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Exploration Potential Of The Lennard Shelf, Canning Basin, Western Australia

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***Abstract:** The Canning Basin, Western Australian is still under-explored for petroleum prospectivity. Hydrocarbon exploration was initially targeted the Devonian reef plays. Recently seismically defined closures with Carboniferous–Permian rocks are the most sought after targets. This paper examines the hydrocarbon potential of the Lennard Shelf analysing the petroleum systems and play types present.*

The study involves interpretation of a recent 3D seismic data integrated with 20 wells with the survey area for seismic facies analysis, well correlation and interpretation and dry hole analysis of drilled wells. Hydrocarbon production or associated shows associated within the wells in the Lennard Shelf from to Carboniferous, in Boundary-1, Lloyd-1 Sundown and West Terrace fields, evidence of a working petroleum system.

The producing reservoirs on the Lennard Shelf is the Betty formation, it is Carboniferous in age, sand dominated with inter-bedded shale units and on seismic it is seen as an interval of of low to high amplitude mostly chaotic reflection. The regional seal is the Winifred Formation shale, high amplitude relative low frequency and continuous reflection interval. From literature it is argued not be very effective as an explanation of a number of dry wells.

The Potential source rock is shale dominated Laurel Formation. Organic matter associated with input of terrestrial materials into the basin, with recorded TOC ranging from from 0.5>2%. Migration of hydrocarbons is probably mostly vertical through. Traps identified on the Lennard Shelf are both structural and stratigraphic, with potential for sand pinch-outs and compressional anticlines.

A dry hole analysis of the Whitewell-1 and the Hangover-1 wells was undertaken for further understanding the trapping mechanism associated in the survey area. These wells were drilled on the crest of a compressional anticline on the Lennard Shelf, but didn't encounter hydrocarbons. On the flank of the same broad anticline structure, the Sundown wells were drilled for Betty Formation reservoir and found a commercial accumulation of hydrocarbons. In determining the dry hole analysis of the wells, a well correlation of respective wells was constructed, seismic surfaces mapped, and petroleum systems quick look analysis was also used for better understanding of the possible source and migration. The result suggest that the Sundown wells found commercial hydrocarbons in stratigraphic traps (Channelised unit or sand pinch out) on the flank of an anticline and a model is proposed that the updip there must be some permeability barrier, possibly a shale dominated unit in the reservoir intervals preventing migration . The Whitewell-1 and Hangover-1 wells didn't find hydrocarbons on the crest of the anticline suggests possibly hydrocarbons migrated and leaked up through the reservoir due the effectiveness of Winifred seal.

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I. INTRODUCTION

A. RESEARCH BACKGROUND

The Canning Basin is one of the largest sedimentary basins in Western Australia, which covers approximately 640 000 km2, of which about 530 000 km2 is onshore. Approximately the same surface area as France or Texas (Fig1). It contains an Ordovician to Cretaceous sedimentary succession that reaches 15 km in thickness within the Fitzroy Trough (Forman and Wales, 1981; Towner and Gibson, 1983; Brown et al., 1984; Yeates et al., 1984; Kennard et al., 1994a).

The Canning Basin was initiated during the Cambro-Ordovician as northwest-southeast trending intracratonic rift and was later affected by several phases of rifting, thermal sag and compression. Deposition in the basin took place during a number of extensional and transpressional events, interspersed with episodes of thermal subsidence (Kennard et al., 1994a).

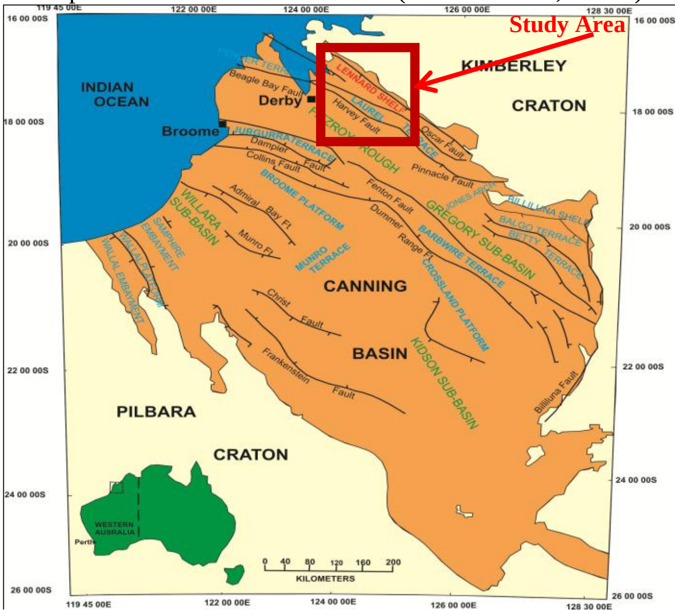

Figure 1: Location map showingGeneral tectonic elements, onshore Canning Basin (modified from Purcell, 1984)

The onshore Canning Basin is under explored for hydrocarbon resources, with relatively minor oil and gas production, although widespread shows at many stratigraphic levels and in different geological settings reveal that there are four active petroleum systems. Despite these positive indicators, the Canning Basin may be the least explored Paleozoic basin in the world.

The interpretation of the high quality 3D seismic data (Bunda 2009 3D seismic survey) acquired on the Lennard Shelf, provided by Buru Energy limited on the northern margin of the Canning Basin western Australia, has provided further analysis for the exploration potential of the Lennard Shelf for better understanding of the petroleum systems and the different traping mechanisms associated in the Shelf. The seismic data covers an area of 223 sq km, and 20 hydrocarbon exploration / appraisal wells drilled within the survey limits provide good subsurface control for the lithofacies, stratigraphy and time/depth control to constrain the mapped horizons and surfaces.(Al-Hinaai and Redfern 2013)

This paper identifies and evaluate the hydrocarbon exploration potential of the Lennard Shelf, Canning Basin Western Australia, and it describes and identifies the petroleum systems for a better understanding of the reservoir rocks, source rocks, seals, trapping mechanisms and migratory pathways, preservation is also of particular interest, which will result into the identification of major prospects, leads in the Lennard Shelf.

B. BACKGROUND AND EXPLORATION HISTORY

Exploration interest in the Canning Basin began in 1919, when the Freney Oil Company, encouraged by indications of oil in a water bore in the Pillara Range, Three of the four Prices Creek wells yielded traces of oil in massive limestone, which was thought to be lower Carboniferous in age. Freney Oil Company also encountered asphaltic shows in drill holes on the Lennard Shelf. In the pioneering phase of exploration between 1922 and 1950, surface mapping was the principal exploration tool. Ten wells were drilled during this period, a number of which recorded encouraging hydrocarbon shows (Australia, 2014; Cadman et al., 1993; SRK-CONSULTING, 1998).

During this initial exploration phase, the stratigraphy was revised and Devonian limestones became the favoured exploration targets and Devonian reef plays on the Broome Platform and Lennard Shelf were tested. During this period, drilling results in the southern Canning Basin provided little encouragement (Burt et al., 2002; Cadman et al., 1993).

Furthermore, there was an exploration boom in the 1980s, with Home Energy, Amoco, IEDC, Mobil, WMC, BHP, Bridge Oil and others joining the search. In 1981, Home Energy made the first commercial oil discovery in the basin with their Blina 1 well and In 1982, also discovered oil in the Grant Group and Anderson Formation in the Sundown 1 well.(Australia, 2014).

Up until the mid-1980s, exploration largely focused on the northern and central parts of the Canning Basin. The primary exploration targets were Devonian and Permian–Carboniferous strata. Many exploration wells had shows, especially oil, but only five discoveries resulted in commercial fields: the Blina, Boundary, Lloyd, Sundown and West Terrace oilfields (Australia, 2014).In 2009, Buru Energy completed the first 3D seismic survey in the Canning Basin – the Bunda Survey.In 2010, Mitsubishi farmed into Buru Energy acreage and provided capital investment for an active exploration program(Buru, 2009).

In October 2011, Buru Energy's Ungani 1 well intersected light oil (~37 degrees API gravity) in dolomitised limestone of the Carboniferous Laurel Formation. This was the first significant oil discovery in the Canning Basin since the 1980s and it generated renewed interest. This was reflected in a higher level of bidding for Canning Basin acreage in subsequent work program bidding rounds.Buru also discovered gas in 2011, in the Laurel Formation at their Valhalla prospect and conducted successful appraisal drilling at their Yulleroo gasfield in 2010 and 2013(Buru, 2013).

The Australian Council of Learned Academies confirmed this assessment and calculated a further 38 TCF of recoverable shale gas in the Laurel Formation (Ratner et al., 2011).As of November 2013, nearly 300 wells had been drilled onshore. Drilling has been accompanied by acquisition of 88 000 line km of 2D seismic and 429 km2 of 3D seismic, all onshore (Buru, 2013).

Furthermore, The Lennard Shelf has been the most prospective in terms of petroleum exploration Fig (2). Currently, exploration activity is concentrated on the Lennard Shelf, Broome Platform and Fitzroy Trough. The southeastern Canning Basin remains largely unexplored with less than a dozen exploration wells drilled and only a few thousand kilometres of seismic data acquired in an area of 200,000 sq km (Burt et al., 2002; Purcell, 1984)

There is a great deal of evidence that the Lennard shelf contains some hydrocarbon accumulations, because its located in a huge underexplored Palaeozoic aged superbasin with

IJIRAS

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evidence of three major petroleum systems, the Ordovician-Silurian, Devonian and the Carboniferous- Permian petroleum systems, and a huge a huge potential for unconventional exploration, the already discovered Blina oil field which will enchance exploration interest for deeper prospectivity.

C. AIMS AND STUDY OBJECTIVE

This study aims to find the following:

- ✓ Hydrocarbon generation potential of the Laurel and Anderson formation.
- ✓ Analysis of the Palaeozoic Petroleum systems associated in the Lennard shelf.
- ✓ Identification of potential traps and further analysis for possible leakage.
- ✓ Identification of stratigraphic traps in Betty and Winifred formation.
- ✓ Comparative analysis of the trapping mechanism associated in the Lennard Shelf.
- ✓ Dry hole analysis of the 20 wells in the study area.
- ✓ Identification of possible leads and prospects for deeper prospectivity on the Lennard shelf.

II. GEOLOGICAL SETTING

A. TECTONO-STRATIGRAPHIC EVOLUTION

The Canning basin is one of the world's largest underexplored Paleozoic basins , it consist of of troughs, terraces, platformsand shelves (Figure,1) based on the current basement configuration and sedimentary fills obtained from gravity and magnetic data. The Canning Basin is a massive intracratonic rift basin cradled between two large Proterozoic cratons (Pilbara-Yilgarn and Kimberley blocks), These are both underlain by a Proterozoic mobile belt. These cratons resulted in the deposition of four fault-bounded tectono-stratigraphic megasequences within the large subbasins which were controlled by northwest-southeast–trending basement lineaments (Fig 3) (Kennard et al., 1994).

The onshore part of the Canning Basin comprises of five main structural elements: these are Lennard Shelf, Fitzroy Trough, Crossland Platform, Kidson Sub-basins, Tabletop(Fig:2) (Shaw et al., 1994).

