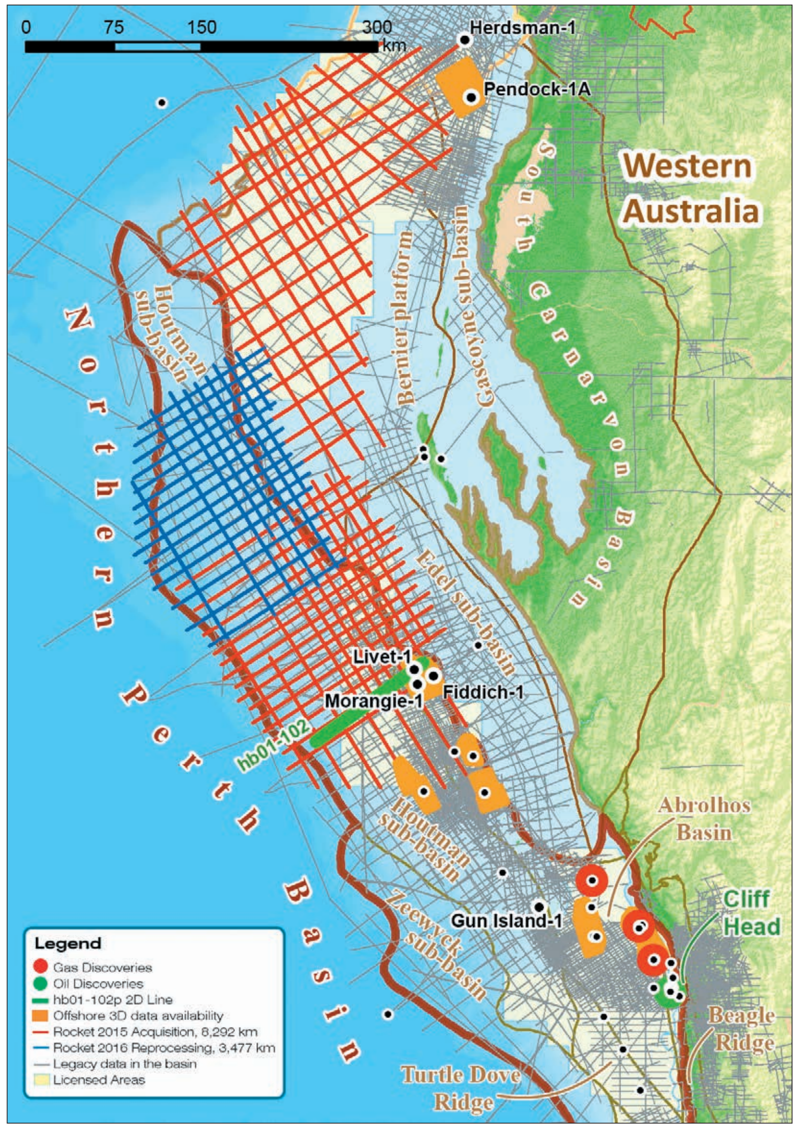
Rocket Seismic fuels Australian exploration

The Offshore Northern Perth Basin: Lessons from Exploration Drilling

Figure 1: *The Offshore Northern Perth Basin (after O'Neill, 2016).*



INTRODUCTION

Despite limited success, the wells drilled in the Offshore Northern Perth Basin provide a wealth of evidence for a viable petroleum system upon the West Australian margin. A review of the exploration successes and failures, combined with a recently acquired long offset deep tow seismic survey, provides invaluable insights that can be used to guide the targeting of future drilling campaigns.

The offshore portion of the Perth Basin (Figure 1) comprises the NNW trending Houtman, Abrolhos and Zeewyck sub-basins as well as two main structural highs. Continental breakup is characterised (e.g. Jones et al, 2011) by a Permian extension event, and two Mesozoic rifting periods culminating in the separation of India and Australia during the Valanginian. The history of the dispersion of the Australian, Antarctic and Indian Plates (e.g. Norvick, 2003) is duly recorded by the Permian to recent sedimentary fill.

Drilling was initiated by BP Petroleum Development Australia Pty Ltd in 1968 with Gun Island-1 (Figure 2). The basin only saw sporadic drilling until the commercial discovery of Cliff Head-1 in 2001 (Figure 3), which led to a renewed interest in the West Australian margin. Subsequent drilling resulted in three non-commercial discoveries at Frankland-1, Perserverance-1 and Dunsborough-1 in 2007 (Jorgensen et al, 2011). Charon-1, drilled by Eni Australia Ltd in 2008 was the last well to be drilled within the offshore province.

