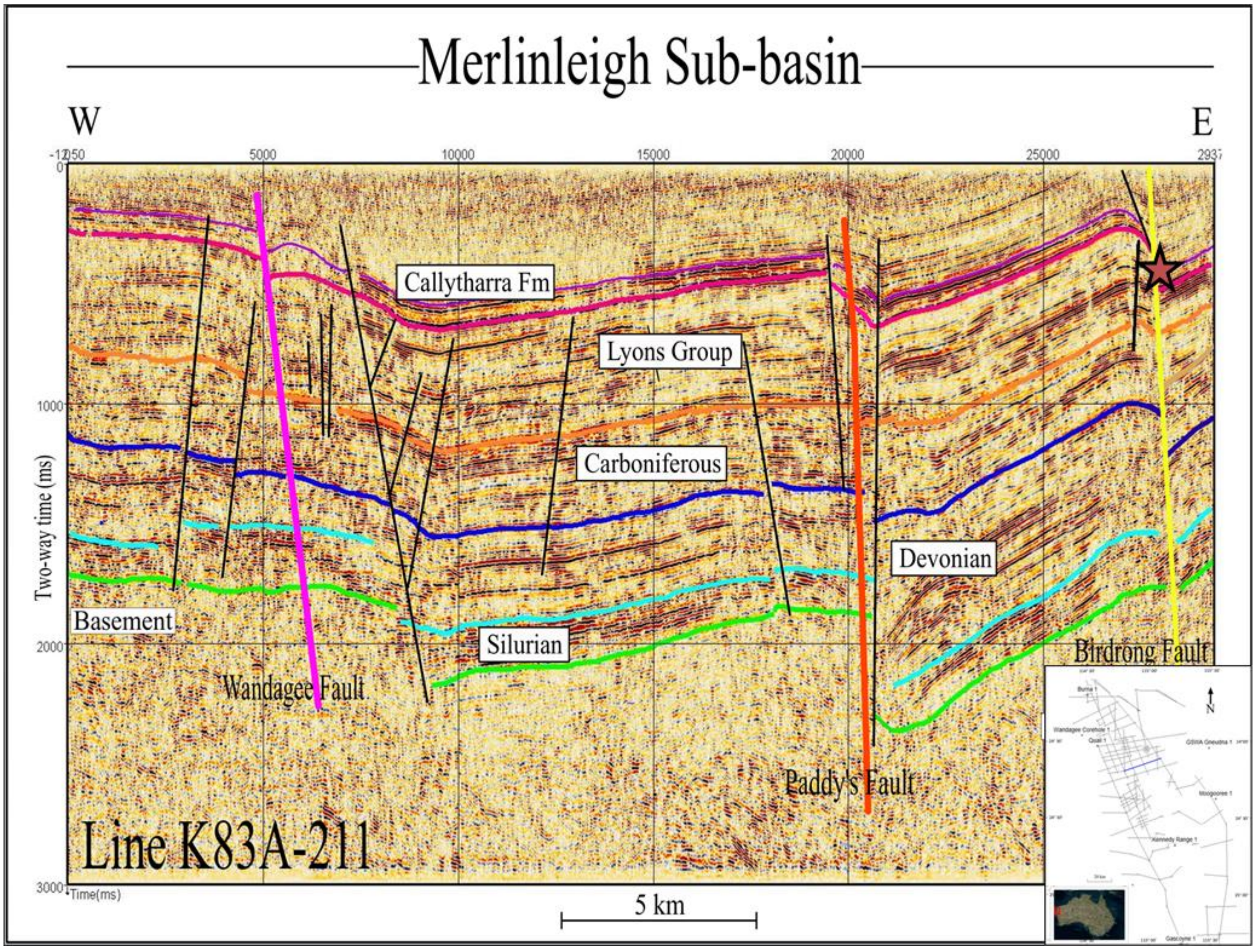


Figure 5.34 Seismic Line K83A-211 highlights the anticlinal features on the eastern margin

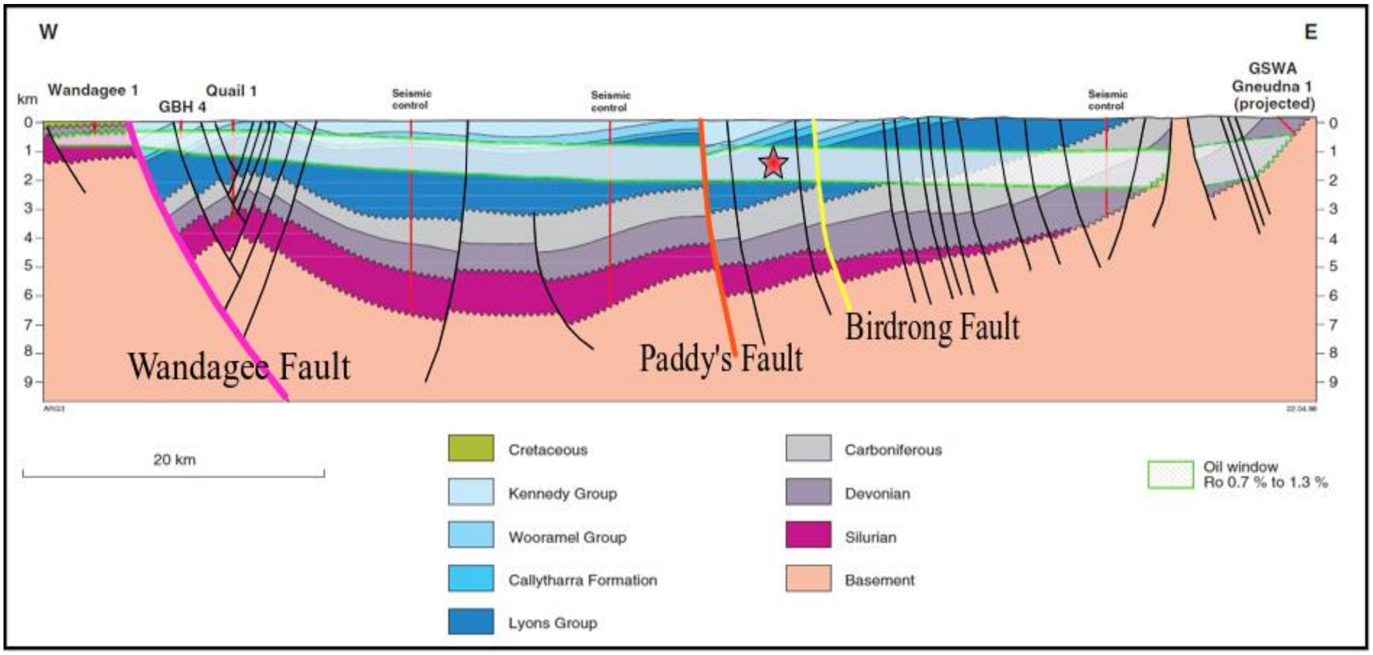


Figure 5.35 Maturation of the Devonian succession across the Merlinleigh Sub-basin (modified from Iasky et al., 1998)