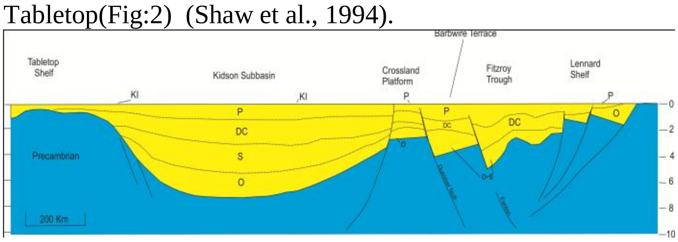

Figure 2: Showing Conceptual southwest/northeast cross section through the Canning basin (modified from Hocking et al., 1994)

The study area is the Lennard Shelf, located at the onshore part of the basin (Fig 1). The basin is characterised by NW-SE trending intracratonic extensional Basins that developed during the Ordovician, later modified by extensional events that resulted in the creation of two major depocentres, separated by a series of platforms, terraces and shelves (Figure 1) (Redfern, 1990, Hocking, 1994, Shaw et al., 1994, D'Ercole et al., 2003, Mory, 2010). The Northern Shelf region includes the Lennard Shelf, which is currently the main target for hydrocarbon exploration in the basin (Fig 3), and the focal point for this paper. Better understanding the subsidence and evolution history of the basin is crucial in identifying possible hydrocarbon plays and prospects for future exploration. The Lennard Shelf is the largest onshore sedimentaty basin in Western Australia, with evidence of relatively shallow basement, it onlaps with the precambrain rocks of the kimberky block in the northern part of the Basin. The southern part of the shelf is separated Westernly by the Harvey Fault system. The Lennard shelf is upto 60 to 100km wide and contains strata up to 4000m.(Crostella 1998)

Sediments deposited within the Canning Basin comprise three mega-sequences each of which correspond to deposition during a major extensional event and terminates by a major compressional event (Samphire Marsh Extension, Pillara Extension and Point Moody Extension) separated by unconformities related to regional compressional and/or transpressional phases (Shaw et al., 1994, Kennard et al.,1994b(Al-Hinaai and Redfern 2013)). These three mega-sequences are:

a. ORDOVICIAN- LATE SILURIAN MEGASEQUENCE

Firstly, the Samphire Marsh Extension mega-sequence of Early Ordovician to Late Silurian age. This contains sediments associated with initial rifting of the basin and the following Carribuddy Sage Phase(Jonasson, Ellis et al. 2001). It is dominated by shallow marine clastic, carbonate and evaporitic rocks and deposition was terminated by the Prices Creek Compressional Movement (D'Ercole et al., 2003; Hocking et al., 2008). It is controlled tectonically by northwest-oriented faults associated with the Samphire Marsh Extension started in the Early Ordovician (Kennard et al., 1994b, Shaw et al., 1994). Subsidence and marine transgression during the Samphire Marsh Extension in the Early Ordovician resulted in deposition of shallow marine sandstones, shales, siltstones, and carbonates of the Nambeet Formation and carbonates of the Willara Formation (Fig 4) and was controlled primarily by southwest-dipping forming flanked half grabens with the exception of Samphire Embayment which represent a graben bounded by a southwest-dipping fault from the north and a northeast-dipping fault from the south (SRK Consulting, 1998(Al-Hinaai and Redfern 2013)). This was followed by a regressive phase in the Mid Ordovician, when the clastics and carbonates of the Goldwyer, and carbonates of the Nita Formation were deposited in shallow marine to subtidal/intertidal areas (Brown et al., 1984). A period of sub aerial exposure and non-deposition occurred from the Later Ordovician to Early Silurian(Jonasson, Ellis et al. 2001).The Ordovician sedimentary rocks have a maximum thickness of about 1000 m. The sag phase of the basin continued into the Silurian - Early Devonian with the deposition of evaporites and redbeds in a restricted marine to continental setting.(Crostella 1998).

Finally, The Intracratonic rifting in the Silurian led to the formation of the Fitzroy Trough and the Kidson Sub-basin. At

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this time, the Fitzroy Trough and Gregory Sub-basin became major depocentres containing predominantly clastic sediments, and the Lennard Shelf reefal carbonates began to grow on pre-existing structural highs(Jonasson, Ellis et al. 2001).

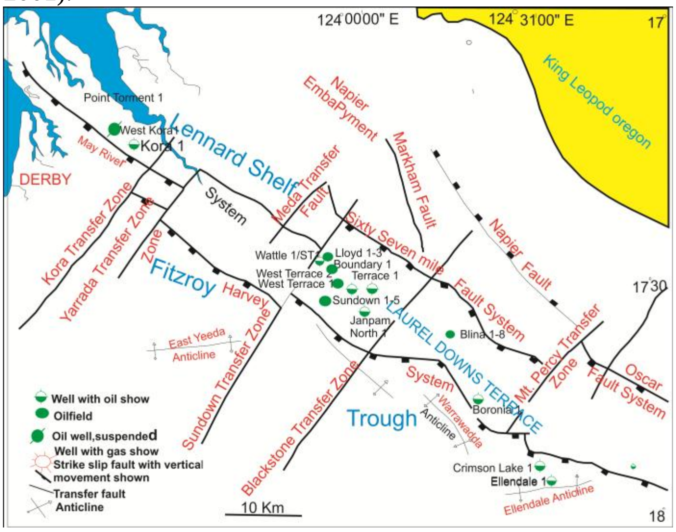

Figure 3: Tectonic lineaments of the western Lennard Shelf (Modified after Shaw et al., 1994), and wells with shows

b. DEVONIAN- LOWER CARBONIFEROUS MEGA SEQUENCE

Secondly, the Devonian–Lower Carboniferous mega-sequence resulted in the deposition of the Nullara Limestone and was associated with the Pillara Extension, Contemporaneously, shales of the Clanmeyer Formation and carbonates of the Luluigui Formation were deposited in shelf and slope environments (Shaw et al., 1994.)It is recorded that significant relative sea-level drop resulting into the deposition of terrestrial to marginal marine sediments and extensive carbonate reefs (D'Ercole et al., 2003). Shallow marine conditions were established over most of the northern basin, resulting in the deposition of limestones, shales and coarse clastics of the Fairfield Group, and interbedded sandstone and mudstone of the deltaic to fluvial Early Carboniferous Anderson Formation. Subsidence and rift-infilling resulted in the deltaic sediments of the Anderson Formation being deposited over the Fitzroy Trough (Brown et al., 1984).The Grant Group is subdivided into the Carolyn, Winifred and Betty Formations (Fig 4). Overlying the Grant Group, the Blina Shale was deposited in the Early Triassic. The Grant Group consists of thick sandstones, with thin, fining-upwards transitions to interbedded shales, and are interpreted as braided fluvial deposits (Ref). Furthermore, Sedimentation ceased during the Mid- to Late Carboniferous which coincided with the Meda Transpressional Event (Shaw et al., 1994; Kennard et al., 1994).

c. UPPER CARBONFEROUS- PERMAIN MEGA SEQUENCE

Lastly, The third mega-sequence is the Upper Carboniferous–Permian mega-sequence which composes of glacial deposit of the Reeves formation and Grant Group, and post-glacial fluvial to Shallow marine siliciclastic sediments of Poole Sandstone, marine shales and silt stones of the Noonkanbah formation and the shallow marine siltstone and sandstones of Liveringa Group (Redfern, 1990; D'Ercole et al., 2003; Hocking et al., 2008; Mory, 2010; Mory & Hocking, 2011). On the Barbwire Terrace (Fig. 5) the Grant Group has been subdivided into the Hoya, Calytrix and Clianthus formations (Redfern, 1990). The Calytrix formation was interpreted to have been deposited in a shallow marine to lacustrine setting during a major deglaciaton event, with little evidence for direct glacial influence on its deposition. (Al-Hinaai and Redfern 2013). The post-Permian section consists of late Middle Jurassic marine sandstones (Wallal Sandstone, Alexander Formation and Jarlemai Siltstone) and Cretaceous continental Broome Sandstone, A thin Quaternary cover of mainly alluvial sediments overlies the Broome Sandstone (Jonasson, Ellis et al. 2001, Al-Hinaai and Redfern 2013). Figure 4 illustrates the generalised stratigraphy.

On the Lennard Shelf the Grant Group is subdivided into the Betty, Winifred and Carolyn formations (Fig. 4), and its interpreted to record glacial deposition based on interpreted outcrop studies. Furthermore, the lack of detailed biostratigraphy data for the Grant Group means that correlation of exposed units to the subsurface is still subjective (Al-Hinaai and Redfern 2013).

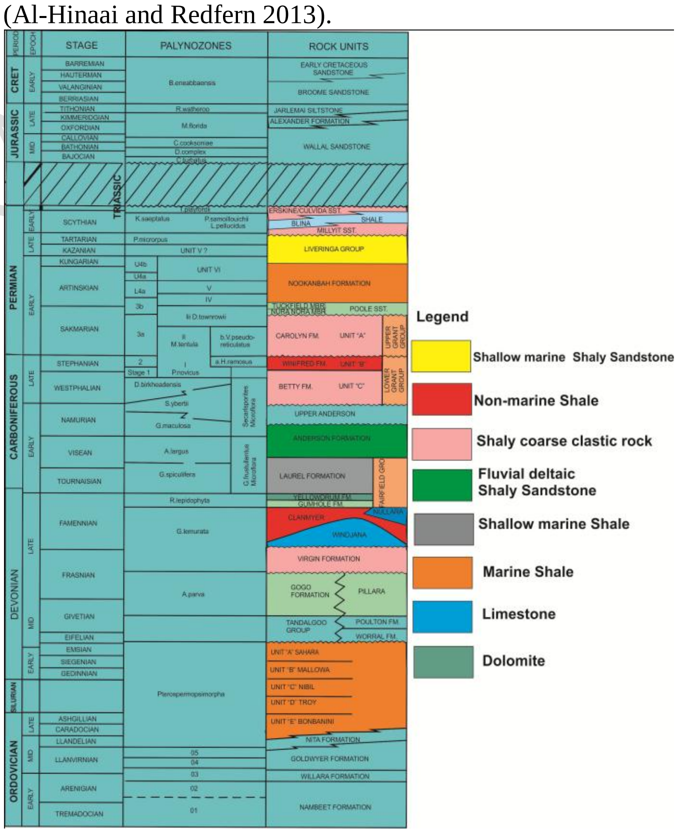

Figure 4: Generalised stratigraphy of the onshore Canning Basin (after Goldstein, 1989 and Kimberley Oil NL Prospectus, 1997)

B. DATA SET

The study is based on a recently acquired high quality 3D seismic data (Bunda 3D 2009 survey) within the Lennard

Shelf, northern Canning Basin, acquired by Buru Energy Limited.

The seismic data covers an area of 223 km², with an inline and crossline spacing of 30 m and a source frequency of 5–80 Hz. The dataset was supplied by Buru Energy Limited as 3D migrated seismic. Twenty exploration and appraisal wells (Fig. 5), drilled within the area covered by the Bunda 3D seismic survey were used to determine formation tops in two way time and provided lithology data to aid the interpretation of seismic facies.

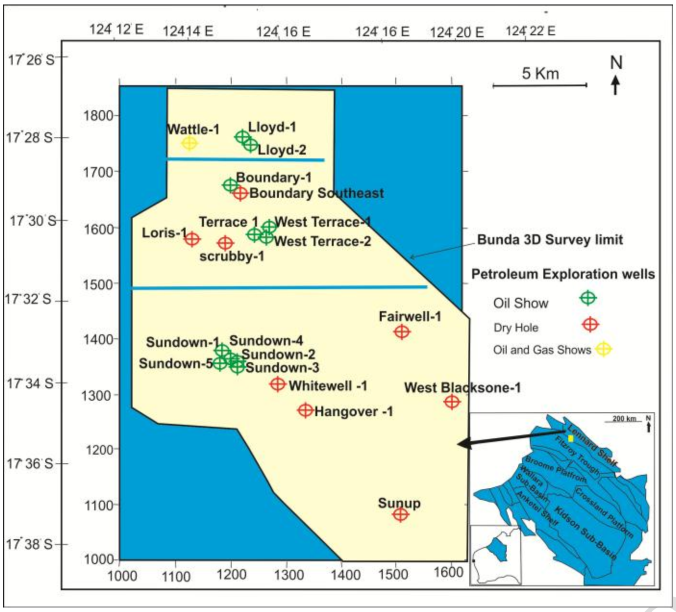

Figure 5: Location of Bunda 3D seismic survey and the 20 exploration and appraisal wells used in the study (Canning Basin map modified from Mory, 2010)

C. METHODOLOGY

This study develops a well-constrained seismic facies interpretation by integrating 3D seismic with an extensive subsurface database. To tie the wells to seismic data, synthetic seismograms were computed for all wells within the study area except for Lloyd 1 and Hangover 1 due to the absence of density logs. Formation tops where converted to TWT using synthetic seismograms incorporated with checkshot data. A velocity model was created with the use of the an average sonic velocity from each formation top in each well, to depth convert the surfaces from TWT to depth(Z).