To re-energize exploration in the area, Spectrum Geo recently acquired a modern long offset 2D seismic survey, called the "Rocket 2D", covering the Houtman sub-basin and Southern Carnarvon Basin (Figure 1). Integration of this new, modern seismic data with the exploration lessons learned from previous drilling campaigns will reveal new plays and provide a toolset for operators to improve the probability of exploration success in the future.

STRATIGRAPHY AND PLAYS

The Offshore Northern Perth Basin contains a Permian to Recent succession of sediments (Jones et al, 2013) overlying a Palaeozoic terranes (e.g. Hall et al, 2012). The Mesozoic is predominantly a coarse-grained clastic succession (Figure 4) though marine incursions in the early Triassic (Kockatea Shale) and Middle Jurassic (Cadda Formation) lead to the deposition of regionally extensive argillaceous deposits (e.g. Norvick, 2003) across the basin.

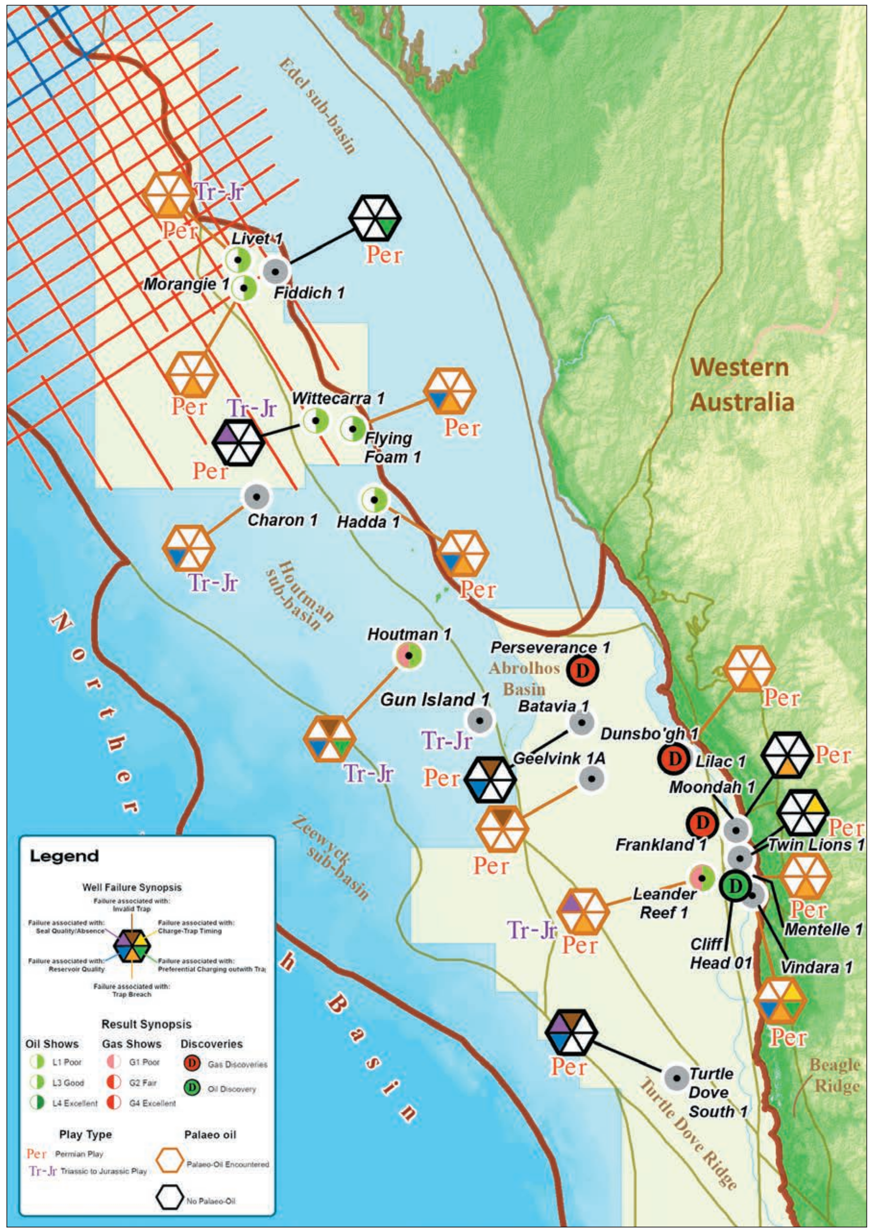


Figure 2: *Figure 2 – Exploration Map (after O'Neill, 2016).*

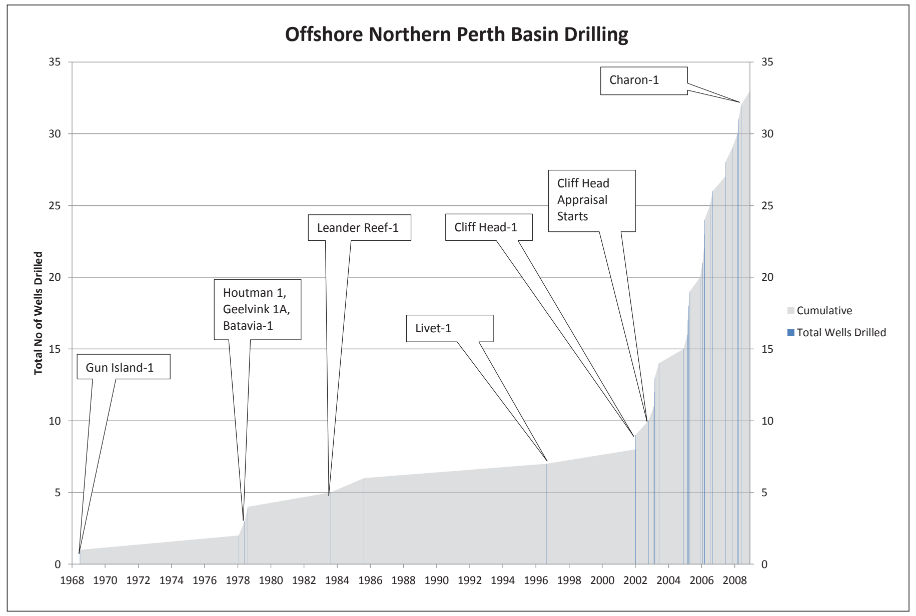


Figure 3: *Offshore drilling activity in The Perth Basin, based on information from the WAPIMS database.*