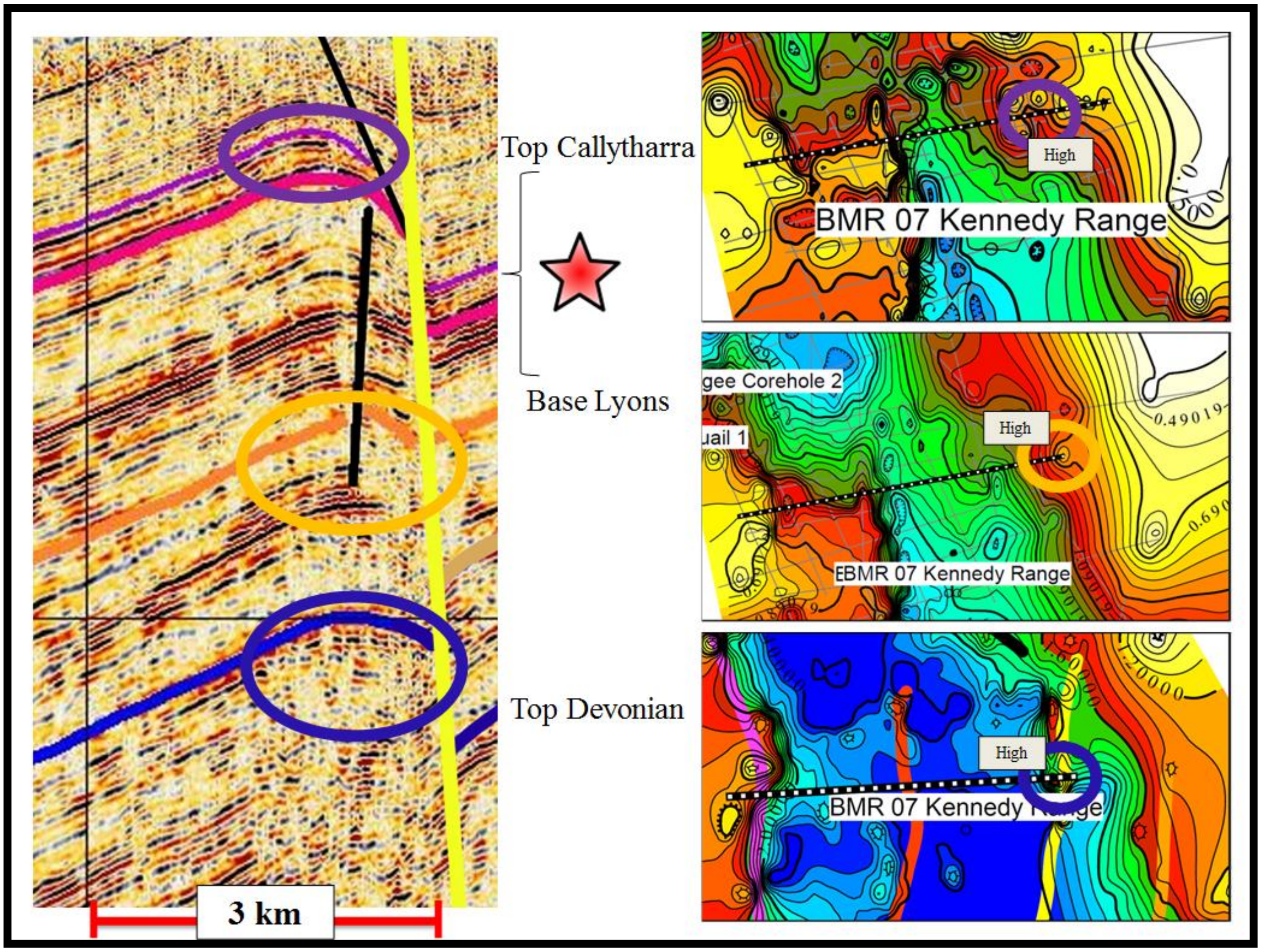


Figure 5.36 Seismic Line K83A-211 displaying anticline from the structures maps associated with each of their horizons (Purple-Callytharra, Orange-Base Lyons, Blue-Devonian). The Red star correlates with Figure 5.35

6. CONCLUSION

The Merlinleigh Sub-basin is a feature along the eastern margin of the Carnarvon Basin. The Carnarvon Basin began as an interior sag during the Late Silurian with the deposition of the shallow marine to non-marine Tumblagooda Sandstone. During the Late Devonian to Early Carboniferous, a sequence of carbonate and clastic sediments were deposited. Interior fractures developed in the Late Carboniferous by down-to-the-west normal faults with a north-to-south trend. Erosion and uplift of the Pre-Cambrian east of the Sub-basin during the Early Permian resulted in deposition of an extensive alluvial fan onto a shallow marine shelf (Lyons Group). A marine transgression followed that deposited an extensive carbonate unit (Callytharra Formation). A subsequent regression deposited an overlying sandy, deltaic Wooramel Group. Uplift and erosion during the Mesozoic removed most of the Permian sequence deposited outside of the Merlinleigh Sub-basin.

The overall form of the Merlinleigh Sub-basin is of a westward thickening, synclinal half-graben fault bounded against the Gascoyne Province by two major en-echelon N-S trending fault systems. The axis of the syncline trends NNW and is cut and compartmentalized by the N-S trending Kennedy and Wandagee Fault systems. Sediments preserved within the syncline range in age from Silurian through to Permian with a maximum sediment thickness adjacent to the Kennedy

Fault in excess of 5,000 meters. The maximum throw across the faulted western margin is in excess of 3,000 meters. The footwall crests of some of these faults create basement inliers along the eastern edge of the basin. Apart from the main basinal syncline, most of the second order folds appear to be closely related to movements along faults possibly to drape above basement horsts. The present day form of the province appears to be largely due to post-depositional structuring events that began in the late Permian and culminated with the Cretaceous break-up of the Australia and Greater Indian, which is represented by a prominent unconformity.

6.1. LIMITATIONS

The techniques used in the interpretation assume that the data used are properly acquired and processed up to and including migration of the data. Assumptions were made over varying distances due to poor quality of some of the seismic lines. The poor seismic data quality could be a function of severe horizontal velocity gradients, high noise areas, high bed dips, and extremely complex geology. However, even in the areas of highly structured areas, the 2D seismic data may contain valuable information that can be used in creating a reasonable subsurface interpretation. Furthermore, as seismic profiles are not geologic profiles, subsurface maps can never perfectly represent the structural configuration within the earth. This is due to lack of perfect and complete velocity functions over the dataset and there is the lack of high-frequency wavelengths required to completely resolve geologic subtleties in the study area. Another limitation is the problem with migration of seismic lines. Migration can only be fully corrected for a true dip line. Because the 2D migration algorithm cannot move data from out of the plane of the line, a line that has an apparent dip and not true-dip will not be fully corrected.

The other issue was within the seismic survey themselves. The study area covered a number of different acquisition projects (appendix A) with different parameters, processing steps, and record lengths. This required matching seismic responses from the differing surveys. The lack of wells in the area limited the ability to accurately identify individual formations within the depositional groups. Without good well control, depths could not be converted from the two-way travel time, further limiting the detail of this report.

Several lines had the appearance of direct hydrocarbon indicators, but the single line anomalies had no third dimension to explore in great detail. These anomalies could be an arbitrary artifact due to reprocessing such as stripping (Figure 6.1). Also, not all of the seismic lines within the dataset allowed for loading due to corrupt SEGY files or lack of navigation files.

Ideally, the interpretations made will help further the subsurface geology in the area and aide in future endeavors as better interpretation techniques become available. Despite the insufficient data coverage, limited well control, overall poor seismic resolution and quality, and frequent jump correlations, the confidence in this interpretation are moderate to good. Although the accuracy of the seismic mapping and resulting structural-stratigraphic framework are regional in scale, this analysis integrated with other geophysical techniques will provide valuable insights into prospective trends for future exploration within the Southern Carnarvon Basin.

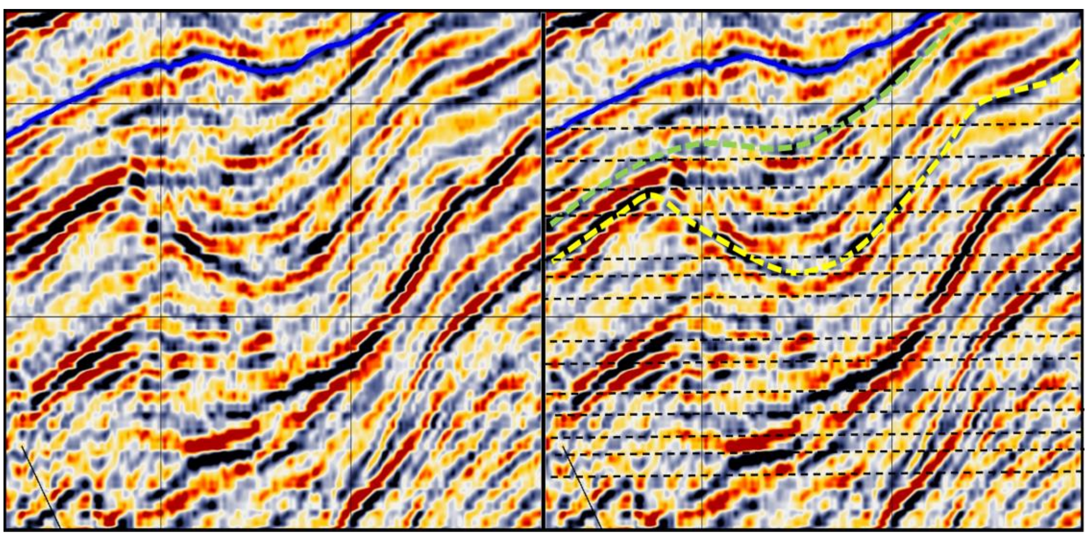


Figure 6.1 Seismic section displaying possible stripping effect due to reprocessing of original data into IHS Kingdom or OpendTect

6.2. RECOMMENDATIONS

Additional seismic coverage will be needed to accurately define prospects with greater confidence, investigate internal seismic attributes for various closures and obtain adequate velocity field for depth conversion. The optimum seismic coverage would be a 3D survey (Figure 6.2), but a well-defined 2D grid (Figure 6.3) would be the first step. A number of seismic sections were integrated with gravity and magnetic data that confirmed structures within the study area. More test wells would be ideal to test formations at depth to accurately tie to seismic data (Figure 6.4). Deeper wells could better identify the stratigraphic horizons and lead to a more in depth analysis. Figure 6.5 displays the structural highs within the Devonian sequence with possible migration pathway directions. The locations selected highlight the potential sites for future well placement.