Seven horizons were picked, corresponding to the Poole Sandstone, Top Grant (Carolyn), Winifred, Betty, Anderson, Base Grant and Laurel formation tops, Faults where interpreted, Channels where interpreted on seismic, Surface and Isochore maps where made of each formation top. The PSQL was used to make vitronite reflection maps, Source regeneration maps, reservoir maps and accumulation maps. Attribute analysis was undertaken to image the channels system within the Carolyn and Betty formations, using RMS attributes, as this offered the optimum response and to identify direct hydrocarbon indicators.

Finally, the petroleum system of the basin was analysed, a dry hole analysis was made for the under produced wells, new prospects were also identified.

The methodology and procedures employed during the period of this research are summarised in figure.

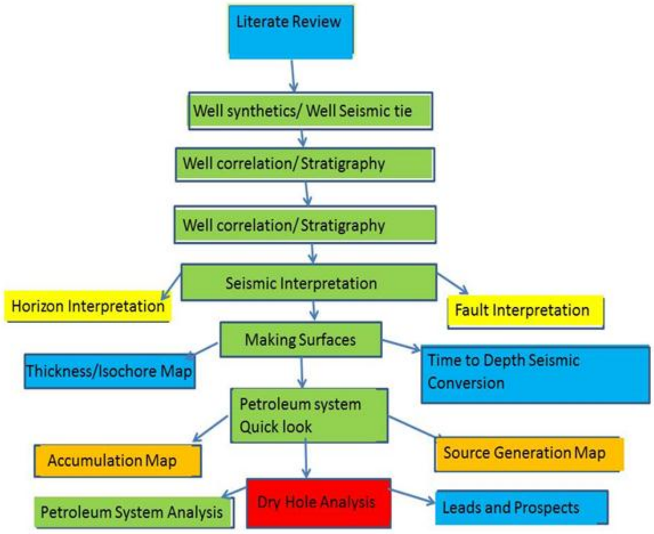

Figure 6: Methodology and Workflow

D. WELL CORRELATION

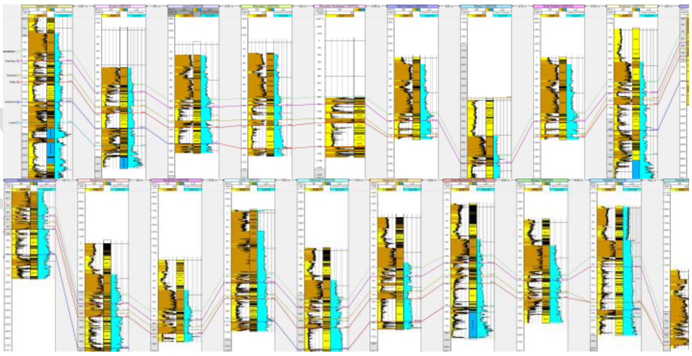

Figure 7: Well Correlation of the 20 wells of the survey area showing lateral variation of facies

E. WELL TO SEISMIC TIE

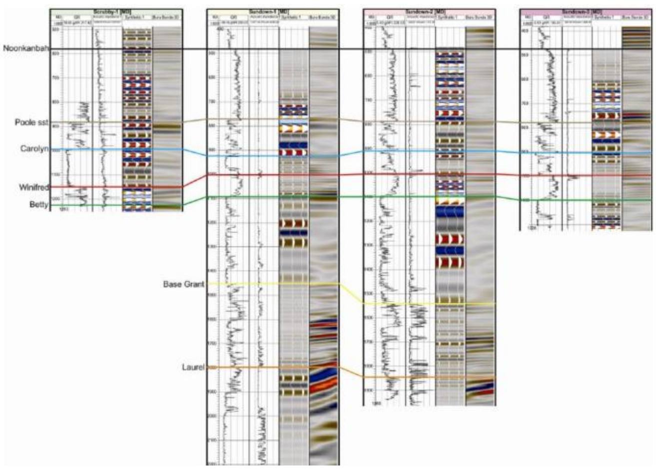

Figure 8: Seismic to well The Scrubby-1 well and the Sundown wells

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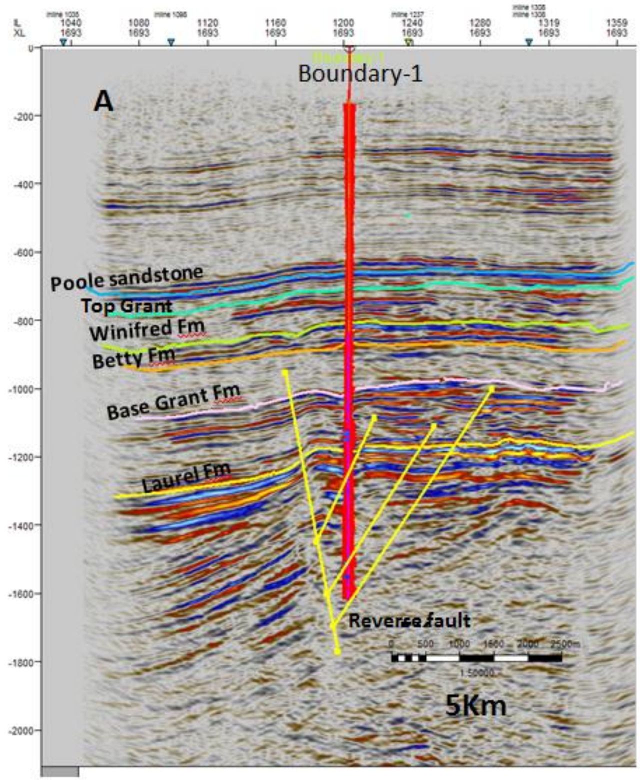
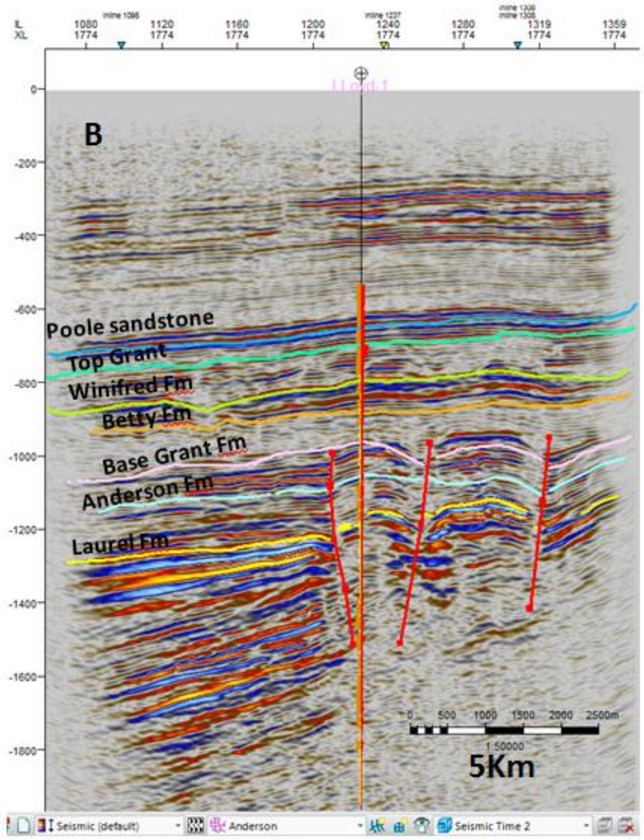
III. SEISMIC INTERPRETATION

A. STRUCTURAL OBSERVATION





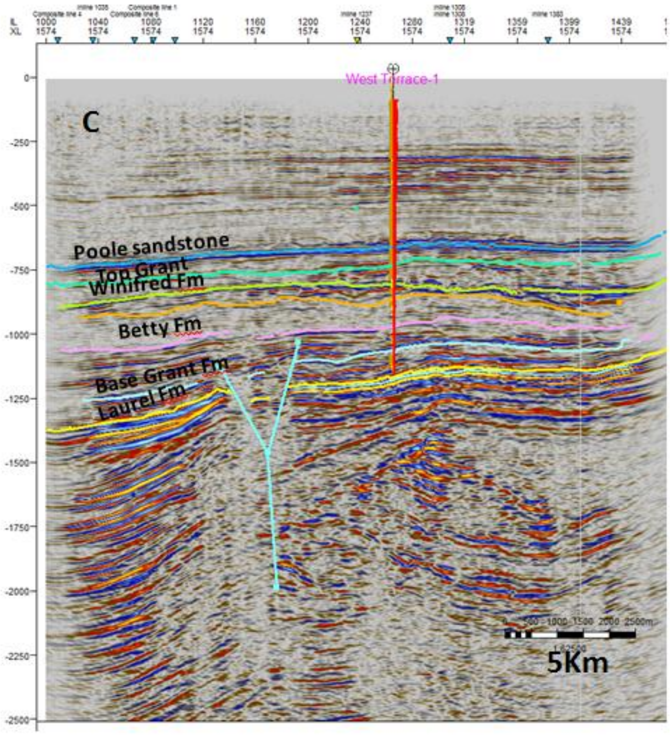
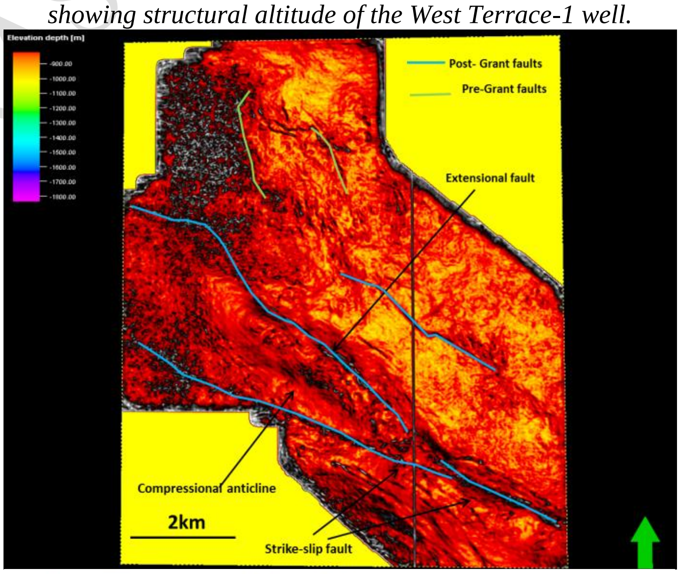


Figure 9:A Seismic section cross line 1673 showing structural altitude of the Boundary-1 well, (B) Cross line 1774 showing structural altitude of the Lloyd-1 well, (C) Cross line 1574 showing structural altitude of the West Terrace-1 well.



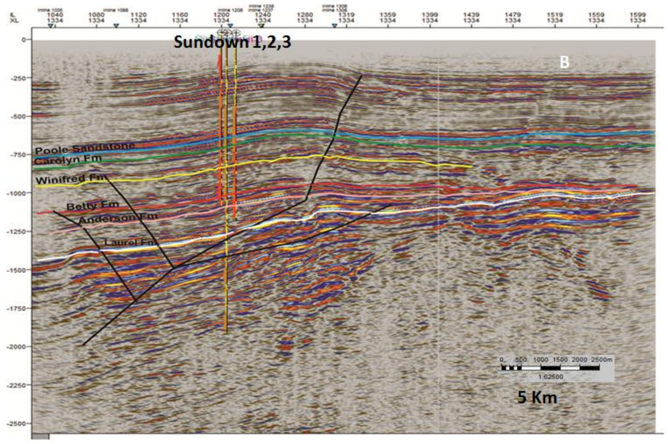


Figure 10: (A) Showing a Z-slice depth converted volume of the Bunda 3D dataset showing pre-Grant and post-Grant faults with variance attribute. (B) Cross line 1334 showing structural altitude of the Sundown fields

B. STRUCTURAL INTERPRETATION

Fig(9) There is no tectonic movement across the post-Grant sequence. The structure can be interpreted as a roller which was superimposed on an inverted fault structure (flower like structure) at the Laurel Formation on the Boundary-1 well, the Boundary-1 was drilled to test the Anderson formation. Crostella (1998) emphasized that the base Grant rollover is due to minor differential compaction over older structure. Due to the fact that an Angular unconformity is present between the Grant Group and Anderson Formation it can be concluded that there are possible large basal channels breaching the Anderson formation. Knauer, (1992) also commented that there are at least five channel surfaces in the Betty Formation.