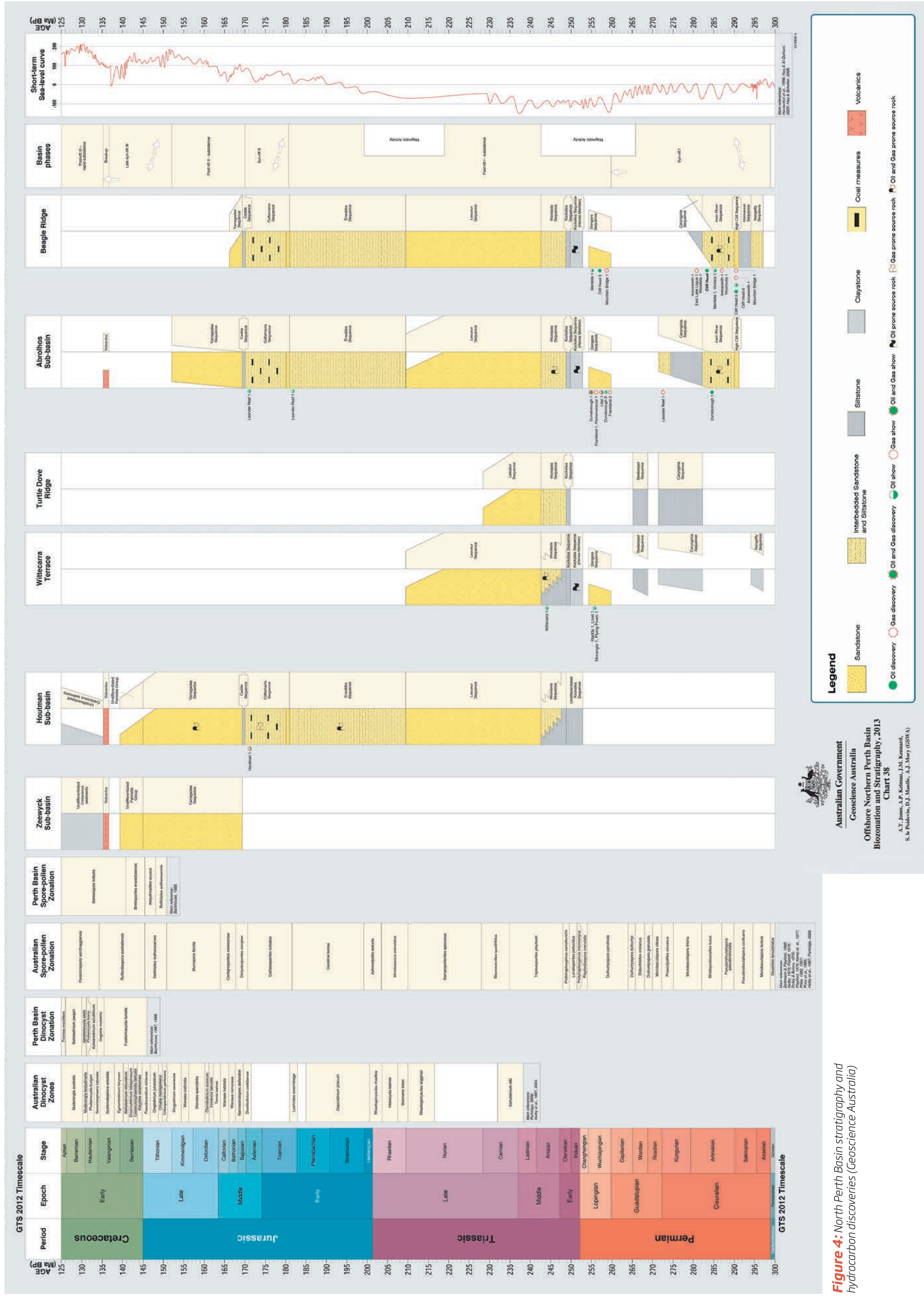


Figure 4: North Perth Basin stratigraphy and hydrocarbon discoveries (Geoscience Australia)

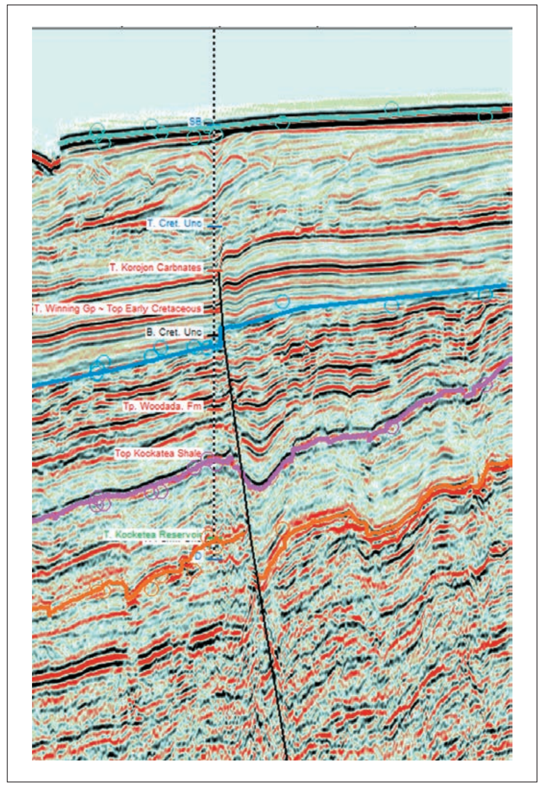


Figure 5A: *Livet-1*

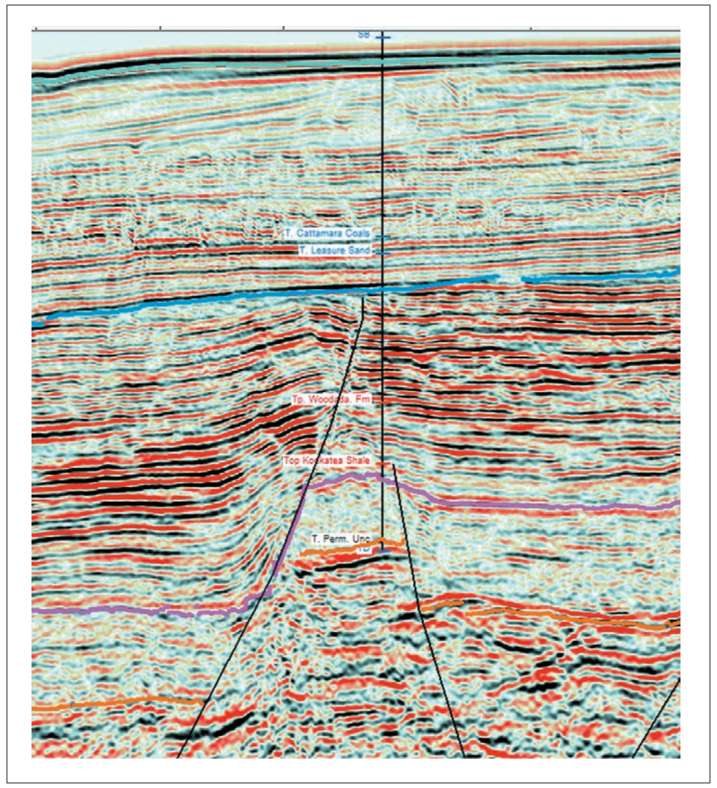


Figure 5B: *Morangie -1*

The Kockatea Shale with its organic rich lower unit (the Hovea Member) overlies a number of coarse-grained units including the Late Permian Wagina/Dongara sandstones. This 'Upper Permian' Play, characterised by Permian reservoirs beneath the Kockatea seal/source, was the principle target in 19 of the 22 offshore wells in the basin (Figure 5), comprising traps of fault bounded structural highs with Kockatea Shale as top and lateral seal across faults. All of the discoveries made to date have been made in this Upper Permian play, and onshore analogues include the Dongara, Hovea and Jingemia oil and gas fields.