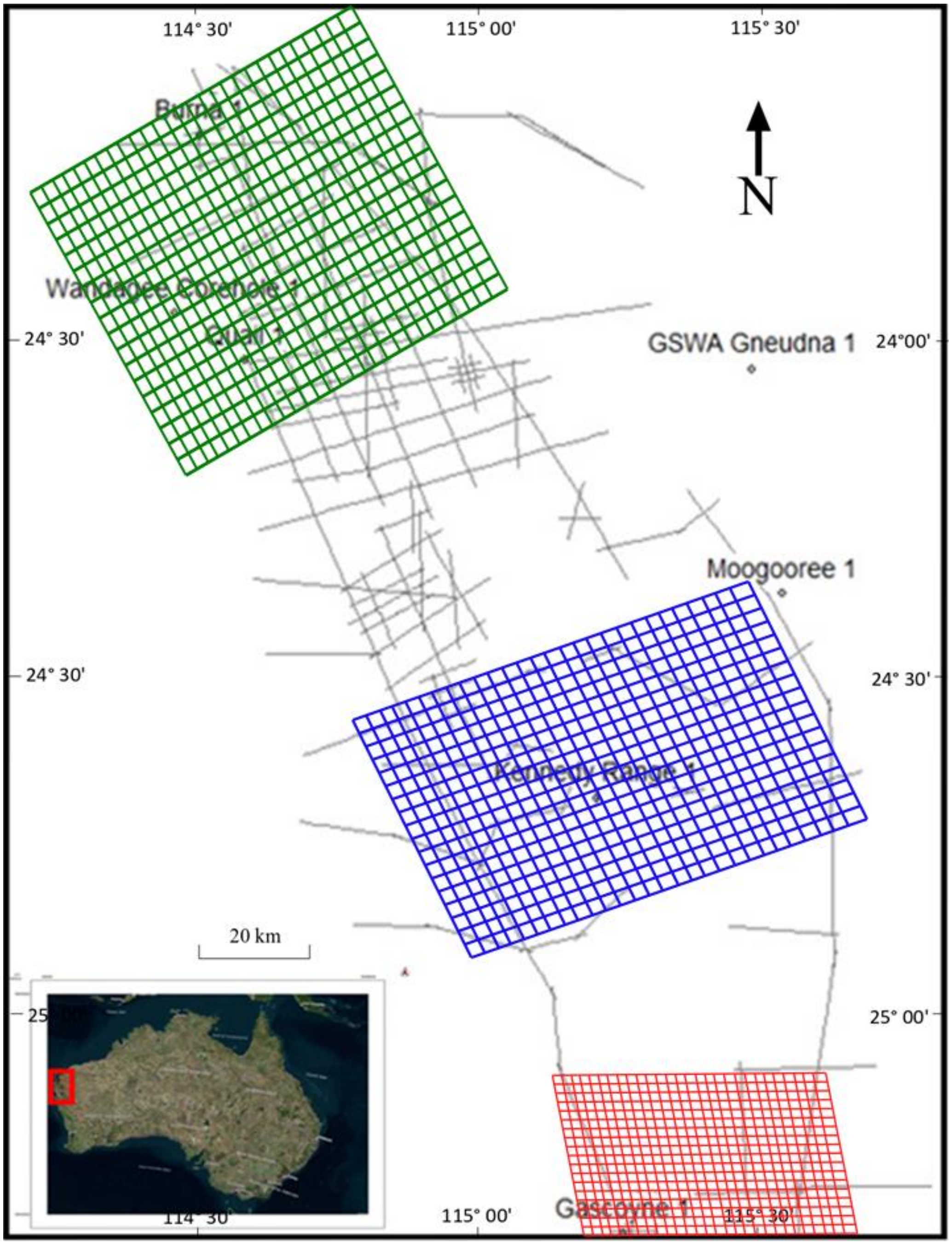


Figure 6.2 Updated basemap of the southern Merlinleigh Sub-basin with the recommended 3D grids highlighted in green, blue, and red, whereas the black lines are current 2D seismic coverage

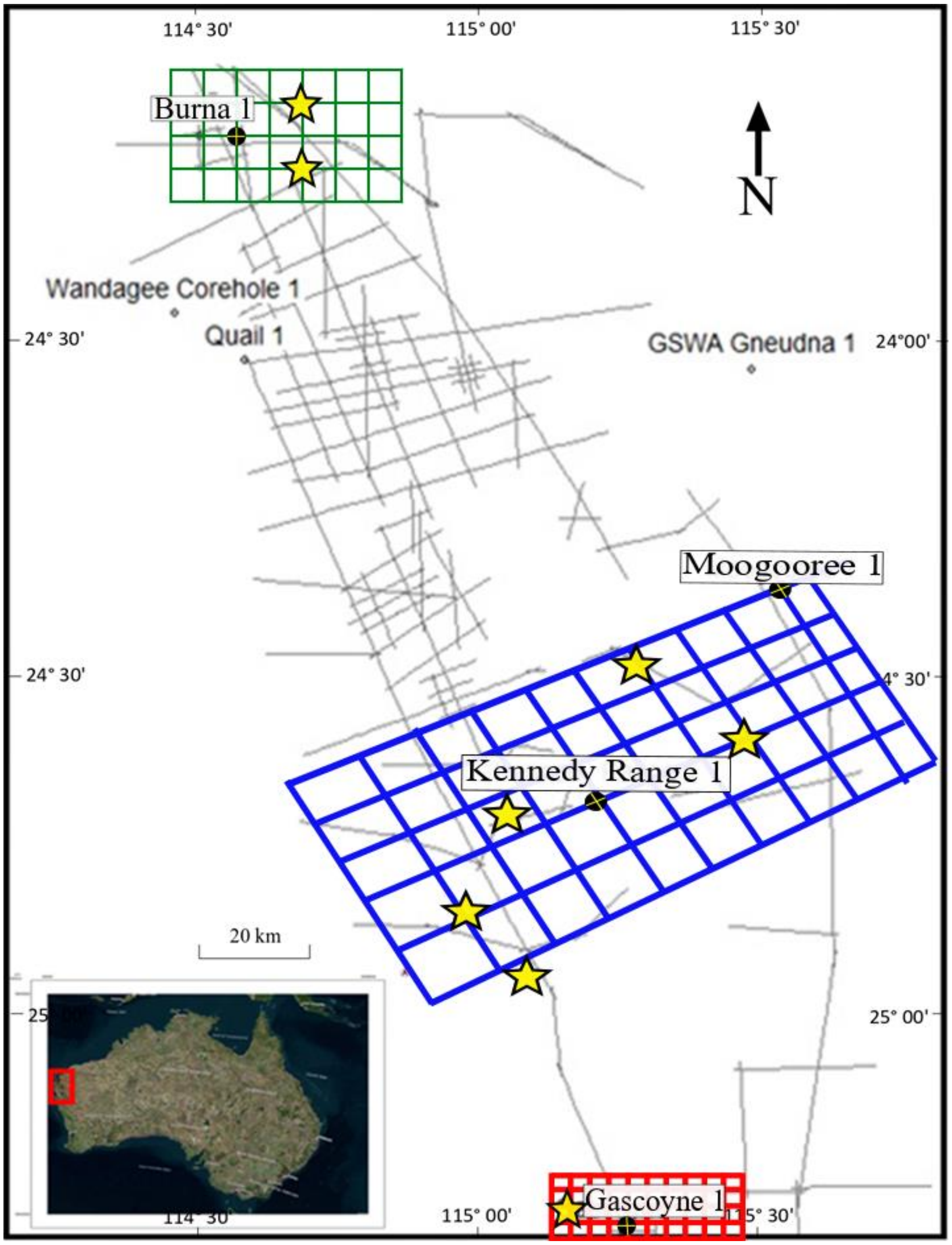


Figure 6.3 Recommended 2D well-defined grid. The basemap displays current seismic coverage with the black lines and proposed seismic grids by the red, blue, and green lines