Fig(9 B) This can be interpreted as a gentle folded structure of the Anderson Formation, it actually the producing reservoir of the Llyod-1 well. The Anderson and Laurel Formations due to their folded nature appears to be fault controlled by compressional forces. The base Grant is an unconformity, there is further evidence of an angular unconformity between the Grant Group and the Anderson Formation. Erosional surfaces can be observed on seismic.

Fig(9 C) This can be interpreted as a four-way dip controlled unfaulted anticline, the Y shaped fault in the West-Terrace-1 field is due to late Triassic to Early Jurassic wrech movement.

Fig(8A) This is a z-slice of the depth converted seismic volume of the survey area, showing the pre-Grant and post Grant faults. First set of faults ranges from NW-SE to NE-SW direction, they are underlay in the Grant Group and terminate at the base, is known as the post Grant faults. The pre-Grant faults form series of horst structures and grabens and half grabens and rotated fault blocks. These are normal faults that show slight thickening in Anderson and Laurel Formation into the hang wall. Above the base Grant unconformity, there is little or no thickening or displacement associated with this faults.

Fig(8B): The Sundown fields are drilled on the flank of a compression anticline on a gentle closure, they are describe as a positive flower-like structure typical of early carboniferous rifting. Production results from this field indicate that the reservoir sands are of various qualities, this is evident that the trap is post depositional.

In discussing the relevance of these structures to hydrocarbon accumulation, the peak hydrocarbon generation from the shales of the Laurel Formation source rocks occurred in the Fitzroy Trough before the Meda Movement Furthermore, migration of hydrocarbons from the Laurel source interval pre-dated the formation of the mid-Late Carboniferous structures. However, throughout the Lennard Shelf the Laurel Formation shales are still immature (Ellyard, 1984).

C. FACIES INTERPRETATION

a. *OBSERVATION*

Horizons were picked over the study area, correlated with well data to the main formation tops. They are the Poole sandstone, Top Grant, Winifred, Betty, Base Grant, Anderson and Laurel Formations.

A summation of the different facies occurrence with respect to seismic observation, different well log response and cutting description, can be shown Table 1.

Formation Tops	Seismic Facies	GR Log	Mud log lithologies
Poole Sandstone	High amplitude continuous planar reflections to a low amplitude chaotic to high amplitude reflection.	Coarsing upward sequences, relatively high GR response compared with the Carolyn formation.	Sandstone with minor interbedded Claystone and siltstone
Carolyn Formatiom	Varying from low amplitude chaotic to continuous high amphitude reflection, with channel like erosional surfaces.	Generally low GR readings with intervals of high GR representing shale dominated intervals	Mainly Claystone with minor Siltstone and minor Sandstone. The Claystones are light to dark grey, fissile. Siltstones are light grey to olive grey, micromicaceous and slightly calcareous. Sandstones are clear, tranculent ,light orange, fine to very coarse, firm to moderately hard.
Winifred Formation	High amplitude, relative low frequency, continuous reflection to a Low amplitude mostly chaotic reflection.	High GR response, base shows a gradual change from the underlying low GR of the Betty Formation.	Claystone dominated with minor Silstones and Sandstones. The Claystones are medium to dark grey, firm to hard with trace to abundant pyrite. Siltstone is light to dark grey, moderately hard to hard, argillaceous and very micromicaceous The Sandstones are light grey to light olive gray, angular to sub angular, moderately sorted with trace of pyrite and lithic fragments
Betty Formation	Low amplitude mostly chaotic reflection to a High amplitude mostly chaotic reflection.	Low GR response, fining upwards sequences	Sandstone dominated with minor Siltstone and Claystone. The Sandstone is light grey, fine to very coarse grained, subangular to subrounded with pyritic and withlithic grains. The Siltstone is medium to dark grey,very argillaceous with pyritic with very fine grained quartz. The Claystone is medium to dark grey,

IJIRAS

			firm to hard, pyritic and slightly carbonaceous.
Anderson Formation	High amplitude mostly chaotic reflection to a High amplitude most chaotic reflections.	Vary from medium to high GR readings	Interbedded sequence of Siltstone and Sandstone with interbeds of Claystone and Limestone. The Siltstone varicoloured with different shades of grey , brown, its argillaceous and calcareous. The Claystone is light to medium grey, occasionally pyritic and partly calcareous. The Sandstone is light grey, friable and firm slightly pyritic with siliceous cement. The Limestone is like to dark buff , medium to dark brown , calcarentic with fossils.
BaseGrant Formation	High amplitude most chaotic reflection to a High amplitude continuous planar reflections.	Vary from medium to high GR readings	
Laurel Formation	High amplitude continuous planar reflections to a low amplitude continous plannar relection.	Very low GR reading	The formation consist predominatly with Sandstones with interbedded Siltones with Limestones and Dolomite. The Sandstone is light grey, very fine to fine grained,varially argillaceous. Siltstone is medium to dark grey, general carbonaceous, pyritic and with very fine quartz. The Dolomite is brown grey, generally crypto to coarsely ccrystalline. The limestone is varicoloured with different shades of colour, generally brittle, fossiliferous and with sparry calcite.

Table 1: Summary of seismic facies with to seismic observation, cutting description and gamma ray response of Poole sandstone, Grant Group, Anderson, Base Grant and Laurel Formation

b. POOLE SANDSTONE

The Poole sandstone Formation is Permian in age, it's a sand dominated sequence containing several coarsening upward siltstones to sandstones units. On seismic its see as a high amplitude continuous planar reflections to a low amplitude chaotic to high amplitude reflection. It has a relatively high GR response compared with the Carolyn formation. Resistivity reading is quite normal, no evidence of an hydrocarbon bearing sand.

c. CAROLYN FORMATION

The Carolyn formation on seismic shows low amplitude chaotic to high amplitude laterally continuous reflections. A U-shape glacial through channel was observed in Xline 1392, which terminates on the Betty formation. The Carolyn formation on well log is identified as a coursing upwards sequence compared to the Poolse sandstone which has a much higher gamma-ray reading compared to the Carolyn formation. The basal part of the Carolyn formation on well interpretation shows a sharp upward change from mudstone to which represents high GR reading to sand dominated sediments representing a low GR reading.

Furthermore, On seismic two sets of erosional surfaces where identified, these are the erosional surface 1 and 2. The erosional surface 1 compose of low amplitude chaotic reflection covered by high amplitude continuous reflection. These channels where observed on the West Terrace 1&2 fields and Scruby-1 field.

d. WINIFRED FORMATION

The Winifred Formation on seismic is seen as a High amplitude, relative low frequency, continuous reflection to a Low amplitude mostly chaotic reflection. When seen on well logs they represent a High GR response, its shale dominated, the base shows a gradual change from the underlying low GR of the Betty Formation, neutron and density log also show a high reading. An erosional surface is observed below the Winifred formation, that eroded most part of the Betty and Anderson formation, there are various truncations and onlap associated with this formation.

e. BETTY FORMATION

On seismic the Betty facies is seen as a high amplitude reflection to a low amplitude chaotic reflection. There is an indication of unconformity, due to various truncations below the surface and onlap above the surfaces. Channels where also observed in this section but cannot be picked throughout the seismic volume, these erosional surface terminates on the Base Grant unconformity. From the wireline log interpretation it can be observed that it was sand dominated due to the change of gamma-ray from a high to a low reading. Rms attribute was use on the Betty formation mapped surface to identify existence of channel like features, lateral continuous channels where found, this channels can act as stratigraphic traps for the Sundown field. Resistivity log shows a high reading evidence of hydrocarbon bearing sands in this unit while Neutron and density logs show a low reading.

f. ANDERSON FROMATION

The Anderson formation underlies the Grant Group, is lower to middle Carboniferous in age, on seismic its seen as a high amplitude mostly chaotic reflection to a High amplitude most chaotic reflections, on wireline logs it varies from

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medium to high GR readings, it forward shows a medium Neutron and a high desnsity reading, lithologies observed area Interbedded sequence of Siltstone and Sandstone with interbeds of Claystone and Limestone, the basal part of the Anderson formation can be seen as an unconformity.

g. BASE GRANT FORMATION

The Base Grant Formation is an unconformity, its carboniferous in age, on seismic its seen as a High amplitude most chaotic reflection to a High amplitude continuous planar reflections. Log interpretation shows a medium to high GR readings, this reflection is not continous in the survey area, it is parallel with the Anderson Formation at the slope of the basin. Lots of onlaps and truncations can be seen in this unit.

h. LAUREL FORMATION

The Laurel Formation is an unconformity overlaid by sandstones the Anderson formation in some location and the Base Grant unconformity in the survey area., its Lower to Middle Carboniferous in age, it is shale dominated, on seismic its seen as High amplitude continuous planar reflections to a low amplitude continous plannar relection. Its highly fault at the western part of the survey.

IV. MAPPED SURFACES

A. TOP POOLE SANDSTONE MAP

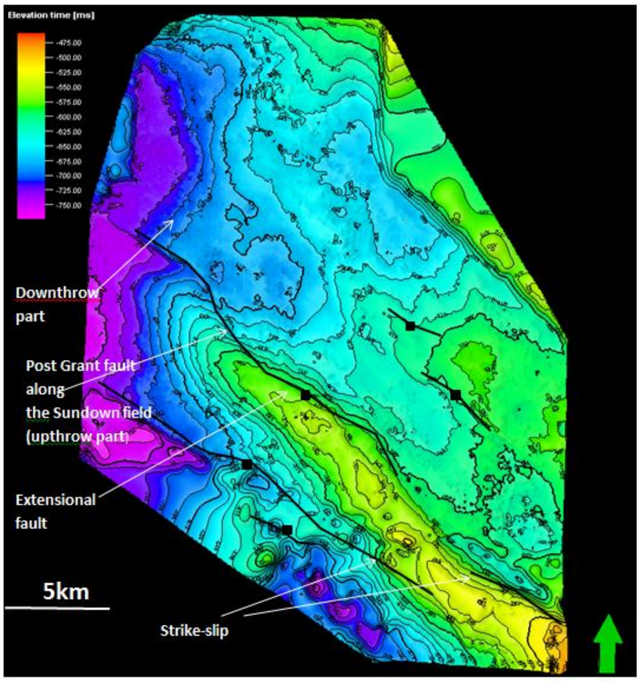

Figure 11: Top Poole sandstone TWT surface map show compressional anticline also extensional faults and strike-slip faults, thickness changes observed on seismic suggest possible a fault controlled topography

B. TOP GRANT (CAROLYN FORMATION) MAP

The Carolyn Formation on seismic varies from low amplitude chaotic to continuous high amplitude reflection, with a channel like erosional surfaces. The Carolyn Formation is overlain by the Poole Sandstone Formation and underlain by the Winifred Formation, it's a relative planar surface, the surface shows a compressional anticline in which the post Grant faults is cutting through on the hanging wall and also a strike-sli[fault on the southern part of the surface. The surface is generally deeping westward and swallowing eastward.

