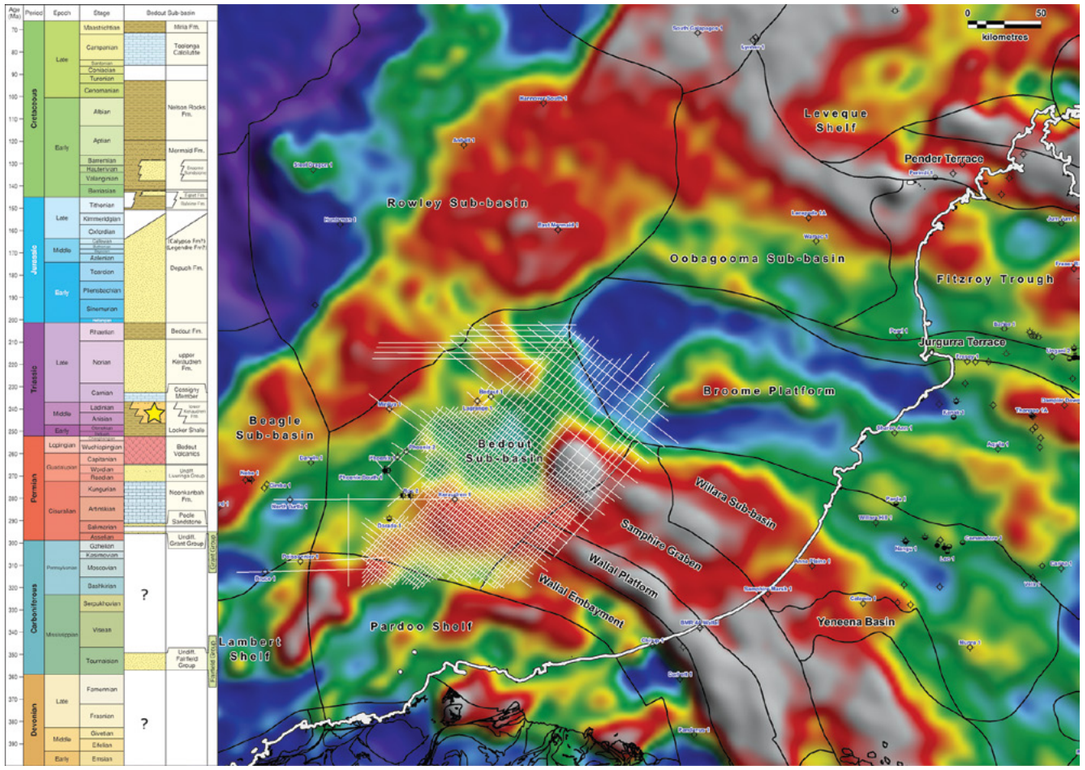


Figure 1: *The Bilby Non-Exclusive 2D Seismic Survey is shown in white in the Bedout Sub-basin. Structural elements of the Offshore Canning Area (black lines, from the Department of Mines, Industry Regulation and Safety, Western Australia) overlaying the free-air gravity anomaly indicating relative highs in whites/reds and lows in blue (Bureau Gravimétrique International, WGM2012 Model). Generalised stratigraphy of the Bedout Sub-basin is modified after Geoscience Australia. Note: a) the thick Jurassic Depuch Fm that may contain Calypso Fm and Legendre Fm equivalents and interbedded siltstones, shales and coals; b) the Lower Keraudren Fm (yellow star); and c) the general absence of Carboniferous and Devonian stratigraphy.*

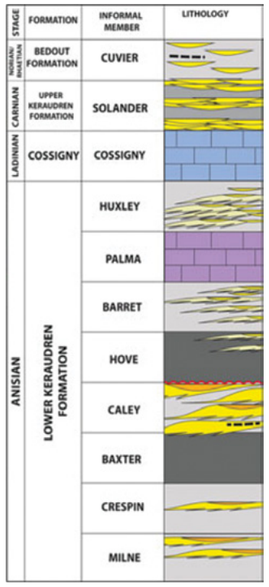
Confronting the Elephant: Dorado-1 and the Prospectivity of the Offshore Canning Area