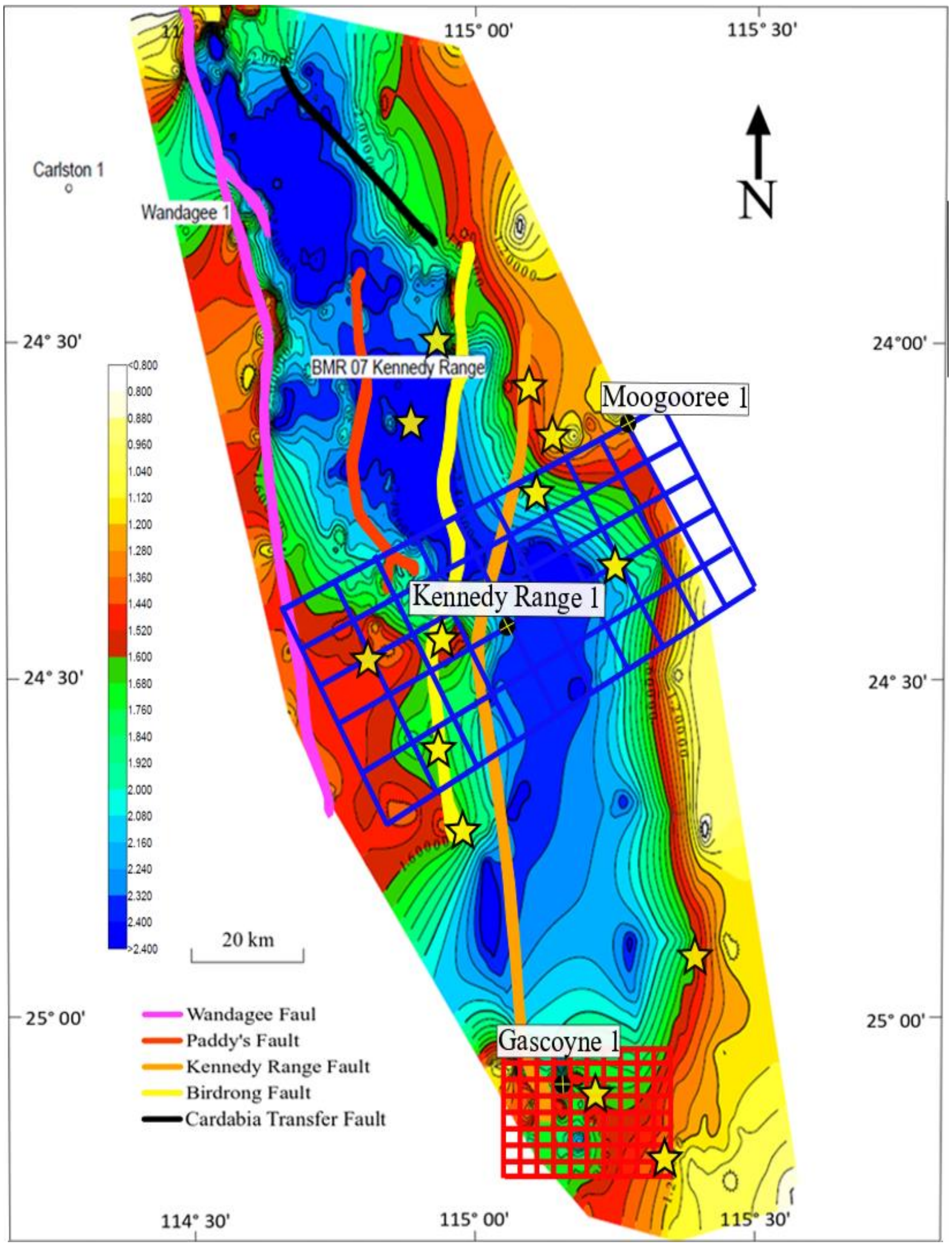


Figure 6.4 Recommendation based off Devonian TWT structure map. Wells are denoted by the yellow stars and were picked based on structural highs and in deepest portions of the Sub-basin near Kennedy Range 1

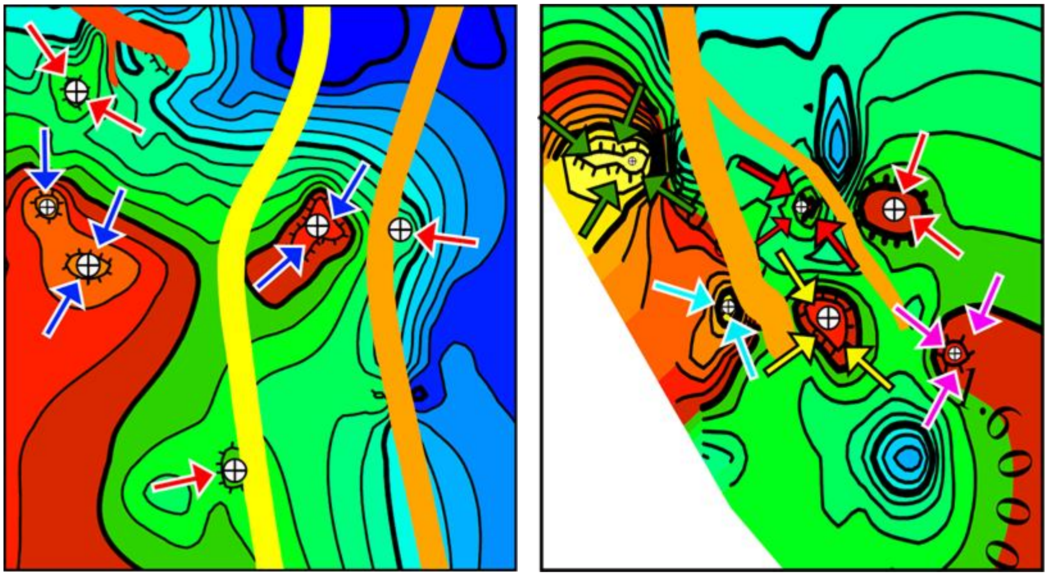


Figure 6.5 Show structural highs from the Devonian TWT structure map with possible migration directions

Appendix A

SEISMIC LINE LEGTHS AND QUALITY OF DATA

Survey Name	Line Name	Length	Shotpoint Range	Quality
Giralia North S.S.	84-10	20.371	101-1118	Fair
	84-12	43.485	87-2260	Fair
Fisherman Point S.S.	87-32	15.003	100-1352	Fair
	88-006	2.775	123-182	Fair
Rough Range Trend S.S.	A85-001	7.788	300-690	Poor
	A85-002	4.182	200-410	Poor
	A85-003	61.143	202-1273	Poor
	A85-004	5.942	200-498	Poor
	A85-006	5.944	200-498	Poor
	A85-008	5.944	200-498	Poor
	A85-010	5.76	200-494	Poor
	A85-011	61.329	257-1454	Poor
	A85-012	5.937	202-499	Poor
	A85-015	14.159	201-910	Poor
	A85-016	5.938	202-499	Poor
	A85-018	5.937	202-499	Poor
	A85-020	5.958	201-499	Poor
	A85-022	5.961	201-499	Poor
	A85-024	5.931	202-499	Poor
	A85-026	5.894	204-499	Poor
	A85-028	5.965	201-499	Poor
	A85-030	5.971	201-499	Poor
	A85-032	5.983	201-499	Poor
	A85-034	5.955	202-499	Poor
	A85-038	5.95	202-499	Poor
	A85-040	5.982	201-499	Poor
	A85-042	5.951	201-499	Poor
	A85-044	6.226	1250-1598	Poor
	A85-046	5.947	501-799	Poor
	A85-048	5.969	201-498	Poor
	A85-050	5.924	201-499	Poor
	A85-054	5.926	201-495	Poor
	A85-056	5.942	201-499	Poor
	A85-060	5.912	201-499	Poor
	A85-062	5.909	201-499	Poor
	A85-064	21.467	0-201	Fair
	A85-066	4.389	0-201	Fair
	A87-068	12.268	411-1639	Poor
	A88-001	6.886	101-445	Fair
	A88-001A	12.499	100-725	Poor
	A88-002	7.213	102-462	Poor
	A88-003	4.021	540-942	Poor
	A88-004	9.185	122-581	Fair