Figure 5 (a, b, c) Legacy seismic examples of key wells drilled in the "Upper Permian Play"

Although only oil shows were recorded in Livet-1 and Morangie-1 immediately below the Kockatea seal, well and seismic analysis confirms different working elements of the petroleum system for this play. The Livet-1 well is reported as water saturated but expected to have contained an oil column at some stage due to residual fluorescence. Seal and/or structure are likely to have been damaged by fault reactivation, as verified by seismic showing the bounding fault extending into the Cretaceous (Figure 5a).

Morangie-1 intersected "immobile oils" due to lateral fault seal failure (Figure 5b). However, it also proved that Kockatea shales can be an excellent oil source rock which, even when locally immature, should be mature in the deeper Houtman basin. It also determined that the Irwin River Coals can be an excellent gas source rock (1-50% TOC) and proved again that the Hovea member is an excellent reservoir.

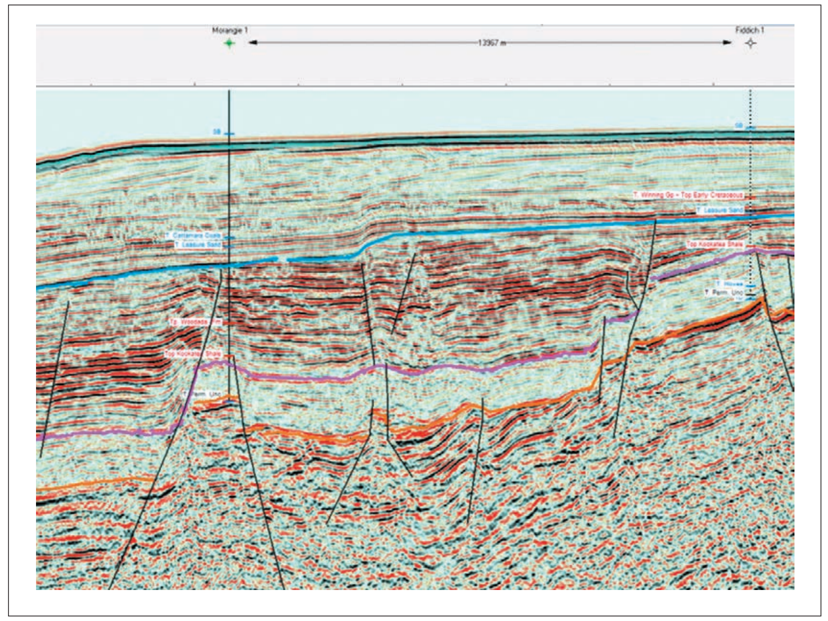


Figure 5C: *Morangie-1 and Fiddich-1*

In contrast to these two wells, in the Cliff Head-1 (drilled in 2001 by Roc Oil (Wa) Pty Ltd) an oil column in the Irwin River Coal Measures was encountered immediately below the Kockatea Shale (Figure 6). Similar structures tested by Frankland-1, Perserverance-1 and Dunsborough-1 discovered non-commercial gas accumulations within the Dongara Sandstones and Irwin River Coal Measures. The identification of a palaeo-oil column (Kempton et al, 2011) in the Cliff Head-3 development well indicates that the structure historically contained a larger accumulation of hydrocarbons.