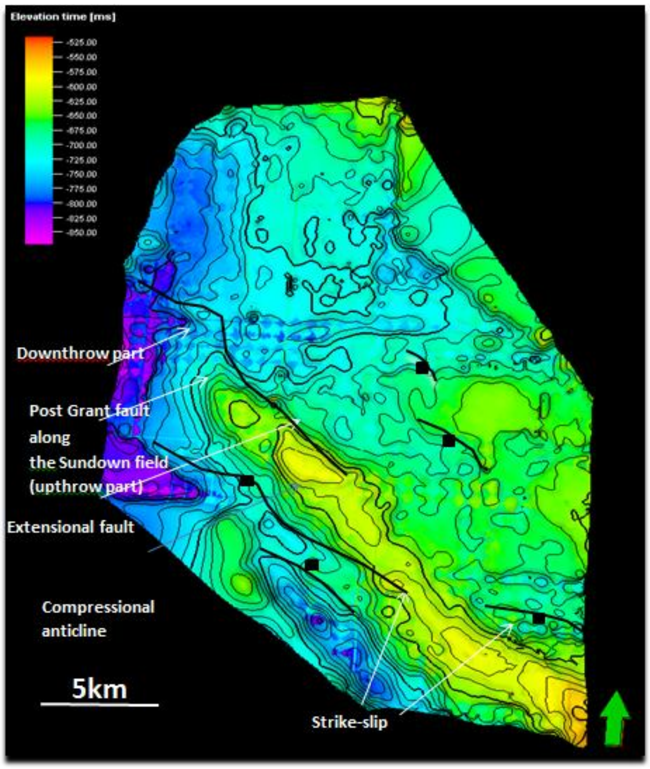

Figure 11: Top Grant TWT surface map show major faults and possible channel like structure at the North central part of the surface

C. TOP WINIFRED FORMATION MAP

The Winifred formation is overlain by the Poolse Sandstone Formation and underlain by the Betty Formation, it's a relative planar surface, it exhibits a High amplitude, relative low frequency, continuous reflection. The surface is generally deeping westward and swallowing eastward, the Winifred formation is acting as an intra-formational seal for the Permian-Carboniferous reservoirs, the surface has a fault controlled topography. This surface exhibits a compressional anticline in which the post Grant faults is cutting through, an evidenced of a strike slip faults is seen on the southern part of the surface. Finally, incisions by channels of the Carolyn Formation eroded some part of the Winifred Formation.

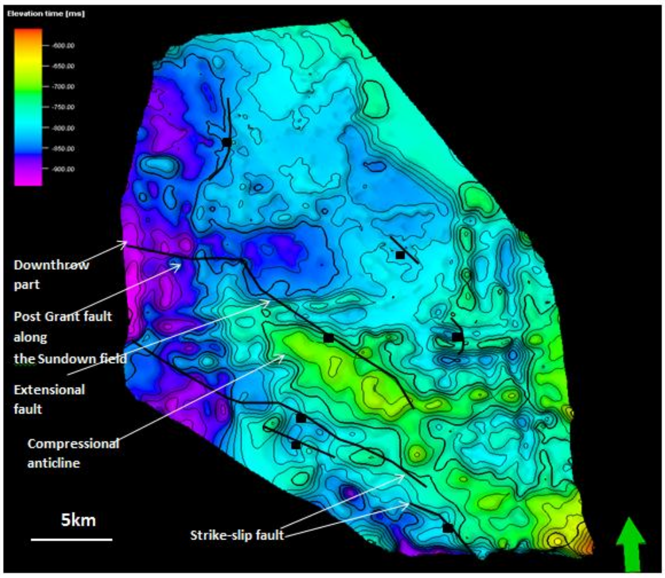

Figure 12: Top Winifred TWT map of showing a faulted topography

D. TOP BETTY FORMATION MAP

The Betty formation is the main producing reservoir of the Grant Group, the surface is generally Deeping westward and swallowing eastward.it has a fault controlled topography, On seismic its was seen as a Low amplitude mostly chaotic reflection. it overlies the Winifred formation which is an intra-formational seal and underlies the Anderson formation. This surface exhibits a compressional anticline in which the post Grant faults is cutting through, an evidenced of a strike slip faults is seen on the southern part of the surface. Furthermore, A channel was seen on seismic that eroded the some part of the Winifred Formation on the West Blackstone-1 well.

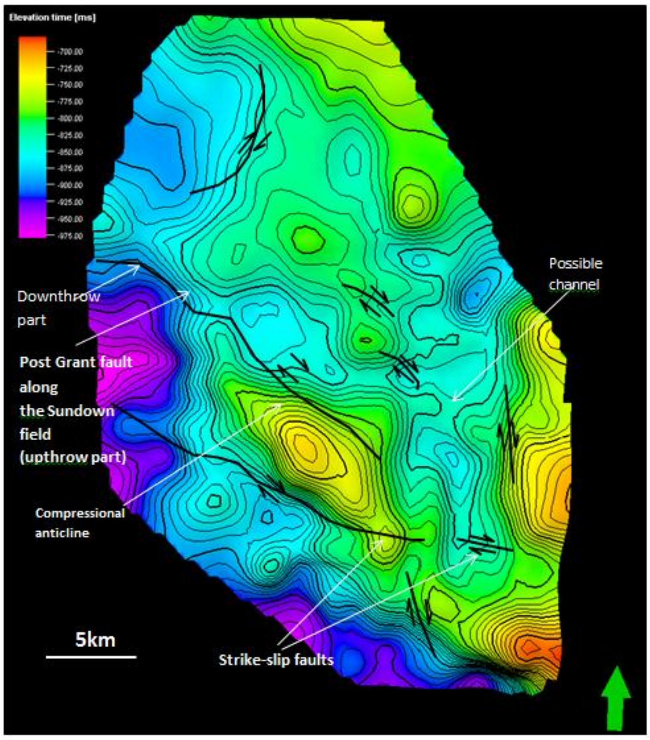

Figure 13: Top Betty Formation TWT surface map showing the closure of the Sundown fields, compressional anticline and syncline on the western part survey, possible location of channels and major faults, also showing closures of major producing fields

E. TOP ANDERSON MAP

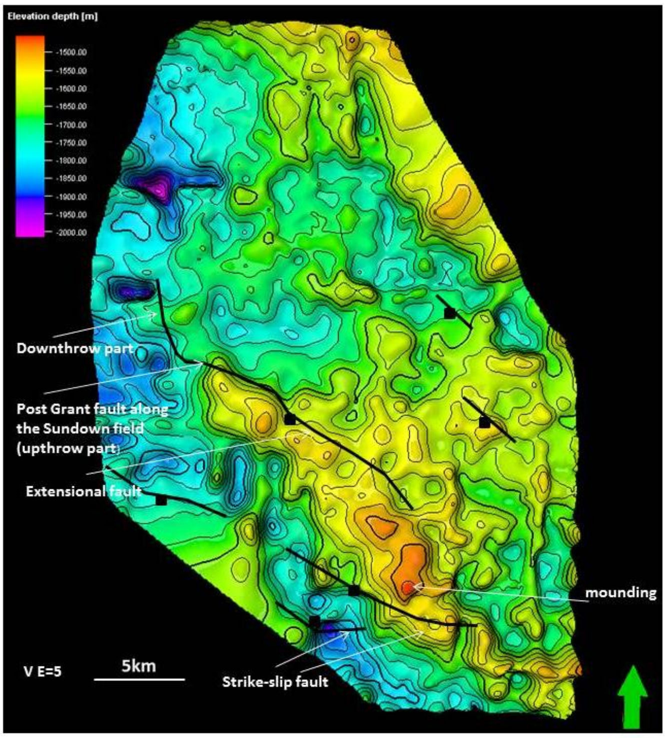

Figure 14: Top Anderson Formation TWT surface map showing mounding on a structural high, strike slip faults and extensional faults

F. TOP BASE GRANT MAP

The Base Grant Formation is an unconformity, it's a high amphitude continuous planar reflections on seismic, it overlies the Laurel formation and underlies the Anderson formation, in the eastern part of the survey area the Base Grant Formation is parallel with Anderson formation, and evidence of that is on the West Blackstone-1 well where the Betty formation, Anderson Formation and alongside the Laurel where total eroded way (Fig,9). The mapped surface of the Base Grant formation shows compressional anticlines, its generally shallowing eastward and deeping westward with evidence of channels and also strike-slip faults.

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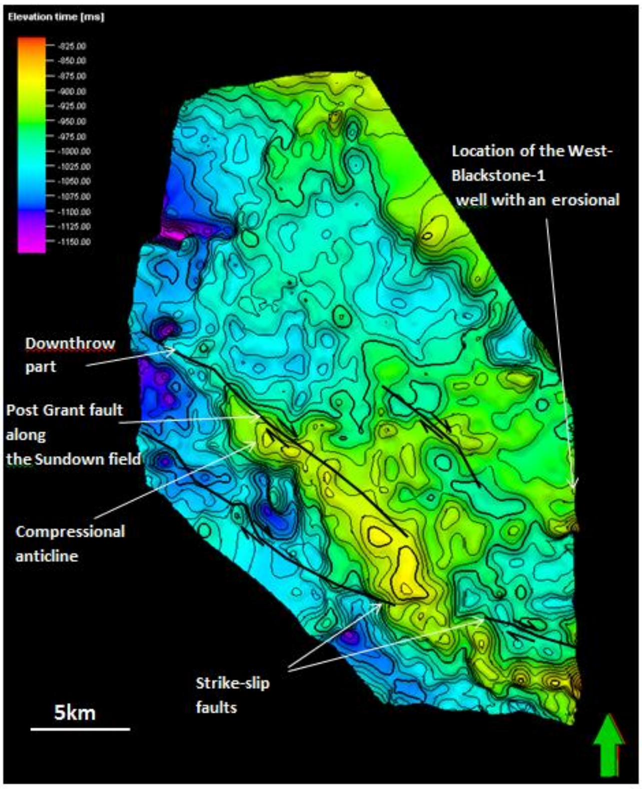

Figure 16: Top Base Grant TWT surface map show the compressional anticline and an erosional surface at the West Blackstone-1 well

G. TOP LAUREL MAP

The Laurel formation is picked on a high amplitude positive reflection, this reflection on well log indicates on GR ashale dominance, the reflection is a high amplitude continuous planar reflection. The surface is Deeping westward and swallowing eastward. The Laurel formation is controlled by extensional faults moving in the NW-NE direction. On the Northern part of the surface a horst structure, a half graben and a normal fault can be observed (fig 8).

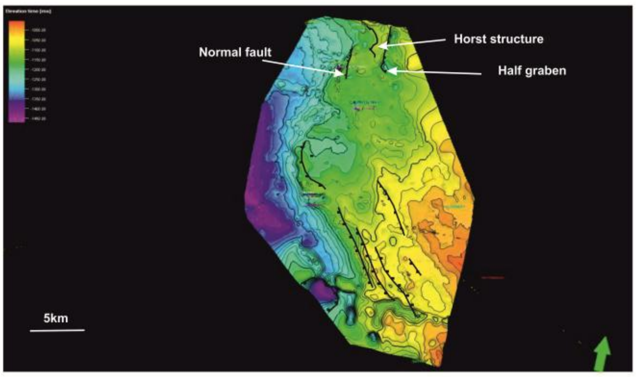

Figure 17: Top Laurel Formation TWT surface map showing normal faults, Horst structure and half graben

H. EROSION SURFACES BELOW THE TOP GRANT

Several erosion surfaces where seen on seismic, from a V- shaped morphology at the northern part of the seismic survey to a U- shaped channelled paleo valley at the southern part, this was evident due to visible truncation and onlaps on the seismic lines. A U-shaped glacial through channel observed within the Carolyn Formation, which eroded most of the sediments of the Winfred and Carolyn Formation.The Channel floor depth is measured from Grant top to eliminate the effect of the later Jurassic-Triassic tectonic fig(14).

I. ISOCHORE MAPS

Isochore maps where for the reservoir surface, source rock and seal to determine the variation of true vertical thickness of the surfaces, also determine accommodation associated in the survey area. The isochore maps between two surfaces displace channels better than a normal TWT surface map.

a. BETTY FORMATION ISOCHORE MAP

The isochore map of the Betty Formation varies in thickness, an isochore map was made between the top Betty formation and the base Betty Formation to determine the true vertical thickness of the surface,(Fig) explains the variation in thickness between both surfaces, the anticlinal structure exhibits a low thickness compared to syncline showing a high thickness. This explains the orientation of the seismic reflection between both surfaces is not identical. Evidence of increased thickness of syncline might be due to possible channels caused by deep incised valleys.