Survey Name	Line Name	Length	Shotpoint Range	Quality
	A88-005	9.086	99-1009	Fair
	A88-006	8.793	150-590	Fair to Good
	A88-007	5.555	102-379	Fair
	A88-008	6.503	101-426	Poor
	A88-009	11.295	101-666	Fair
	A88-010	13.508	166-841	Fair
	A88-011	15.111	72-827	Fair
	A88-012	27.082	146-1499	Poor
	A88-013	42.597	101-2232	Fair
	A88-014	6.19	101-410	Poor
	A88-015	6.502	101-426	Poor
	A88-016	5.871	101-396	Poor
	A88-017	29.768	120-1608	Fair
	A88-018	22.312	101-1221	Poor
	A88-019	7.23	101-474	Poor
	A89-001	8.684	100-500	Fair
	A89-002	5.001	100-350	Fair
	A89-003	5.004	100-350	Fair
	A89-004	4.997	100-350	Fair
	A89-005	5.116	100-350	Fair
	A89-006	6.165	100-398	Fair
	A89-007	5.597	100-375	Fair
	A89-008	8.29	100-500	Fair
	A89-009	7.761	100-475	Poor
	A89-010	37.681	1-100	Fair
	A89-011	6.131	100-400	Fair
	A89-012	6.164	100-400	Fair
	A89-013	6.166	100-400	Fair
	A89-014	6.177	100-400	Fair
	A89-015	6.19	101-400	Fair
	A89-016	8.288	100-507	Poor
	A89-017	7.12	100-450	Poor
	A89-018	4.874	211-450	Poor
	A89-019	6.136	100-400	Poor
	A89-020	6.127	100-400	Poor
	A89-021	6.141	100-400	Poor
	A89-022	6.142	100-400	Poor
	A89-023	5.1	100-350	Fair
	A89-024	5.117	100-350	Poor
	A89-025	7.222	102-450	Poor
	A89-026	7.271	100-450	Poor
	A89-027	7.245	100-450	Poor
	A89-028	5.862	161-450	Poor

Survey Name	Line Name	Length	Shotpoint Range	Quality
	A89-029	7.122	100-450	Poor
Shark Bay M.S.S.	B65-001	91.046	33-490	Poor
	B65-002	105.522	1-527	Poor to Fair
	B65-004	41.437	42-251	Poor
	B65-014	13.654	432-503	Poor
Lyndon-Quobba S.S.	B72-001L	108.559	1-406	Good
	B72-002LE	106.203	1-397	Poor to Fair
Ballythana Hill S.S.	BH65-016	18.23	198-337	Poor
	BH65-017	34.482	253-512	Poor
	BH65-018	22.601	397-564	Poor
	BH65-019	24.009	433-615	Poor
	BH65-028	14.093	328-435	Poor
Bullara S.S	BULL-85-020	40.637	112-1738	Good
	BULL-85-022	26.75	112-1172	Good
	BULL-85-024	45.459	101-1818	Good
Bernier S.S.	CG82-02M	48.256	236-2190	Poor to Fair
	CG82-04M	41.206	1-1637	Poor
	CG82-06M	29.288	1-1168	Poor to Fair
	CG82-10M	12.603	1-503	Poor
Lyell Range 1983 Land S.S.	CG83-09L	28.191	64-855	Fair
Lake Mcleod West S.S.	CG85-001L	5.571	1-140	Poor
	CG85-002L	17.044	1-117	Poor
	CG85-003L	56.813	1-189	Poor to Fair
	CG85-004L	63.366	1-189	Poor
	CG85-005L	54.671	1-164	Poor
	CG85-006L	6.565	1-161	Poor
	CG85-007L	6.175	1-153	Poor
	CG85-008L	5.184	203-330	Poor
	CG85-009L	4.339	1-110	Poor
	CG85-010L	4.33	1-105	Poor
	CG85-011L	20.137	203-671	Poor
	CG85-012L	0	1-121	Poor
	CG85-013L	11.055	203-471	Poor
Carlston S.S.	CP93-01	10.008	100-500	Fair
	CP93-02	11.996	100-580	Fair
	CP93-03	14.995	93-693	Fair
	CP93-04	13.001	100-620	Fair
	cp94-05	5.973	100-340	Fair
	CP94-06	3.992	100-260	Poor
	CP94-07	4.993	100-300	Poor to Fair
	CP94-08	6.971	100-380	Poor to Fair
	CP94-09	4.989	100-300	Fair

Survey Name	Line Name	Length	Shotpoint Range	Quality
South Carnarvon Onshore Phase 1 Spec S.S.	CW90-01	47.495	202-2101	Fair
	CW90-02	58.78	202-2551	Fair
	CW90-03	70.499	202-3018	Poor
	CW90-04	59.049	209-2507	Poor
	CW90-05	26.408	202-1257	Poor to Fair
	CW90-06	56.183	216-2462	Fair
J84A S.S.	J84A-002	7.395	2004-2284	Fair
	J84A-003	3.206	2578-2682	Poor
	J84A-004	7.28	2000-2290	Poor
	J84A-005	20.232	2000-2808	Fair
	J84A-006	18.28	2056-2780	Fair
	J84A-008	10.788	2024-2442	Fair
	J84A-009	8.461	2030-2366	Poor to Fair
	J84A-011	11.425	2010-2460	Poor to Fair
	J84A-012	20.132	2000-2804	Fair
	J84A-015	11.894	2000-2476	Poor to Fair
	J84A-019	13.969	2004-2556	Poor to Fair
	J84A-023	10.005	2000-2399	Fair
	J84A-025	4.932	2004-2192	Poor
	J84A-027	7.254	2000-2288	Poor
	J84A-029	7.41	2004-2294	Poor
	J84A-031	12.138	2004-2464	Poor to Fair
	J84A-033	9.216	2002-2369	Poor to Fair
	J84A-035	9.262	2000-2360	Fair
	J84A-037	6.698	2000-2266	Poor to Fair
	J84A-039	4.885	2004-2196	Poor to Fair
	K82A-101	33.845	2003-2971	Fair
K82A S.S.	K82A-101A	20.469	2003-2495	Poor
	K82A-101B	13.435	2040-2425	Poor
	K82A-101C	17.117	2001-2450	Poor
	K82A-101D	49.435	2003-2641	Poor
	K82A-102	37.805	2567-3650	Fair
	K82A-102A	12.298	2003-2355	Poor
	K82A-102B	46.164	2003-3324	Poor
	K82A-103	26.439	2003-2758	Fair
	K82A-104	10.125	2003-2293	Fair
	K82A-104A	17.324	2001-2496	Poor to Fair
	K82A-105	52.31	2003-3502	Good
	K82A-106	4.633	2003-2136	Poor
	K82A-107	20.583	2006-2597	Poor
	K82A-108	18.627	2003-2537	Poor to Fair
	K82A-109	52.42	2003-3507	Good

Survey Name	Line Name	Length	Shotpoint Range	Quality
	K82A-110	35.99	2196-3225	Poor to Fair
	K82A-111	16.977	2361-2848	Fair
	K82A-111A	16.959	2360-2846	Poor
	K82A-112	20.132	2003-2579	Poor
	K82A-112A	18.754	2003-2540	Poor
	K82A-113	16.589	2003-2479	Fair
	K82A-113A	20.5	1999-2582	Fair
	K82A-115	12.991	2003-2375	Good
	K82A-115A	7.73	2003-2224	Poor to Fair
	K82A-116	36.696	2003-3053	Poor
	K82A-116A	36.588	2003-3051	Fair
	K82A-116B	28.798	2075-2898	Fair
	K82A-117	36.302	2003-3042	Poor to Fair
	K82A-117A	2.774	2003-2082	Poor
	K82A-117B	5.981	2003-2174	Poor
	K82A-117C	17.478	2004-2504	Poor
	K82A-118	66.104	1988-3880	Fair to Good
	K82A-119	8.76	2004-2254	Fair
	K82A-120	50.749	2003-3456	Fair
	K82A-121	17.965	2005-2518	Poor
	K82A-121A	5.19	2003-2151	Poor
	K82A-121B	6.551	2003-2190	Poor
	K82A-123	15.242	2003-2440	Poor
	K82A-123A	14.296	2001-2411	Poor
	K82A-123B	8.002	1999-2228	Poor
	K82A-123C	12.168	2003-2352	Poor
	K82A-123D	5.949	2003-2173	Poor
	K82A-123E	10.636	2003-2308	POOR
	K82A-123F	9.276	2003-2269	POOR
	K82A-123G	4.724	2003-2138	POOR
	K82A-125	12.218	2003-2353	Fair
	K82A-127	12.134	2003-2351	Poor to Fair
	K82A-127A	15.909	2003-2459	Poor to Fair
	K82A-127B	9.772	2003-2283	Poor to Fair
	K82A-127C	10.466	2003-2303	Poor to Fair
	K82A-129	15.822	2003-2456	Poor to Fair
	K82A-131	20.555	2003-2591	Poor to Fair
	K82A-133	10.412	2003-2301	Poor to Fair
	K82A-135	34.649	2003-2995	Poor to Fair
	K82A-137	38.445	2003-3104	Fair
	K82A-137A	17.925	2003-2516	Poor
	K82A-139	33.413	2012-2968	Fair to Good
K83A S.S.	K83A-201	14.699	2002-2589	Poor