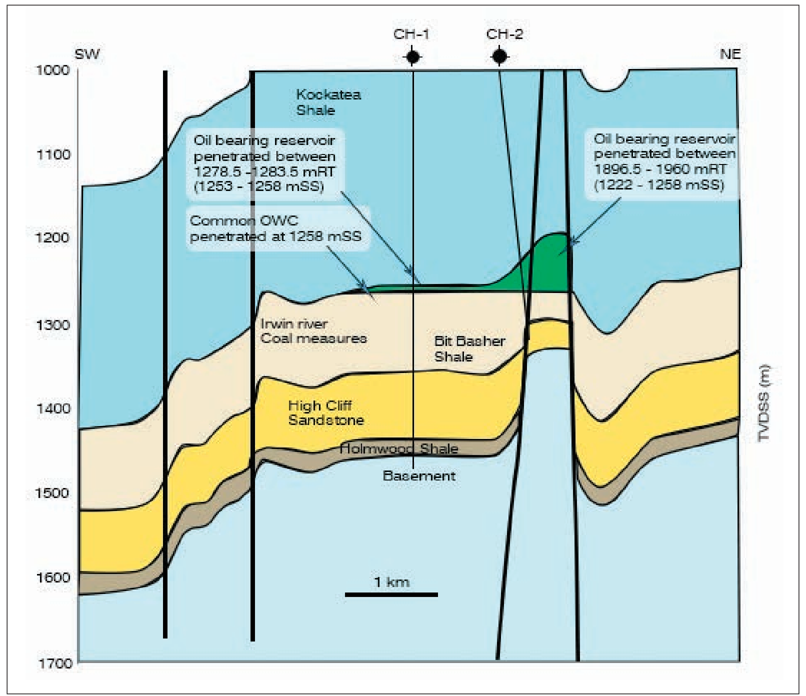


Figure 6: *A schematic section through the Cliff Head Discovery (Jones & Hall, 2002) shows sandstones containing an oil column in a fault bounded anticlinal structure sealed by the Kockatea Sequence.*

Fiddich-1 well, drilled on a well-defined 3 way dip, fault-bounded structural closure (Figure 5c), is classified as a dry hole with the main failure attributed to charge and incorrectly mapped migration pathways. Located updip from Morangie-1, the source rocks are also suspected to be immature at this even shallower depth. However, it proved excellent reservoir (12-27% porosity, 86% Net to Gross).

The lower Permian sediments below the High Cliff Sandstones have only been tested within four wells (Cliff Head-1, Twin Lions-1, Mentelle-1, Vindara-1) which were drilled on the crest of fault bounded structural highs. Intra Permian Shales or even the Kockatea Shale may also seal these older sediments due to the presence of an Upper Permian unconformity surface. These sediments are thought to have been geographically limited to syn-extensional growth wedges on the hanging walls of major NNW trending faults (e.g. Harris, 1994, Norvick, 2003). Until Spectrum's Rocket survey, these localised depocentres have proved difficult to map aerially due to the wide spacing of existing 2D seismic lines and sparse 3D seismic coverage (only 2,705km^2 in the Perth Basin equivalent to 2.7% of the basin).

The younger 'Triassic-Jurassic' play consists of Triassic and Jurassic sandstones with localised intra-formational seals below the middle Jurassic Cadda Formation shale. Traps for this play include tilted fault blocks and compressional folds. Though it was the primary target in five of the exploration wells, there have been no offshore discoveries to date. However, shows were recorded in Houtman-1, Wittecarra-1 and Leander Reef-1 and residual oil found in four wells, points to temporary preservation of charge, and subsequent remigration or breach. Onshore, this younger play has been successful at Mt Horner and North Yardanago, where hydrocarbons are reservoired in the Cattamarra Coal measures, below a Cadda Formation regional seal.

A detailed summary of Offshore Northern Perth Basin exploration wells is presented by Jorgensen et al (2011).

RESERVOIR QUALITY

Reservoir property data (Table 1) compiled from laboratory testing and petrophysical interpretations (O'Neill, 2016) within the well completion reports reveal favourable permeabilities within the Cattamarra Coal measures and sand lenses within the Cadda Formation. Porosities of up to 30% have been measured through the Triassic – Jurassic reservoir section.

Sequence	Average Porosity (-)	Permeability (mD)	Wells
Yarragadee	17.93 - 25	1324.9 - 1454.65	Charon-1, Geelvink-1A
Cadda	8.82 - 25	0.26 - 16.57	Charon-1, Geelvink-1A, Houtman-1
Cattamarra	3.12 - 30	0.12 - 9.5	Batavia-1, Geelvink-1A, Houtman-1
Eneabba	18 -24	N/A	Batavia-1, Geelvink-1A
Lesueur	15 - 30	N/A	Batavia-1, Geelvink-1A, South Turtle Dove-1B
Woodada	15 - 30	N/A	Geelvink-1A, South Turtle Dove-1B
Kockatea	6 - 17	N/A	Geelvink-1A, Livet-1, Perseverance-1
Dongara	2 - 25	0.9 - 65.76	Cliff Head-3 & 10, Batavia-1, Dunsborough-1, Fiddich-1, Flying Foam-1, Frankland-1, Geelvink-1A, Hadda-1, Livet-1, Perseverance-1, Twin Lions-1, Vindara-1
Beekeeper	11 - 18	N/A	South Turtle Dove-1B
Carynginia	5 - 12	N/A	Batavia-1
Irwin River	5 - 26.2	0.03 - >1000	Cliff Head-1 - 5, 8, 9 , 11 - 13, Dunsborough-1, Frankland-1, Geelvink-1A, Mentelle-1, Twin Lions-1, Vindara-1
High Cliff	9.2 - 19	1.3 - 243	Cliff Head-1 - 6, Dunsborough-1, Frankland-1, Mentelle-1, Twin Lions-1, Vindara-1
Tumblagooda	18.9 - 19.4	118 - 124	Hadda-1