Andrew Weller – Searcher Seismic Pty Ltd
Said Amiribesheli – Discover Geoscience Pty Ltd

INTRODUCTION

The Offshore Canning Area is a NE-SW trending region on the North-West Shelf (NWS) of Australia consisting of the Roebuck and Offshore Canning Basins (Figure 1). In comparison with the other regions of the NWS, the Area is conspicuous by the absence of commercial oil and gas developments. The basins have long been bypassed by exploration companies because of limited hydrocarbon discoveries, perceived absence of mature source rocks and its remoteness to producing fields.

Recent hydrocarbon discoveries in the Bedout Sub-basin of the Roebuck Basin (Figure 1) have caused a wholesale change in thinking in this hitherto underexplored region. Commencing in 2014, Phoenix South-1 discovered oil, which was closely followed by Roc-1 (2015) that discovered gas



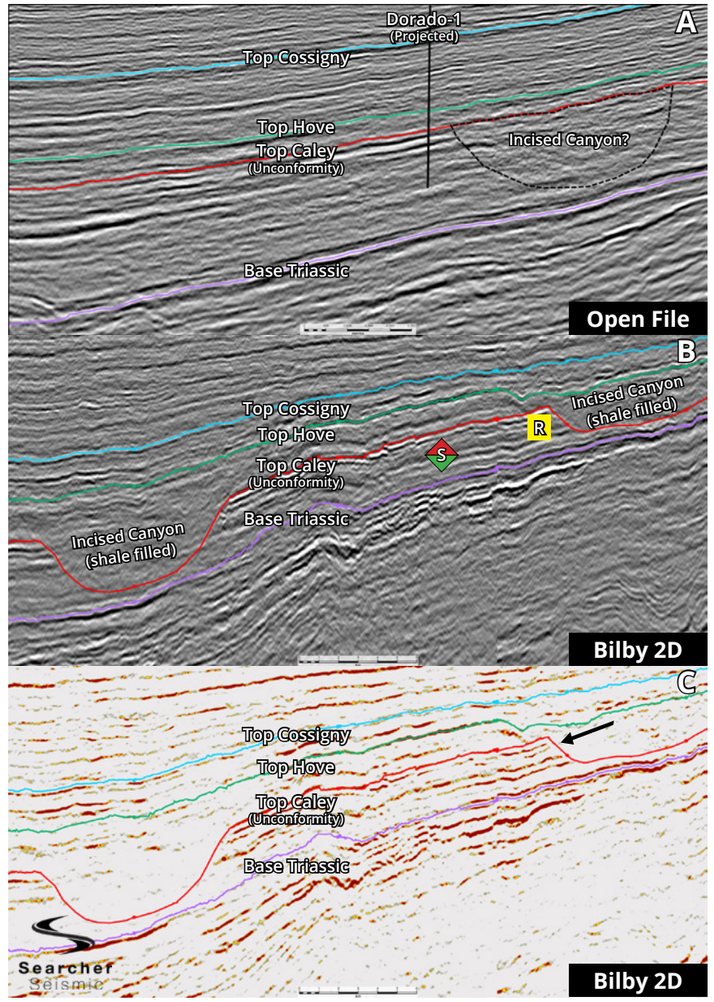


Figure 2: *Dorado-1 in vintage 2D seismic data and lookalikes in the Bilby seismic data. A: The Dorado discovery relied on sealing facies being present in the incised canyon to the southern edge to the trap, which is not visible on open file 2D seismic due to the paucity of data. B: Clear definition of the geometry of an example incised canyon in Bilby seismic data inboard of Dorado with source and reservoir in the Lower Keraudren Fm and shales from the Hove Member providing the seal. C: Amplitude Variation with Angle (AVA) acts as lithology indicator for the main Caley reservoir (reds) and the Hove seal (nothing). Here the AVA Attributes suggest the presence of good multi-layer stacked reservoir in the Lower Keraudren Fm sands highlighted by the black arrow. "S" means potential source; "R" means potential reservoir. Triassic stratigraphy of the Bedout Sub-basin is from Thompson et al. (2018).*