Survey Name	Line Name	Length	Shotpoint Range	Quality
	K83A-202	20.047	2002-2804	Poor
	K83A-203	15.51	2002-2621	Poor to Fair
	K83A-204	23.724	2002-2950	Fair
	K83A-205	21.328	2002-2854	Poor to Fair
	K83A-206	26.445	2086-3140	Fair to Good
	K83A-207	14.717	2000-2588	Poor to Fair
	K83A-208	26.134	1950-2994	Fair
	K83A-209	11.468	1602-2060	Poor
	K83A-210	5.915	3015-3252	Fair
	K83A-211	29.372	2016-3190	Fair
	K83A-211X	0	1626-2072	NONE
	K83A-212	15.145	2002-2608	Poor to Fair
	K83A-213	26.214	2002-3048	Fair
	K83A-214	8.343	2002-2336	Poor to Fair
	K83A-215	6.004	2002-2242	Poor
	K83A-216	16.847	2002-2676	Poor
	K83A-217	8.82	2050-2402	Poor to Fair
	K83A-218	13.605	1990-2534	Fair
	K83A-219	14.659	2002-2588	Fair
	K83A-220	38.888	2266-3821	Fair
	K83A-221	17.205	2002-2690	Fair
	K83A-226	15.8	2002-2634	Poor to Fair
	K83A-227	11.881	2002-2476	Poor to Fair
	K83A-228	12.657	2003-2510	Poor
	K83A-229	6.451	2078-2336	Poor
	K83A-231	10.798	2002-2434	Poor
	K83A-232	9.626	1913-2298	Fair
	K83A-233	9.898	2002-2398	Poor
	K83A-234	9.147	2002-2368	Fair
	K83A-236	9.048	1866-2228	Poor to Fair
	K83A-237	8.299	2002-2334	Poor to Fair
	K83A-238	19.464	2002-2780	Poor
	K83A-239	5.902	2002-2238	Poor to Fair
	K83A-240	13.257	2002-2532	Fair
	K83A-241	4.899	2002-2198	Poor to Fair
	K83A-242	4.876	2003-2198	Fair
	K83A-243	4.849	2002-2196	Poor to Fair
	K83A-244	4.899	2002-2198	Poor to Fair
	K83A-245	18.897	2002-2758	Poor to Fair
	K83A-247	11.61	2002-2466	Poor
	K83A-249	7.202	2010-2298	Poor to Fair
	K83A-261	9.397	2002-2378	Poor
	K83A-262	11.399	2002-2458	Poor

Survey Name	Line Name	Length	Shotpoint Range	Quality
	K83A-263	8.396	2002-2338	Poor
	K83A-265	8.898	2002-2358	Poor to Fair
	K83A-270	10.893	2002-2438	Poor
	K83A-271	5.894	2002-2238	Poor
	K83A-273	5.892	2002-2238	Poor
	K83A-275	7.851	2003-2317	Poor
	K83A-280	11.593	2014-2478	Poor to Fair
	K83A-281	12.241	2002-2492	Poor to Fair
	K83A-282	8.021	1968-2289	Poor
	K83A-283	11.915	2001-2478	Poor
	K83A-285	8.815	2002-2355	Poor
	K83A-287	6.899	2002-2278	Poor
	K83A-289	5.901	2002-2238	Poor
Locker 1967 S.S.	L67-54	49.945	1059-1972	Fair
	L67-55	23.974	982-1346	Fair
	L67-56	17.929	1001-1132	Fair
	L67-57	22.139	1001-1172	Poor
	L67-58	10.052	1034-1058	Poor
	L67-59	6.663	1087-1186	Poor
	L67-60	13.283	684-994	Fair
	L67-71	26.544	1007-1601	Good
	L67-72	17.215	1005-1393	Poor
	L67-73	15.229	740-1081	Poor
	L67-74	7.167	1021-1181	Poor
	L67-75	16.347	736-981	Poor
	L67-76	13.644	1005-1209	Poor
	L67G-H	5.326	874-995	Poor
	L67G-J	36.109	652-995	Poor
	L67G-K	26.26	1004-1395	Fair
	L67G-L	20.046	729-1176	Fair
	L67G-M	14.361	860-1180	Fair
	L67G-N	10.079	860-1084	Fair
	L67G-R	9.104	980-1184	Poor
	L67G-U	3.78	1006-1090	Poor
	L67GY-E-K	28.216	323-923	Poor to Fair
	L67GY-T-X	35.583	363-429	Poor
	L67Y-L	14.514	924-1253	Fair
	L67Y-M	8.239	815-995	Poor
	L67Y-N	6.231	1006-1146	Poor
	L67Y-P	9.049	779-995	Poor to Fair
	L67Y-Q	13.305	1000-1298	Poor
	L67Y-R	7.37	830-995	Poor to Fair
	L67Y-S	26.169	595-1178	Fair

Survey Name	Line Name	Length	Shotpoint Range	Quality
	L67Y-U	11.713	731-991	Poor
	L67Y-W	23.154	1010-1525	Poor
Mia Mia S.S.	MM-001	21.577	469-629	Poor
	MM-002A	37.842	189-476	Poor
	MM-002B	21.59	481-642	Poor
	MM-003	63.7	4-481	Poor
	MM-004	56.691	4-427	Poor
	MM-005	30.762	405-634	Poor
	MM-006A	37.204	4-282	Poor
	MM-006B	28.986	287-502	Poor
	MM-007A	42.928	2-323	Poor
	MM-007B	40.797	322-626	Poor
	MM-008A	32.912	4-249	Poor
	MM-008B	37.271	245-524	Poor
	MM-009	61.594	4-465	Poor
	MM-010A	35.608	4-270	Poor
	MM-010B	34.706	265-522	Poor
	MM-010C	18.499	528-664	Poor
	MM-011A	17.854	15-149	Poor
	MM-011B	25.026	298-482	Poor
	MM-012	26.729	4-204	Poor
	MM-013	37.522	6-288	Poor
	MM-014	28.723	67-285	Poor
	MM-015	37.516	6-288	Poor
	MM-016	45.891	6-352	Poor
	MM-017	37.393	4-285	Poor
	MM-018	10.472	004-83	Poor
	MM-019	14.824	4-115	Poor
	MM-020	21.223	4-163	Poor
	MM-021A	37.357	5-288	Poor
	MM-021B	7.209	284-347	Poor
	MM-021C	12.144	256-444	Poor
	MM-022	16.173	4-124	Poor
	MM-023	51.921	6-286	Poor
	MM-024	29.482	6-167	Poor
	MM-025	17.479	6-137	Poor
	MM-026	21.783	6-168	Poor
	MM-027	21.477	5-125	Poor
	MM-028	28.492	6-218	Poor
	MM-029	15.674	6-124	Poor
	MM-030	21.378	6-166	Poor
	MM-031	9.863	008-82	Poor
	SR62-C-L	39.94	170-270	Good

Survey Name	Line Name	Length	Shotpoint Range	Quality
Wooramel S.S.	W65G-2	0	144-156	NONE
Gnaraloo West S.S.	WG67-031	0	1-144	NONE
Yalbalgo Yaringa S.S.	YY65-009	26.912		
	YY65-020	27.187		
	YY65-022	23.187		
	YY65-024	22.663		
	YY65-025	16.884		
	YY65-027	16.546		
		6461.269	**km**	

Appendix B

Seismic Byte Number and Navigation for Loading

Survey Name	CDP BYTE	Navigation		No SEGY Files
Yalbalgo-Yaringa	17	SYY65		Yanrey
Wooramel Recon SS	17	SW65		Woodleigh
South Carnarvon Onshore	17	SCW90		Quobba
Shark Bay	17	SB65		Patterson Trap
Sextant Land	17	SB75		Minilya
Saltmarsh Recon	17	SSR62		Kennedy Detail
Mia Mia	17	SMM		Hamelin SS
Lyndon-Quobba	17	SB72		Goanna Hill SS
Lyell Range	17	SCG83		Giralia SS
K83A	17	SK83A		GA South Carnarvon
K82A	17	SK82A		Byro
Hyde Soak Recon	17	SHS64		**Unable to Determine**
Giralia North	17	SGN84		Sandy Point
Carlston & Carlston	17	SCP93		Lake Macleod
Bernier 1982	17	SCG82		Locker 1967
Fisherman Point	17	SFP87		K82B
Gnarraloo West	17	NO NAV		J84A
Cuvier MSS	17	NO NAV		Bullara 2
Locker 1967	21	SL67		
J84A	185	SJ84A		
Bullara SS	203	SBULL		