Table 1: *Table 1 - Reservoir property data compiled from the Well Completion Reports after O'Neill (2016). The well completion report authors are detailed in the References.*

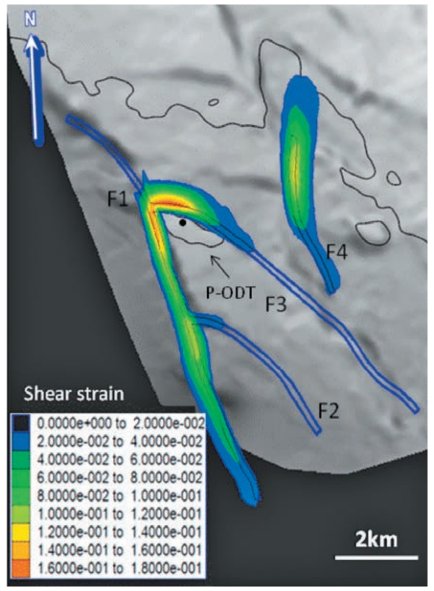


Figure 6A: *Geomechanical modelling of the Morangie-1 structure indicates high risk of reactivation during the NW-SE oriented, Middle Jurassic to Early Cretaceous extensional event. The base of the palaeo-oil column identified in the Dongara Sandstone is associated with these high risk faults. Modified from Langhi et al (2012).*