and condensate, and in 2018 Dorado-1 discovered oil. These discoveries targeted reservoirs in the Triassic Lower Keraudren Formation (Fm) that are older than the traditional Triassic plays on the NWS (Thompson et al., 2018; stratigraphic chart, Figure 1). These accomplishments in the Bedout Sub-basin are helping remedy the historically poor understanding of this region of the NWS and now stand as analogues for other lookalikes in the Area.

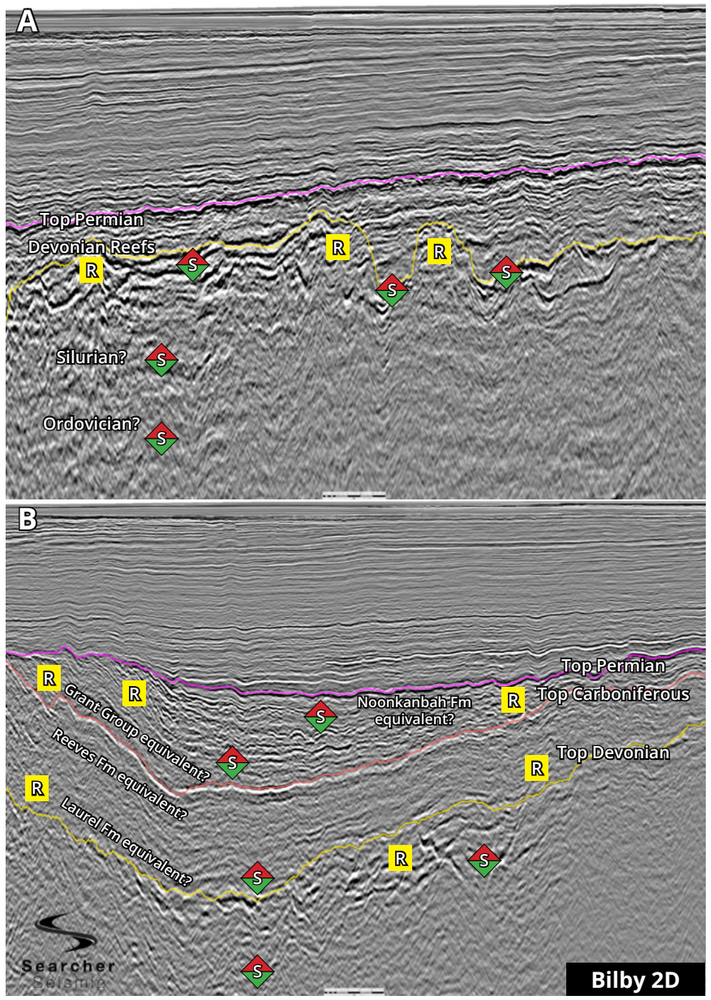
Searcher Seismic's modern Bilby Non-Exclusive 2D Seismic Survey acquired long-offset, high resolution seismic in the Bedout Sub-basin, Pardoo Shelf and Broome Platform, Western Australia. The Bilby seismic data provides a grid of modern, high quality data to help identify prospective stratigraphic and structural trends in the region and ties the recent hydrocarbon discoveries and generally sits inboard of them (Figure 1).

The Bilby 2D Seismic Survey addresses multiple issues with the legacy open file data in the Area. The acquisition utilised a modern 8km Sercel RD solid streamer with significantly improved sensitivity and frequency response over the legacy data. This was combined with a denser shot-point interval for improved fold and a larger source array to improve penetration of the signal.

The processing of the Bilby seismic data leveraged the improvements in the new acquisition with a broadband anisotropic PSTM workflow; migration anisotropic parameters were defined using geological horizon constraints and incorporating well data, which ensured useful data to 50 degrees incidence angle.