Appendix C

Well Data for Loading
Key wells highlighted in yellow

Well	UWI	Sub-basin	Latitude	Longitude	Structure	Seismic location	Start depth (m)	TD (m)	Oil show	Gas show
Airey Hill 1	W001038	Gascoyne Platform	-23.07000	113.8700000	Anticline		0	1037	L0 Nil	G0 Nil
Bidgemia 1	W000861	Merlinleigh Sub-basin	-25.27000	115.3400000			0	211.84	L0 Nil	G0 Nil
BMR 05 Yanrey	W001498	Merlinleigh Sub-basin	-22.66000	114.2500000	Anticline		0	630.94	L0 Nil	G0 Nil
BMR 06 Kennedy Range	W001499	Merlinleigh Sub-basin	-24.10000	114.7700000			0	305	L0 Nil	G0 Nil
BMR 07 Kennedy Range	W001500	Merlinleigh Sub-basin	-24.10000	114.7800000			0	609	L0 Nil	G0 Nil
Brooke 1	W002466	Gascoyne Platform	-22.44000	114.0700000	Anticline		0	1168	L0 Nil	G0 Nil
Bullara 1	W001647	Gascoyne Platform	-22.70000	113.8900000	Faulted Anticline	VP 231 Line A89-03	0	1130	L0 Nil	G0 Nil
Bullara 1	W001647B	Gascoyne Platform	-22.70000	113.8900000	Faulted Anticline	VP 231 Line A89-03	720	1300		
Burna 1	W001353	Merlinleigh Sub-basin	-23.67000	114.4400000	Fault Trap		0	767.7	L0 Nil	G0 Nil
Cape Cuvier 1	W000020	Gascoyne Platform	-24.23000	113.4000000	Anticline		0	457.2	L0 Nil	G0 Nil
Carlston 1	W002515	Gascoyne Platform	-23.83000	114.1900000		CP93-02 SP 337	0	1003	L0 Nil	G0 Nil
Central Rough Range 1	W002387	Gascoyne Platform	-22.42000	114.0800000	Anticline	SP 299 on line A86.46	0	1155	L0 Nil	G0 Nil
Chargoo 1	W000681	Gascoyne Platform	-23.60000	113.9300000	Sheet Sand Bodies		0	428	L0 Nil	G0 Nil
Coburn 1	W002117	Gascoyne Platform	-26.70000	114.2300000			0	1093	L0 Nil	G0 Nil
Cody 1	W001793	Gascoyne Platform	-21.97000	114.3000000	Fault Trap	SP 172 Line MC88-55A	0	3165	L0 Nil	G0 Nil
Cooper 1	W002726	Gascoyne Platform	-22.08000	114.2000000	Four-way dip closure	MC87-06 SP 605	0	2103	L0 Nil	G0 Nil
Dirk Hartog 01	W000755	Gascoyne Platform	-25.720000	113.0500000			0	338.3	L0 Nil	G0 Nil
Dirk Hartog 02	W000756	Gascoyne Platform	-25.740000	113.0100000			0	256	L0 Nil	G0 Nil
Dirk Hartog 03	W000757	Gascoyne Platform	-25.750000	112.9700000			0	272.8	L0 Nil	G0 Nil
Dirk Hartog 04	W000758	Gascoyne Platform	-25.700000	113.0100000			0	457.2	L0 Nil	G0 Nil
Dirk Hartog 05	W000759	Gascoyne Platform	-25.760000	113.0300000			0	281.64	L0 Nil	G0 Nil
Dirk Hartog 06	W000760	Gascoyne Platform	-25.790000	113.0300000			0	304.8	L0 Nil	G0 Nil
Dirk Hartog 07A	W000761	Gascoyne Platform	-25.780000	113.0800000			0	274.32	L0 Nil	G0 Nil
Dirk Hartog 08A	W000762	Gascoyne Platform	-25.810000	112.9800000			0	364.5	L0 Nil	G0 Nil
Dirk Hartog 09A	W000763	Gascoyne Platform	-25.870000	113.1000000			0	257.6	L0 Nil	G0 Nil
Dirk Hartog 10	W000764	Gascoyne Platform	-25.950000	113.1600000			0	267	L0 Nil	G0 Nil
Dirk Hartog 11	W000765	Gascoyne Platform	-25.960000	113.1300000			0	249	L0 Nil	G0 Nil
Dirk Hartog 12	W000766	Gascoyne Platform	-25.960000	113.1000000			0	277.4	L0 Nil	G0 Nil
Dirk Hartog 13	W000767	Gascoyne Platform	-26.030000	113.1700000			0	297.2	L0 Nil	G0 Nil
Dirk Hartog 14	W000768	Gascoyne Platform	-25.890000	113.1500000			0	297.2	L0 Nil	G0 Nil
Dirk Hartog 15	W000769	Gascoyne Platform	-25.890000	113.0300000			0	320.95	L0 Nil	G0 Nil
Dirk Hartog 16	W000770	Gascoyne Platform	-25.820000	113.1100000			0	259.1	L0 Nil	G0 Nil
Dirk Hartog 17B	W000771	Gascoyne Platform	-25.870000	113.0800000	Anticline		0	1523.4	L0 Nil	G0 Nil
Dune 1	W002840	Gascoyne Platform	-22.440000	114.1100000	Horst Block		0	1401	L0 Nil	G0 Nil
East Marrilla 1	W000828	Merlinleigh Sub-basin	-22.910000	114.6200000	Anticline		0	638.25	L0 Nil	G0 Nil
Exmouth Structure Hole 1	W000025	Merlinleigh Sub-basin	-22.390000	114.1100000			0	536	L0 Nil	G0 Nil
Exmouth Structure Hole 2	W000026	Merlinleigh Sub-basin	-22.360000	114.1400000			0	618	L0 Nil	G0 Nil
Garden Mill 1	W001267	Gascoyne Platform	-22.560000	114.4700000	Anticline	SP 331 Line82-02	0	555	L0 Nil	G0 Nil
Gascoyne 1	W001354	Merlinleigh Sub-basin	-25.040000	115.0200000	Fault Trap	SP 2152 Line K83A-229	0	527	L0 Nil	G0 Nil
Giralia 1	W000027	Gascoyne Platform	-22.990000	114.1700000	Anticline		0	1243.58	L0 Nil	G0 Nil
Gnaraloo 1	W000682	Gascoyne Platform	-23.680000	113.7900000			0	499.9	L0 Nil	G1 Poor
Grierson 1	W000028	Gascoyne Platform	-24.200000	113.7700000			0	438	L0 Nil	G0 Nil
Grierson 2	W000029	Gascoyne Platform	-24.200000	113.7900000			0	458	L0 Nil	G0 Nil
Grierson 3	W000030	Gascoyne Platform	-24.200000	113.7600000	Anticline		0	442	L0 Nil	G0 Nil
GSWA Ballythanna 1	W001987	Byro Sub-basin	-26.060000	115.6700000	Anticline		0	465.2	L0 Nil	G0 Nil
GSWA Barrabiddy 1A	W002081	Gascoyne Platform	-23.830000	114.3300000		Line W90-06 SP 2377	0	238	L0 Nil	G0 Nil
GSWA Barrabiddy 1A	W002081B	Gascoyne Platform	-23.830000	114.3300000		Line W90-06 SP 2377	0	782.9		
GSWA Boologooro 1	W002487	Gascoyne Platform	-24.320000	113.9000000		Nearest line is B72-01L 20km to south	0	383.3	L0 Nil	G0 Nil
GSWA Edaggee 1	W002484	Gascoyne Platform	-25.360000	114.2300000		Nearest line W65S-001B 13km to the north	0	351	L0 Nil	G0 Nil
GSWA Gneudna 1	W001988	Merlinleigh Sub-basin	-23.970000	115.2200000			0	492.1	L0 Nil	G0 Nil
GSWA Mooka 1	W002080	Merlinleigh Sub-basin	-24.980000	114.8100000		Line W90-006 SP 2380	0	418	L0 Nil	G0 Nil
GSWA Woodleigh 1	W002316	Gascoyne Platform	-26.060000	114.6700000			0	333.1	L0 Nil	G0 Nil
GSWA Woodleigh 2A	W002317	Gascoyne Platform	-26.060000	114.5300000			0	618.3	L0 Nil	G0 Nil
GSWA Woodleigh 2A	W002317A	Gascoyne Platform	-26.060000	114.5300000			0	198		
GSWA Yinni 1	W002489	Gascoyne Platform	-26.060000	114.8200000			0	158.2	L0 Nil	G0 Nil