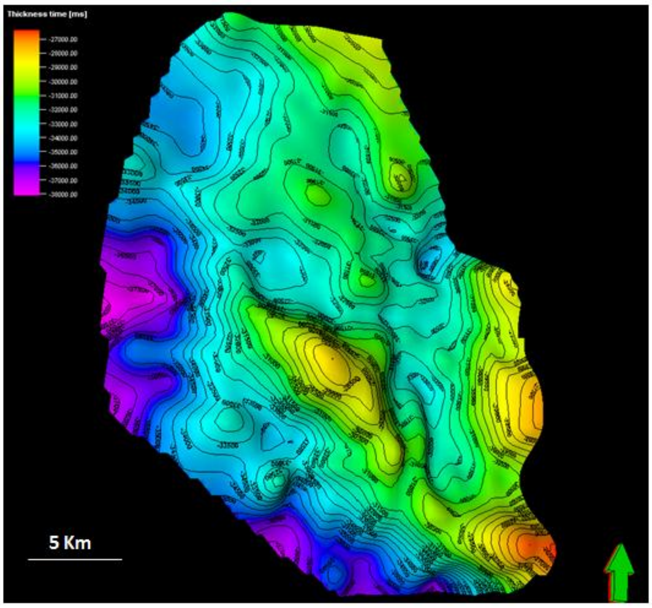

Figure 18: Betty Formation Isochore map showing thickness variation

b. WINIFRED FORMATION ISOCHORE MAP

The Winifred Formation generally thickens south-westward, fig(), the isochore map was made between the top

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Winfred Formation and the base Winfred Formation to determine the true vertical thickness of the surface. The Winifred formation is an intra-formational seal of most of the producing reservoirs in the Lennard Shelf, the top of the formation represents a high GR response, base shows a gradual change from the underlying low GR of the Betty Formation, the western most part of surface is shale dominated and represent a good sealing presence, the anticline along the Sundown field show moderate thickness of the sediments or probable sand dominance, this might explain the sealing integrity of the shale's, furthermore there might be possible leakage whenever the pressure differential across the seal exceeds the threshold displacement pressure, allowing fluids to migrate through the pore spaces in the seal (Redfern)

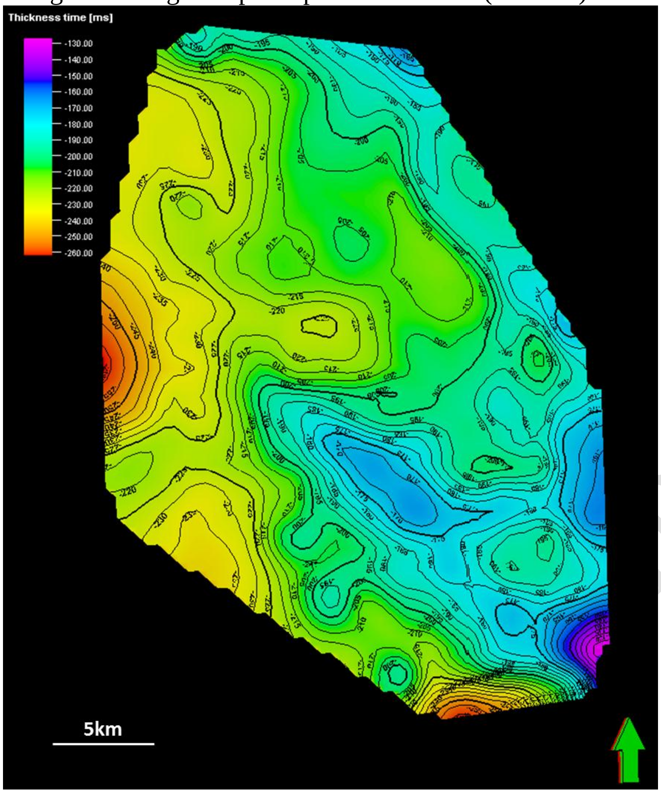

Figure 19: Thickness map of the Winifred Formation showing good sealing capacity at the South-eastern part of the surface. (Colour reversal of thickness)

c. LAUREL FORMATION ISOCHORE MAP

The Laurel Formation is generally thickening Westward, the isochore map was made between the top Laurel Formation and 60ms TWT below Laurel Formation to determine the true vertical thickness of the surface. The Laurel Formation is shale dominated and it's the main source rock of most the producing fields in survey area due to its generative potential. The thickness of the Western part of the survey area is due to high possible gross rock volume, total organic carbon, kerogen type, and pyrolysis parameters.

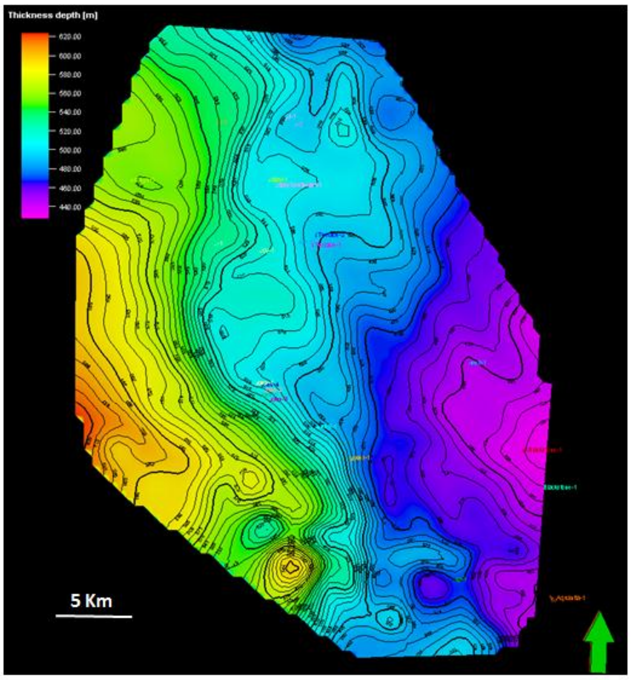

Figure 20: Thickness map of the Laurel formation moving Westward

d. ATTRIBUTES

RMS attribute was extracted to map direct hydrocarbon indicators of the Betty Formation. The amplitude is the squared root of the squared amplitude, divided by the number of live samples.

V. PETROLEUM SYSTEM ANALYSIS

A. PETROLEUM SYSTEM OF THE LENNARD SHELF, CANNING BASIN

The petroleum supersystem and system concept as applied by Bradshaw (1993) and Bradshaw et al.(1994) defines combinations of play elements into broad regional groupings bounded by major climatic and/or tectonic events. Magoon and Dow (1991) defined a petroleum system as a mature source rock and all its generated hydrocarbon accumulations

Burt et al., 2002 and D'Ercole et al., 2003 explained and evaluated the petroleum system elements of the lennard shelf and emphasized that charge, timing, migration, reservoir quality, and trap integrity are the key risks within the basin. As this was based mostly on well data from the field, the following summary is restricted to reservoir quality, seals, source potential, and maturity.

The offshore area of the basin has similar structures and contains terraces, platforms and troughs but as yet little hydrocarbon has been discovered (Colwell and Stagg, 1994).The most effective traps in the Lennard shelf occur along the margins of platforms and terraces when coarse grained facies pinch out upslope against faults, these traps terms to be faulted, 4 way dip closures, anticlines and Compressional culmination with internal stratigraphic traps.

Potential reservoirs in Lennard Shelf are the Grant Group and Anderson Formations which are both sandstone reservoir and also the Laurel formation which is both a clastic and carbonate reservoir. There is hydrocarbon shows in the Grant formation between 945-950 m of the Boundary -1 well which was driiled to test a near high a mapped four-way dipped closure, with good porosities ranging above 22%.

Seals in the Lennard Shelf are associated with different formations (Grant, Laurel, Anderson, Nullara, Gogo, May River member and the Fairfield Group). Lithologies are mostly shale and siltstones. Potential sandstone reservoirs in the Fairfield Group may be sealed intra-formationally by marine shales. The Anderson Formation reservoirs may also be sealed intraformationally, with good thick alluvial mudstones intersected at White Hills-1 (Griffiths and Young, 2002)

The petroleum system elements are discussed with respect to specific plays and field examples from the table below.

Reservoir	Seal	Source	Trap/Objective	Discovery well/Type
Upper Carboniferous to Permian-Lennard Shelf				
Grant Group Sandstone	Grant Group shale And silt stones	Laurel Fm.,shales In Fitzroy Through	Commpresional culmination with internal stratigraphic traps.	Sundown 1, oil
			Unfaulted four-way dip closure within a paleo-monadnock.	West Terrace 1, oil
			Nil	Boundary 1, oil
			Faulted, four-way dip closure onLaurel Fm. carbonate horizon.	Crimson Lake 1, oil
Carboniferous-Lennard Shelf				
Anderson Fm., sandstone	Anderson Fm., shales	Nil	Nil	Point Torment 1, gas
		Laurel Fm., shales in Fitzroy Trough	Four-way dip closure	Lloyd 1, oil Kora 1, West Kora 1;
Laurel Fm., carbonates			Compressional culmination with internal stratigraphic traps	Sundown 1, oil
			Four-way dip closure	Terrace 1, oil
Laurel Fm., sandstone	Laurel Fm., shales		Reef-like seismic anomaly	Meda 1, oil
Carboniferous — Fitzroy Trough				
Laurel Fm., limestone	Laurel Fm., shales	Laurel Fm., shales	Anticline	St George Range 1, gas
Laurel Fm., Sandstone				Valhalla 1, gas
Laurel Fm., Clastics	Laurel Fm., shales	Laurel Fm., shales	BCGA	Valhalla 2, gas
Laurel Fm., Clastics	Fairfield Group, shales	Gogo Fm., shales	Faulted, four-way dip closure on Intra-Fairfield Gp	Ellendale 1, oil and gas
Devonian — Lennard Shelf and Barbwire Terrace				
Yellow Drum Fm., leached dolostones	Fairfield Group, shales	Gogo Fm., shales	Compaction drape closure over Devonian reef	Blina 1, oil
Nullara Fm., carbonates	Nullara Fm., shales		Reef-like seismic anomaly	Jampam North 1, oil
Nullara Fm., calcarenite				Meda 1, gas
Nullara Fm., leached dolostones	May River Member, shales		Shale draped biohermal and biostromal mound	Blina 1, oil
Gogo Fm., clastics	Gogo Fm., shales		Nil	Boronia 1, oil
Mellinjerie Ls., dolostones	Lower Pillara Fm., shales	Nil	Fault dependent closure at top Nita Fm. level	Mirbelia 1, oil
Ordovician — Mowla Terrace and Barbwire Terrace				
Nita Fm., fractured dolostones	Nita Fm., shales	Goldwyer Fm., shales	Tilted fault block with internal fourway dip closure	Pictor 1, oil and gas
Goldwyer Fm., fractured carbonates	Goldwyer Fm., shales		Fault dependent closure at top Nita Fm. level	Dodonea 1, oil
Nambeet Fm., fractured dolomitic sandstones	Possibly Upper Nambeet Fm.	Upper Nambeet Fm. ?		Dodonea 1, gas
Ordovician — Broome Platform and Willara Sub-basin				
Nita Fm., dolomite	Nil	Goldwyer Fm., shales in Kidson Sub-basin	Broad, gentle anticlinal closure	Looma 1
Acacia Ss. member of Willara Fm., sandstone	Nil			
Nita Fm., carbonates	?Carribuddy Gp, ?shales and evaporites	?Goldwyer Fm., shales in Willara Sub-basin	Nil	Cudalgarra 1

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B. UPPER CARBONIFEROUS TO PERMAIN PLAY

This plays is known as the Larapintine (L4 Gondwannan G1 Petroleum system)(Fig 6)., In terms of reservoir quality of the Carboniferous–Permian of the Canning Basin, Havord et al. (1997) indicated the presence of excellent sandstone reservoirs in the Grant Group and beyond to the Anderson, although it decreases with age and depth.

The Grant Group has porosities that range from 1.2% to 40% (average 20%), and permeabilities up to 5520 md (average 605 md in the central part of the basin).Presently the only producing fields in the Permian of the Canning Basin are the Boundary, Sundown, and West Terrace fields on the Lennard Shelf (Jonasson, 2001). Estimated production as at 31 December 2008 from Boundary, Sundown, and West Terrace fields on the Lennard Shelf was 125.8 ML since 1984 (Department of Mines and Petroleum, 2009). This is less than half that of the production capacity from the Blina field, 25 km to the east-southeast, that produces from the base of the Lower Carboniferous Fairfield Group and the top of the Upper Devonian Nullara Limestone.