Integration of the recent discoveries with regional geology, the new Bilby seismic data, and high-end geophysics (i.e. Quantitative Interpretation (QI) techniques) suggest the entrapment and sealing mechanism are the key elements to understanding of the petroleum systems in the region.

The Bilby data reveals several potential reservoir-seal pairs in the Mesozoic strata and deeper Paleozoic character, much of which has generally assumed not be present and unimaged to date (stratigraphic chart, Figure 1).



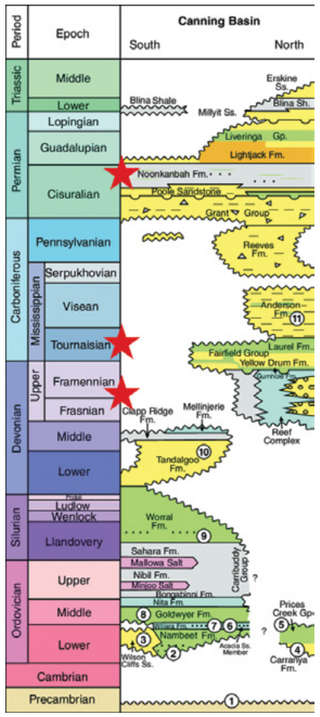


Figure 3: *Paleozoic character and potential observed in the Bilby seismic data (depth). A: The extension of the Devonian Reef Complexes in the Offshore Canning Area hypothesised by Playford (1982). B: Generalised Paleozoic character highlighting the Devonian, Carboniferous and Permian sedimentary sequences. The Laurel Fm, Reeves Fm, Grant Group and Noonkanbah equivalents highlighted remain untested in the Offshore Canning Area. "S" means potential source; "R" means potential reservoir. Generalised Paleozoic stratigraphy of the Onshore Canning Basin is from Haines et al. (2013). The red stars denote the plays that hypothetically extend offshore that are discussed in the text.*

This paper discusses the underexplored and unexplored Mesozoic and Paleozoic hydrocarbon potential in the Offshore Canning Area, inspired by the recent landmark oil, gas and condensate discoveries in the Bedout Sub-basin.

EXPLORATION HISTORY OF THE OFFSHORE CANNING BASIN

The Offshore Canning Area has been relatively underexplored. Prior to the Phoenix South-1 oil discovery (2014), only 2 wells were considered discoveries in the general region (i.e. Phoenix-1, gas, 1980 and Nebo-1, oil, 1993). Most of the unsuccessful wells had been attributed to the lack of hydrocarbon charge. The absence of large accumulations encouraged E&P companies to spend exploration budget in the more prolific adjacent Carnarvon and Browse Basins (Wehr et al., 2015).

Jurassic

Nebo-1 (1993) discovered oil within Mid-Jurassic Calypso Fm in a fault-dependent anticlinal closure (Kufpec Australia Pty Ltd, 1993). The oil recovered at Nebo-1 is interpreted to be derived from lacustrine shales, possibly from an Early to Mid-Jurassic deltaic sequence. This has subsequently been interpreted as a thick sequence of sandstones with interbedded siltstones, shales and coals from a fluvio-deltaic system (Insight Petroleum and Searcher Seismic, 2015).

The source rock units identified within the Early to Mid-Jurassic are the Depuch Fm and Athol Fm (Smith, 1999; stratigraphic chart, Figure 1). The sandstone of the Calypso Fm (and Legendre Fm) have excellent reservoir properties, suggesting reservoir presence and quality is not the major risk for Mid Jurassic plays in the Area.

Lower-Middle Triassic

Early Triassic sedimentation in the region is dominated by the shales and siltstones of the marine transgressive Locker Shale (stratigraphic chart, Figure 1), which is also regarded as a potential hydrocarbon source rock in the Area (Insight Petroleum and Searcher Seismic, 2015). The Locker Shale grades upwards into the dominantly fluvio-deltaic Lower Keraudren Fm, which is composed of thick sandstone beds, typically with sharp bases, interbedded with shales and siltstones and minor coals. The Lower Keraudren Fm was deposited rapidly during the Anisian of the Middle Triassic and reaches a thickness of >5km in the depocentre of the Bedout Sub-basin (Minken et al., 2018).