Hamelin Pool 1 (M188)	W000711	Gascoyne Platform	-26.030000	114.2100000	Diapir		0	1595	L0 Nil	G0 Nil
Hamelin Pool 2 (M188)	W000712	Gascoyne Platform	-26.150000	114.3600000	Anticline	1.2miles S of SP 838 Line 12	0	1219.2	L0 Nil	G0 Nil
Hope Island 1	W000692	Gascoyne Platform	-22.160000	114.4800000			0	1426.46	L0 Nil	G0 Nil
Kalbarri 1	W000868	Gascoyne Platform	-27.270000	114.1100000			0	1540	L0 Nil	G0 Nil
Kennedy Range 1	W000166	Merlinleigh Sub-basin	-24.500000	114.9900000	Faulted Anticline		0	2226.6	L0 Nil	G2 Fair
Lake Macleod 1	W003076	Gascoyne Platform	-24.590000	113.5400000		2km east of SP1500 line CG83-01	0	894	L0 Nil	G0 Nil
Lefroy Hill 1	W001481	Gascoyne Platform	-22.370000	114.1400000	Faulted Anticline	B85-118 SP 324	0	1374	L1 Poor	G0 Nil
Lefroy Hill 1	W001481B	Gascoyne Platform	-22.370000	114.1400000	Faulted Anticline	B85-118 SP 324	743	1512		
Marrilla 1	W000053	Merlinleigh Sub-basin	-22.930000	114.5000000			0	456.3	L0 Nil	G0 Nil
Merlinleigh 1	W000150	Merlinleigh Sub-basin	-24.500000	114.9900000	Anticline		0	304.8	L0 Nil	G0 Nil
Merlinleigh 2	W000151	Merlinleigh Sub-basin	-24.480000	114.9900000	Anticline		0	306.32	L0 Nil	G0 Nil
Merlinleigh 3	W000152	Merlinleigh Sub-basin	-24.490000	115.0000000	Anticline		0	166.12	L0 Nil	G0 Nil
Merlinleigh 4	W000153	Merlinleigh Sub-basin	-24.490000	114.9900000	Anticline		0	135.64	L0 Nil	G0 Nil
Merlinleigh 5	W000154	Merlinleigh Sub-basin	-24.470000	114.9900000	Anticline		0	175.26	L0 Nil	G0 Nil
Midway Hill 1	W001480	Gascoyne Platform	-22.530000	114.0200000	Faulted Anticline	SP 706 Line A85-44	0	1319	L0 Nil	G0 Nil
Moogooree 1	W000855	Merlinleigh Sub-basin	-24.250000	115.2600000			0	128	L0 Nil	G0 Nil
Moogooree 2	W000858	Merlinleigh Sub-basin	-24.280000	115.2100000			0	191.7	L0 Nil	G0 Nil
Mydas 1	W001884	Gascoyne Platform	-21.750000	114.3800000	Fault Trap	SP 1210 Line LC89-143	0	1476	L1 Poor	G0 Nil
North Giralia 1	W001395	Gascoyne Platform	-22.530000	114.3000000	Anticline	SP 760 Line 84-06	0	936	L0 Nil	G0 Nil
Pendock 1	W000737	Gascoyne Platform	-23.280000	113.3400000	Anticline		0	242.62	L1 Poor	G0 Nil
Pendock 1	W000737B	Gascoyne Platform	-23.280000	113.3400000	Anticline		0	2500.88		
Quail 1	W000051	Merlinleigh Sub-basin	-23.950000	114.5000000	Anticline		0	3580	L0 Nil	G0 Nil
Quobba 1	W001325	Gascoyne Platform	-24.340000	113.4400000	Anticline	VP535 CG83-12L	0	1931	L0 Nil	G1 Poor
Remarkable Hill 1	W000714	Gascoyne Platform	-22.960000	114.1600000	Anticline		0	3206.5	L0 Nil	G0 Nil
Roberts Hill 1	W001483	Gascoyne Platform	-22.400000	114.1000000	Faulted Anticline		0	1265	L1 Poor	G0 Nil
Rough Range 01A (Re-Entry)	W002159	Gascoyne Platform	-22.420000	114.0800000		A86- 1A	0	1108	L3 Good	G1 Poor
Rough Range 02	W000034	Gascoyne Platform	-22.430000	114.0700000	Anticline		0	1243.3	L0 Nil	G0 Nil
Rough Range 03	W000035	Gascoyne Platform	-22.410000	114.0900000	Anticline		0	1193.29	L0 Nil	G0 Nil
Rough Range 04	W000036	Gascoyne Platform	-22.420000	114.0800000	Anticline		0	1146.05	L0 Nil	G0 Nil
Rough Range 05	W000037	Gascoyne Platform	-22.420000	114.0800000	Anticline		0	1149.71	L0 Nil	G0 Nil
Rough Range 06	W000038	Gascoyne Platform	-22.420000	114.0800000	Anticline		0	1126.85	L0 Nil	G0 Nil
Rough Range 07	W000039	Gascoyne Platform	-22.440000	114.0700000	Anticline		0	1304.85	L0 Nil	G0 Nil
Rough Range 08	W000040	Gascoyne Platform	-22.450000	114.0600000	Anticline		0	1194.5	L0 Nil	G0 Nil
Rough Range 09	W000041	Gascoyne Platform	-22.450000	114.0700000	Anticline		0	1171.65	L2 Fair	G0 Nil
Rough Range 10	W000042	Gascoyne Platform	-22.420000	114.0900000	Anticline		0	1139.95	L2 Fair	G0 Nil
Rough Range 11	W001792	Gascoyne Platform	-22.420000	114.0800000	Anticline	VP 311 Line A86-42	0	1168	L0 Nil	G0 Nil
Sandalwood 1	W001643	Gascoyne Platform	-22.760000	113.8500000	Faulted Anticline	SP 428 Line A85-10	0	1350	L0 Nil	G0 Nil
Star Finch 1	W003054	Gascoyne Platform	-24.730000	113.7400000		CG 83-01L SP 3050	0	400	L0 Nil	G0 Nil
Tamala 1	W000869	Gascoyne Platform	-26.650000	113.6400000			0	1225.3	L0 Nil	G1 Poor
Tent Hill 1	W001632	Gascoyne Platform	-22.180000	114.6200000	Faulted Anticline	Line U SP 730	0	580	L0 Nil	G0 Nil
Tess 1	W002485	Gascoyne Platform	-22.370000	114.1400000	Faulted Anticline		0	1393.6	L0 Nil	G0 Nil
Wandagee 1	W000007	Gascoyne Platform	-23.890000	114.4000000		SP 258 Minilya Reflection Line A	0	1073.2	L0 Nil	G1 Poor
Wandagee Corehole 1	W000008	Gascoyne Platform	-23.890000	114.4000000		SP258 Line A	0	220	L0 Nil	G0 Nil
Wandagee Corehole 2	W000009	Merlinleigh Sub-basin	-23.890000	114.5300000		SP291 Line A	0	309	L0 Nil	G0 Nil
Wandagee Corehole 3	W000010	Gascoyne Platform	-23.830000	114.3400000		01/2mile S of Subroos Tank	0	223	L0 Nil	G0 Nil
Warroora 1	W000049	Gascoyne Platform	-23.510000	113.8800000	Anticline		0	1826.4	L1 Poor	G0 Nil
West Giralia 1	W001388	Gascoyne Platform	-22.650000	114.1700000	Anticline	SP 1291 Line84-12	0	789	L0 Nil	G0 Nil
Whitlock Dam 1	W001399	Gascoyne Platform	-22.830000	114.1900000		SP 1220 Line 84-09	0	413	L0 Nil	G0 Nil
Woodleigh 1981/2	W001129	Gascoyne Platform	-26.050000	114.6700000		SP 250 Line 8002N	0	189	L0 Nil	G0 Nil
Woodleigh 1982/01	W002153	Gascoyne Platform	-26.250000	114.8500000	Stratigraphic Trap	Line 8002S SP 33400	0	206.7	L0 Nil	G0 Nil
Yaringa 1	W000157	Gascoyne Platform	-26.060000	114.3600000	Faulted Anticline		0	2288.4	L0 Nil	G0 Nil
Yaringa East 1	W002116	Gascoyne Platform	-25.890000	114.3900000			0	829	L0 Nil	G1 Poor

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