There is little information on seal capacity available from the onshore part of the basin to date. Nevertheless, at least some sealing capacity is demonstrated by shales and silt within the Grant Group of the Boundary, Sundown, and West Terrace fields on the Lennard Shelf (Jonasson, 2001).To date, hydrocarbon shows within the Poole Sandstones have been rare. This may be indicative of either the poor sealing quality of the Noonkanbah Formation or the stratigraphic remoteness of the reservoirs from mature source rocks (Goldstein, 1989). Shale units in the Grant Group are unlikely to form effective seals, because the glacial character of the unit implies seal capacity could be compromised or highly variable where sufficient coarse-grained sediment has been mixed into fine-grained facies.

Potential source rocks in the Carboniferous-Permian play is gas to oil and gas prone, and that generation capacity can be good to excellent in the Grant Group, Poole Sandstone, and Noonkanbah Formation. These shales have TOC ranging from >2% and S1+S2 is >2.5 mg/gm rock.

Reservoirs in this play are likely to occur in graben margins, carbonate banks and shoals or possibly in fluvial tidal channels and also sand bars or landward. Towards the trough there is evidences of thick deltaic sequences which provides excellent potential reservoirs (Brown & others, 1984).

Potential source rocks are in the shallow marine to lagoonal facies of the lower Laurel Formation. It is probably oil generative on the margins of the Fitzroy Graben and overmature within the graben (Brown & others, 1984).The trapping mechanism associated with this play are Compressional culmination with internal stratigraphic traps, four-way dip closure while a reef-like seismic anomaly can be found in Sundown 1, Lloyd 1 and Terrace 1 fields.

C. HYDROCARBON POTENTIAL

The petroleum potential of the Lennard Shelf is discussed by referring to the factors controlling the hydrocarbon accumulation discovered. Reservoirs, seals, traps, source rocks, and migration paths are analysed critically are all**.**

a. RESERVOIR AND SEAL

Within the Lennard Shelf hydrocarbons are found both on clastic and carbonate rocks. The Blina field which is the biggest oil field in the region produces from Nullara Limestone and dolomite from the Yellow drum formation. Vearncombe et al. (1995), describes the Porosities depending entirely by fractures and permeability is secondary resulting from shear stresses due to wreching of the Meda Movement. It is possible that primary porosity and peameabilities of this carbonate rocks must have been destroyed by diagenesis before the migration of hydrocarbons in this region, secondary processes must have prevented early hydrocarbon migration. Furthermore, Dorling et al. (1996) emphasis, that rocks closer to faults have great chances of been stressed and possible more heavily fracture, also the lager once have more intense fracture to enhance hydrocarbon productivity.

Clastic reservoirs in the Lennard Shelf are encountered within Carboniferous Betty and Anderson formations, wireline log interpretation of the carbonate field suggest that migration of hydrocarbons occurred only after diagenesis processes that altered any porosities and permeability may have been present in the Devonian and Carboniferous section. This might be why there are no oilfields in the Anderson formation due to the lack of secondary porosities and permeability.

The main reservoir of the Lennard Shelf is the Betty Formation but it lack and effective seal, log data shows a Low GR response, fining upwards sequences of thin and tight sandstones, on seismic it represents a Low amplitude mostly chaotic reflection to a High amplitude mostly chaotic reflection. The critical factor for the presence of hydrocarbon in the Carboniferous is due to the presence seal because upward migration is present. The Winifred formation is an intra-formational seal and the main sealing unit of the Grant group, in seismic it represents a high amplitude, relative low frequency, continuous reflection to a Low amplitude mostly chaotic reflection and on well log its exibits a High GR response, base shows a gradual change from the underlying low GR of the Betty Formation, this is evident of a shale dominated interval.

The Carboniferous-Permian reservoirs are thick, porous and permeable sandstones which require a regional extension seals but are not common in fluvial system. In this effect the reservoir sand might shale out within short distances, on this note, a less extensive intra-formational shale can still provide an adequate trap. Tight sandstones may accumulate hydrocarbons via permeability barriers, these are some of the reason why the only small fieds are present in the Betty and and Anderson Formation.

b. TRAPS

The kinds of traps present within the Lennard Shelf ranges from stratigraphic traps (Updip wedge-out / Pinch-out and confined Incised valley play), and combination traps (confined Incised valley with anticlinal closure and updip stratigraphic / structural pinch-out play) and structural traps. The producing reservoir in Lloyd field is within a tight fault-bounded anticlinal structure (Diekman,1992), which is as a result of strike-slip movement of the Late Carboniferous Meda movement.

The Sundown field are examples of such anticlines that are superimposed on carboniferous structures and show rejuvenation of pre-existing faults, they are large elongate NW-SE trending dip close Anticline. The Boundary and West Terrace oilfields are controlled controlled by very gentle four-way dip closures due to rejuvenation, drape, or differential compaction over older structures. The West Terrace-1 well is interpreted as a stratigraphic trap in the Grant Group, do it fail

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due to seal, the producing field is a four-way dip closure controlled by an unfaulted anticline sealed by the Winifred shales.

c. SOURCE ROCK AND MIGRATION PATHWAY

The potential source rock of the Lennard Shelf is the Laurel Formation, hydrocarbon generation is mainly from this unit. On seismic its represented as a high amplitude continuous planar reflections to a low amplitude continous plannar relection, on wrireline logs its represented a very high GR reading. The organic matter is charecaterized by great input of terrestrial materials with marine contribution in an oxygenated environment, Toc ranging from 0.5-2% and Vitonite reflection (0.6-0.7). Alexander et al., 1985 suggested that the Laurel Formation source rocks in the Blackstone-1 are excellent source rocks, this can matched to the interpretation from a mudlog. On the Grant group the source rock is marginally mature to mature, very poor to poor oil and gas/ condensate source rock. Migration of hydrocarbon in the Shelf is mainly from NE trending faults caused by the mid-Late Carboniferous Meda Movement connecting the deeper Fitzroy Trough, where the Laurel formation interval reaches maturity of hydrocarbon generation.

a. UNCONVENTIONALS PLAY

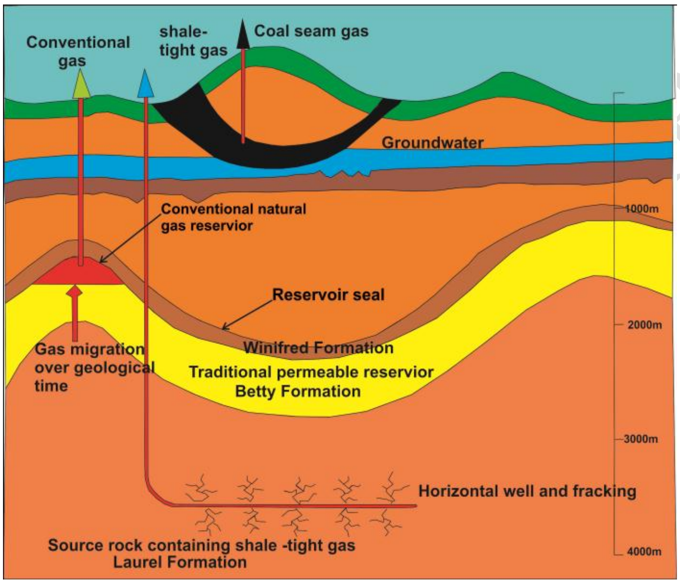

Figure 21: Showing an Unconventional play (modified from Buru energy annual report)

Unconventional plays associated in the Lennard Shelf are shale tight gas, shale oil, coal seam gas. This type of of geological formations hosting natural gas are contained in rock layers located 2,000m-4,000m below the surface with low permeability. To flow commercial gas trapped within these rock layers hydraulic fracturing is required. The Laurel formation is the producing source rock and reservoir.it has a maximum vitronite reflection of 2.0% and average Hydrogen index of 0.13 gHC/g*TOC*, TOC ranging from 0.5-2%. Resent analyses of the potential vast unconventional shale gas resources in the Cannig Basin eastimates nearly 800 Tcf from the Goldwyer Formation.

VI. DRY HOLE ANALYSIS

A dry hole analysis of the Whitewell-1 and the Hangover-1 wells was undertaken for further understanding the trapping mechanism associated in the survey area. These wells were drilled on the crest of a compressional anticline on the Lennard Shelf, but didn't encounter hydrocarbons. On the flank of the same broad anticline structure, the Sundown wells were drilled for Betty Formation reservoir and found a commercial accumulation of hydrocarbons. In determining the dry hole analysis of the wells, a well correlation of respective wells was constructed, seismic surfaces mapped, and petroleum systems quick look analysis was also used for better understanding of the possible source and migration. The result suggest that the Sundown wells found commercial hydrocarbons in stratigraphic traps (Channelised unit or sand pinch out) on the flank of an anticline and a model is proposed that the updip there must be some permeability barrier, possibly a shale dominated unit in the reservoir intervals preventing migration . The Whitewell-1 and Hangover-1 wells didn't find hydrocarbons on the crest of the anticline suggests possibly hydrocarbons migrated and leaked up through the reservoir due the effectiveness of Winifred seal.

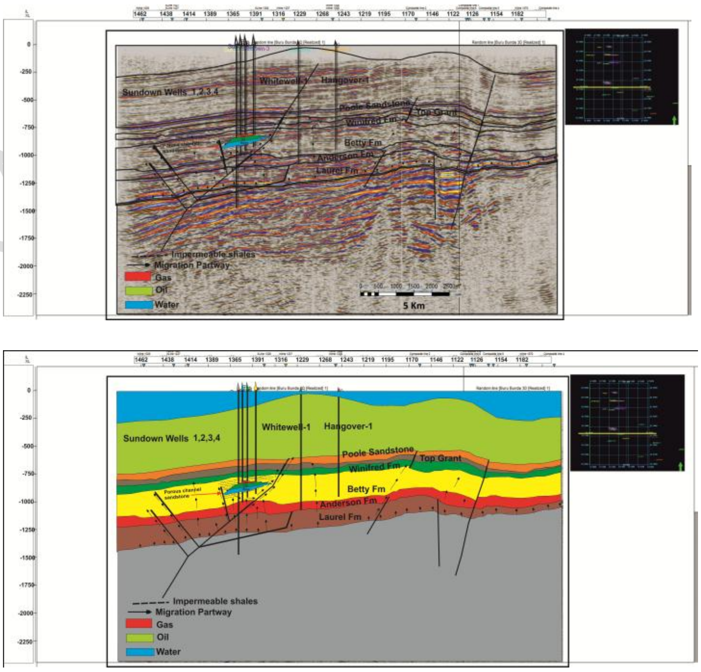

Figure 22: (A) showing Interpretation of crossline 1328 displaying structural altitude of the Sundown wells, White well and Hangover, (B) show a carton displaying the interpreted horizon and migration pathways of the Sundown field

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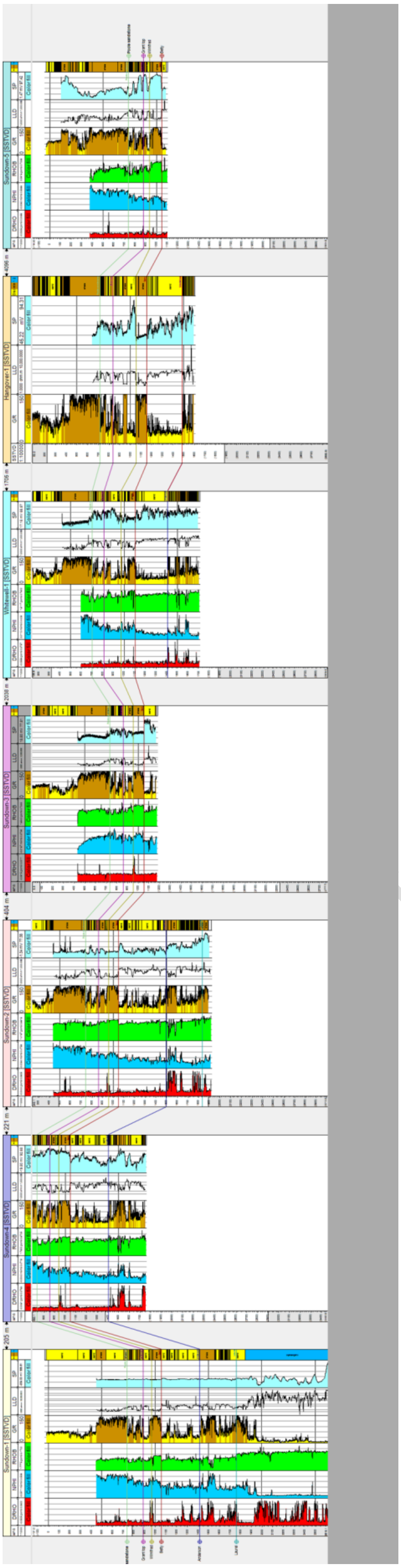