A major regional marine incursion followed by a highstand in the Ladinian of the Middle Triassic and decrease in sediment supply resulted in the deposition of a carbonate-dominated Cossigny Member (stratigraphic chart, Figure 1).

Different characteristics within the Lower Keraudren Fm mean that it can be further subdivided into eight informal units (from older to younger: the Milne, Crespin, Baxter, Caley, Hove, Barret, Palma, and Huxley Members) (stratigraphic chart, Figure 2), the Caley Sandstone of which has emerged as the key reservoir unit (Woodward et al., 2018).

This was most recently shown in Dorado-1 where it displayed excellent reservoir and fluid characteristics in highly porous (~20%) and permeable (100 to 1,000 millidarcy) sands (Carnarvon Petroleum, 2018a) that are preserved at depths >4,000m (Woodward et al. 2018), which were historically presumed to be of poor reservoir quality.

The cyclical nature of sedimentation within the Lower Keraudren Fm (from low energy lagoonal and hemipelagic facies to higher energy fluvio-deltaic facies) indicates that the potential for several source, reservoir and seal opportunities exist (Thompson et al., 2018).

Prior to the Dorado-1 oil discovery, one major source rock interval of lagoonal facies origin has been intersected within the Caley Member, the organic matter of which has been typed to be of a mixed land-plant and non-marine or brackish algae type (Woodward et al., 2018). However, deeper drilling in Dorado-1 encountered additional oil discoveries in the older Crespin and Milne Members (i.e. stacked plays; Carnarvon Petroleum, 2018b). The source rock for the Milne discovery is believed to be organic-rich lagoonal facies within the older members of the Lower Keraudren Fm.

At the unconformable Caley-Hove boundary, along the sub-basin southern margin, several large incision canyons have cut into the shelf, some of which are >500m, implying a tectonic decrease in accommodation (Minken et al., 2018). These canyons were then filled with the laterally continuous, fine-grained, hemipelagic shale Hove Member that provides a regional seal (such as in Dorado-1).

UNDISCOVERED HYDROCARBON POTENTIAL

Searcher Seismic has been intrigued by the Offshore Canning Area for some time and believe the region remains underexplored, has been overlooked, and still holds a lot of potential.

Lower-Middle Triassic

Dorado has been reported to be one of the largest oil discoveries in NWS history (Carnarvon Petroleum, 2018c). Prior to drilling, Dorado's structural-stratigraphic trap was perceived to be high risk as the features unequivocally relied on sealing facies to be present in the large incised canyon.

Like Dorado-1, exploration success inboard of the well relies on good quality seismic data for delineation of prospects in relation with reservoir presence and quality, sealing capacity (top, base and lateral) and trapping mechanisms. Review of the vintage open file seismic data reveals that the canyon geometry of Dorado is not obviously evident (Figure 2A). However, the modern Bilby seismic data provides a high quality image to help identify similar prospective trapping mechanisms across the region (Figure 2B).

The Caley Sandstone at Roc-1 exhibits a class 2p AVO response (Woodward et al., 2018), which warrants similar seismic investigations in the Area. The Bilby seismic data enables a robust lithology discrimination through QI techniques. Figure 2C demonstrates Dorado lookalike features where lithological content of both reservoir and seals can be discriminated through AVA attribute analyses that can also be extrapolated across the region. The presence of multiple source and reservoir-seal pairs in the Lower Keraudren Fm and the proven stratigraphic trapping mechanisms provide encouragement to further examine the Triassic hydrocarbon potential elsewhere in the Area.