Figure 23: Well correlation of the Sundown fields alongside Whitewell and Hangover

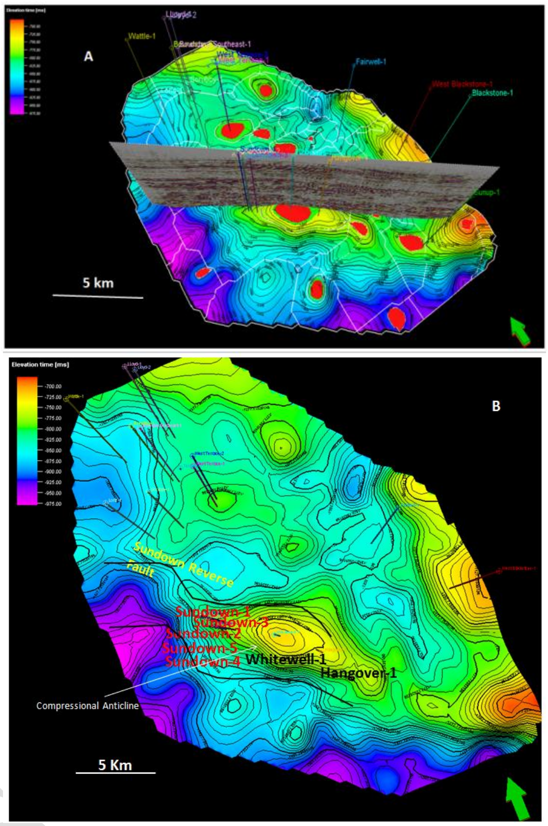

Figure 24: (A) TWT surface map of the Betty Formation showing an arbitrary line across the seismic volume along the proposed wells with accumulation of oil and gas. (B) shows a depth converted surface map of the Betty formation.

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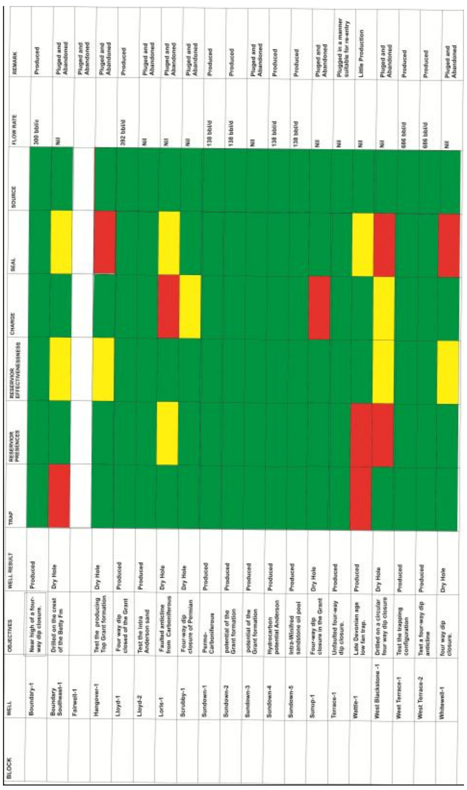
A PETROLEUM SYSTEM EVENT CHART WAS MADE FOR THE 20 WELL IN THE LENNARD SHELF



BLOCK	WELL	OBJECTIVES	WELL RESULT	FLOW RATE	REMARK
	Boundary-1	Near high of a four-way dip closure.	Produced	300 bbl/s	Produced
	Boundary Southeast-1	Drilled on the crest of the Betty Fm	Dry Hole	Nil	Pluged and Abandoned
	Fairwell-1				Pluged and Abandoned
	Hangover-1	Test the producing Top Grant formation	Dry Hole		Pluged and Abandoned
	Lloyd-1	Four way dip closed of the Grant	Produced	392 bbl/d	Produced
	Lloyd-2	Test the intra Anderson sand	Produced	Nil	Pluged and Abandoned
	Loris-1	Faulted anticline from Carboniferous	Dry Hole	Nil	Pluged and Abandoned
	Scrubby-1	Four-way dip closure of Permian	Dry Hole	Nil	Pluged and Abandoned
	Sundown-1	Permo-Carboniferous	Produced	138 bbl/d	Produced
	Sundown-2	potential of the Grant formation	Produced	138 bbl/d	Produced
	Sundown-3	potential of the Grant formation	Produced	Nil	Pluged and Abandoned
	Sundown-4	Hydrocarbon potential Anderson	Produced	138 bbl/d	Produced
	Sundown-5	Intra-Winifred sandstone oil pool	Produced	138 bbl/d	Produced
	Sunup-1	Four-way dip closure in the Grant	Dry Hole	Nil	Pluged and Abandoned
	Terrace-1	Unfaulted four-way dip closure.	Produced	Nil	Plugged in a manner suitable for re-entry
	Wattle-1	Late Devonian age low fan trap.	Produced	Nil	Little Production
	West Blackstone -1	Drilled on a circular four way dip closure	Dry Hole	Nil	Pluged and Abandoned
	West Terrace-1	Test the trapping configuration	Produced	686 bbl/d	Produced
	West Terrace-2	Test a four-way dip anticline	Produced	686 bbl/d	Produced
	Whitewell-1	four way dip closure.	Dry Hole	Nil	Pluged and Abandoned

PROSPECT AND LEADS

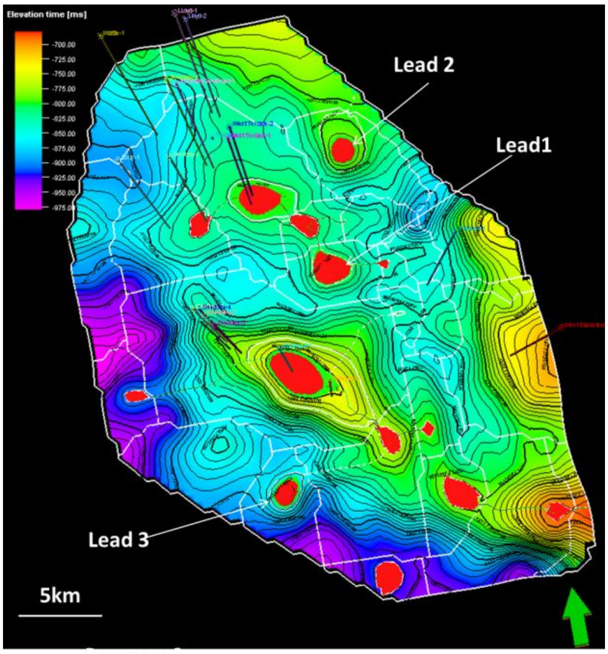


Figure 25(): Showing Top Betty Fomation TWT map showing proposed prospects for futher prospectivity

A petroleum system quick look was used to locate hydrocarbon accumulation in the Lennard Shelf and possible migration pathways, 3 leads are further propose for further exploration targets, they are all located in closed structures, Leads 1 is located closed to the producing West Terraces fields which are all drilled in the same closure, Lead-1 could be drilled test and remaining hydrocarbons at the flank of the structure.

VII. RESULT AND DISCUSSION

In order to understand the hydrocarbon potential of the Lennard Shelf, Canning Basin, a recent 3D seismic dataset integrated with 20 well was used to evaluate the the hydrocarbon prospectivity in the area.

Firstly, in other to make a seismic facies interpretation, a well to seismic tie was generated, formation tops where converted to TWT using synthetic seismic seismogram which was incorporated with checkshots. Horizons were picked over the study area, correlated with well data to the main formation tops. They are the Poole sandstone, Top Grant, Winifred, Betty, Base Grant, Anderson and Laurel Formations. A well correlation was done for the 20 well showing lateral variation of facies. Two major faults where observed in the study area, these are the pre-Grant and Post-Grant faults. The Pre-Grant faults ranges from NW-SE to NE-SW direction, they are underlined in the Grant Group and terminates at the base, the post-Grant form series of horst structures and graben and half grabens, its actually an extensional fault that show thickening in laurel and Anderson Formation. For better understanding of the trapping style of survey area, the structural style of producing fields where determine. Fig(9A) Shows the structural alteration of the Boundarty-1 field, its interpreted as a roller which was superimposed on a flower like structure at the Laurel Formation, this structure was formed due to minor differential compaction over older structure. Fig(9B) Further analysis was a gentle folded structure of the Anderson Formation and Laurel observed in the Lloyd-1 field, which are controlled by compressional forces.

Furthermore, in analysing the facies interpreted, the Betty Formation will be use as a model, its was observed on seismic as a high amplitude reflection to to a low amplitude chaotic reflection, lots of truncation and on laps are see on seismic, Log interpretation shows a sand dominated units with little interbedded shale, resistivity logs show a high reading of hydrocarbon bearing sands, some lateral continuous channels were also found, they can act as channelized sand or pitchout. Surface maps where made from the interpreted facies and sedimentation rate of the facies were further understood. The Winifred Formation can be illustrated is a planar surface which generally deeps westward and shallows eastward, it has a fault controlled topography. Isochore maps where made to further understand the true vertical thickness of the surfaces and also determine accommodation in the survey area. RMS attributes where map for surfaces and hydrocarbon bearing units where further discovered, Channels where also found in the Betty Formation but was not laterally continues. The Carboniferous-Permian Petroleum system analysis was made based on literature view and the key plays where further determine. The hydrocarbon potential of the survey area was also determine discussing the individual petroleum systems elements in the Lennard Shelf. A petroleum event chart was made for the 20 wells.

Finally a dry hole analysis of the Whitewell-1 and the Hangover-1 wells was undertaken for further understanding the trapping mechanism associated in the survey area. These wells were drilled on the crest of a compressional anticline on the Lennard Shelf, but didn't encounter hydrocarbons. On the flank of a broad anticline structure, the Sundown wells were drilled for Betty Formation reservoir and found a commercial accumulation of hydrocarbons. In determining the dry hole analysis of the wells, a well correlation of respective wells was constructed, seismic surfaces mapped, and petroleum systems quick look analysis was also used for better understanding of the possible source and migration. The result suggest that the Sundown wells found commercial hydrocarbons in stratigraphic traps (Channelised unit or sand pinch out) on the flank of an anticline and a model is proposed that the updip there must be some permeability barrier, possibly a shale dominated unit in the reservoir intervals preventing migration . The Whitewell-1 and Hangover-1 wells didn't find hydrocarbons on the crest of the anticline suggests possibly hydrocarbons migrated and leaked up through the reservoir due the effectiveness of Winifred seal.

VIII. CONCLUSION KEY FINDING AND RECOMMENDATION TO THE INDUSTRY

In the Lennard Shelf, all the components of a working petroleum system have been proven. Four petroleum systems have been identified in the onshore Canning Basin.

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The Laurel Formation in the Lower Carboniferous Fairfield Group is the proven source rock, it is characterized by greater input of terrestrial material with little marine contribution.

The Lower Carboniferous Anderson and Upper Carboniferous Winifred intraformational Marine shales and evaporites are the main sealing units. The critical factor for the presence of oil in the Carboniferous is probably the presence of the seal because upward migration appears to be widespread in the Lennard Shelf.

The main reservoirs are the massive, blocky fluvial-channel sandstone within the Betty Formation (Grant Group) and The Nullara Limestone that produces from a highly fractured carbonate interval.

Traps associated in the Lennard Shelf are structural and stratigraphic traps, four-way dip closures, anticlines, these Small-scale stratigraphic traps are provided in such settings by intra-formational seals formed of fine-grained units resting on flooding surfaces.

The best prospects should occur marginal to structural highs, which act as a source of coarse debris, and where rates of subsidence are sufficiently high to have allowed the deposition of fine-grained facies.

UNCERTAINTIES ANALYSIS AND RISKING

Key uncertainties identified during the period of research include:

Uncertainty in checkshot data in identifying actual formation tops

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