Paleozoic Potential

The Paleozoic sequences for the region are best described from the Onshore Canning Basin where they overlie Pre-Cambrian crystalline basement of the Pilbara and Kimberley Blocks. Onshore, the Paleozoic sediments are more than 11,000m thick in the Fitzroy Trough, thinning to less than 5,000m on the Broome Platform.

The oldest sedimentary sequence known in the Canning Basin is the Early Ordovician to Silurian (stratigraphic chart, Figure 3), which consist of marine shales, carbonates and evaporites with minor thin sandstones. The Base Devonian represents the angular unconformity associated with Early Devonian Prices Creek Compressional Movement. The megasequence above this unconformity includes a Late Devonian syn-rift succession (initiated by the Pillara Extension), which comprises an Upper Devonian Reef Complex (Insight Petroleum and Searcher Seismic, 2015; stratigraphic chart, Figure 3).

The onshore Blina oil field was discovered in 1981 in an Upper Devonian Reef Complex and Playford (1982) hypothesised that the reef complexes exist in the Offshore Canning Area too.

The vintage seismic data in the offshore region is plagued with short streamer lengths and imaging of the Paleozoic is few and far between. With an 8km streamer length, the Bilby seismic data has imaged what it is believed to be the offshore extension of the Devonian Reef Complexes that potentially sit in the oil window (Figure 3A), which warrant further investigation.

The Carboniferous Tournasian-Visean cycle consists of carbonates and shoreface clastics overlain by marine carbonates and shales (the Laurel Fm, stratigraphic chart, Figure 3). The Tournasian-Visean cycle hosts the majority of the oil and gas occurrences on the Lennard Shelf (e.g. Edwards and Streitberg, 2013 and Kingsley and Streitberg, 2013). From a geochemistry perspective, the Lower Carboniferous looks ambiguous with fair-to-good total

organic carbon readings (Ghori, 2013), although it is prospective (Kingsley and Streitberg, 2013).

In the offshore region, the Carboniferous (and older) is generally assumed not to be present over much of the Area (stratigraphic chart, Figure 1). There is certainly Carboniferous character offshore that can be observed in the Bilby seismic data (Figure 3B); the Bilby seismic data can therefore answer questions about the extension of the Laurel Fm into the Offshore Canning Area.

The sedimentary sequence overlying the Carboniferous angular unconformity representing the erosional surface after the Meda Transpressional Event consists of the Reeves Fm (Apak and Backhouse, 1998), the fluvial and glacigene Grant Group, the shallow marine Poole Sandstone, the Noonkanbah Fm (marine shale) and the fluvio-deltaic Liveringa Group (stratigraphic chart, Figure 3; Insight Petroleum and Searcher Seismic, 2015). Organically-rich marine shales within the upper Grant Group are the main source rock interval within upper Carboniferous and Lower Permian onshore. Additionally, the Permian Noonkanbah Fm has demonstrated good source potential onshore although it is immature (Mory, 2010). Noonkanbah (and Grant Group) character is observed offshore on the Bilby seismic data (Figure 3B) and is relatively deeper than what is observed onshore and is therefore potentially more mature in the offshore section.

CONCLUSIONS

The recent breakthrough oil, gas and condensate discoveries in the Bedout Sub-basin, offshore Australia unequivocally shed light into a hitherto underexplored region. Historically, the lack of hydrocarbon exploration in the region has been attributed to the lack of source rock, a hypothesis that was overly simplified.

The recent discoveries suggest entrapment and sealing mechanisms are the key to exploration success, which ultimately requires high quality seismic data. Dorado-1 is a classic example where the open file vintage seismic data failed to reveal entrapment and a sealing mechanism, however, the Bilby seismic data clearly shows the trap geometry and reservoir-seal content through high quality seismic and QI techniques.

Similar to the Phoenix and Dorado discoveries, the deeper Paleozoic potential in the region has been overlooked due to a lack of understanding of the petroleum systems and a paucity of seismic data. The recent Triassic discoveries as well as the Paleozoic play potential of the Area is fundamentally changing the "moose pasture" status of the Offshore Canning Area into true elephant hunting ground! ◗

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