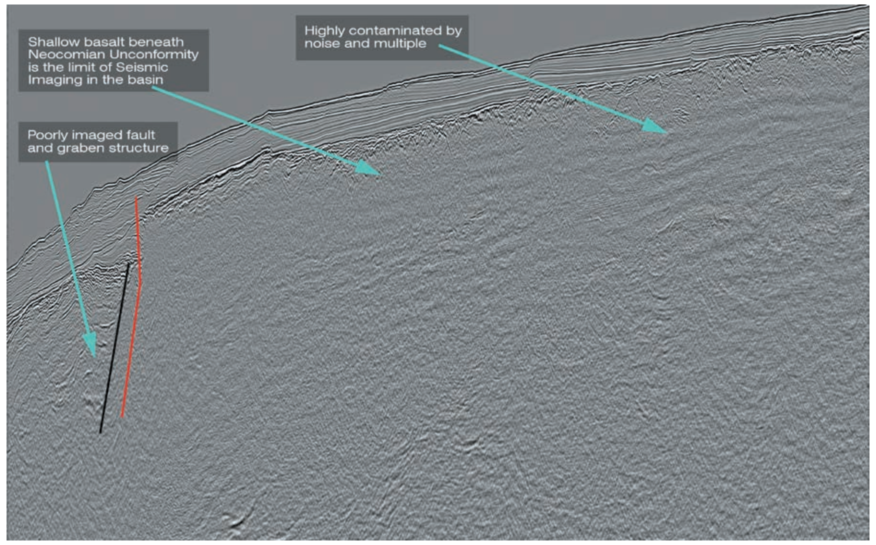


Figure 7A: *Legacy seismic.*

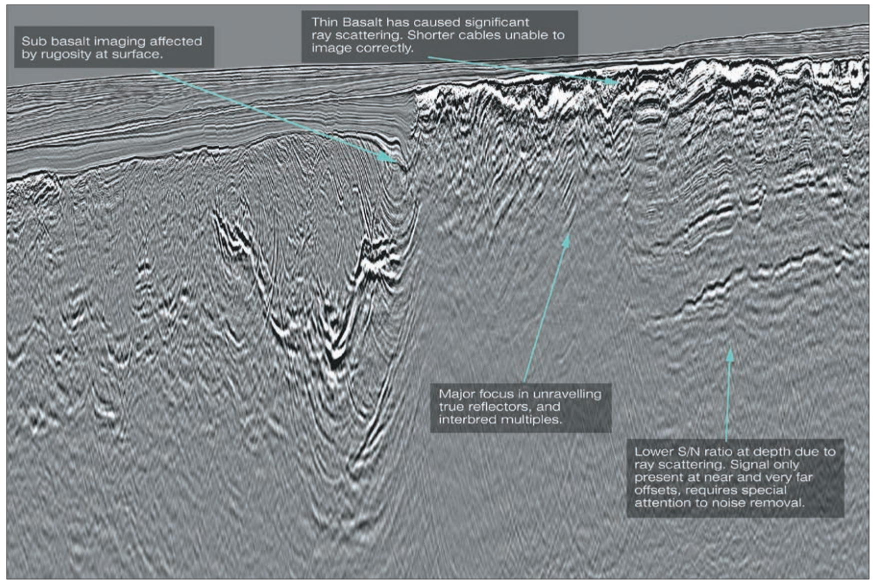


Figure 7B: *2015 Rocket Phase 1 seismic line very close to legacy seismic line above. Rocket Phase 1 results reveal a previously unimaged sedimentary basin below a "thin basalt" layer.*

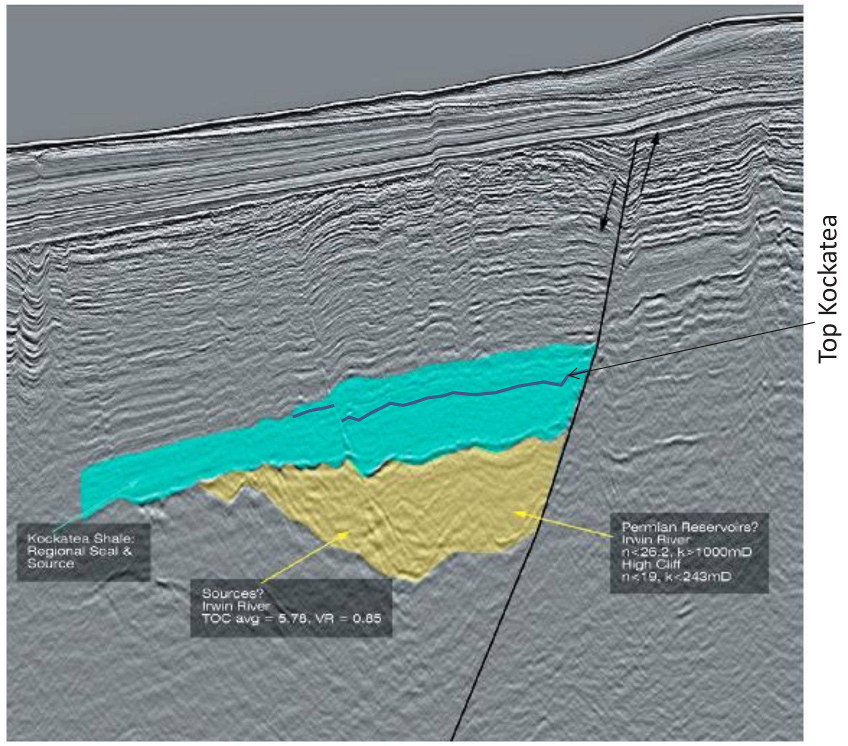
PALAEO-OIL ACCUMULATIONS

Palaeo-oil accumulations (Kempton et al, 2011) have been identified in several wells (Figure 2). These palaeo-oil zones, within wells testing fault-bounded structures suggest that trap breaching by fault reactivation is an important failure mechanism within the offshore basin. Structural traps may have formed and reactivated during the three extensional phases identified in the basin and may also have been influenced by a Miocene inversion event proposed by Jones et al (2011). Langhi et al (2012) undertook geomechanical modelling to assess the risk of trap breaching during the Middle Jurassic to Early Cretaceous extensional event which was characterised by NW-SE extension. Their model of the Morangie-1 structure (Figure 6a) indicated a high risk of reactivation associated with bounding faults within the vicinity of the well. Similar modelling at the Cliff Head Discovery found that the Oil Water Contact in the field was associated with faults with a low reactivation risk. The modelling suggests that faults sub-parallel to the extension axis are at lower risk of extensional reactivation than more orthogonally oriented faults, providing explorers with a tool for screening further structural leads in the basin.

NEW PLAYS REVEALED BY ROCKET 2D

Not much is known about the subsurface configuration and nature of the offshore South Carnarvon Basin, predominantly due to the presence of what have been believed to be shallow basalts, providing a major barrier to seismic imaging (Figure 7a). Many have suggested that either shallow basement or perhaps very thick basalts underlay the main Cretaceous unconformity present in the area. However, gravity mapping has suggested the presence of a sedimentary basin, perhaps several kilometres thick, which had not been imaged before. Preliminary results from Rocket Phase 1 strongly support the presence of such a basin as large rotated fault blocks are being imaged below a "thin basalt" layer (Figure 7b).

Additionally, to date none of the drilled wells have tested the lower Permian syn-extensional wedges deposited locally on major fault hanging walls. These localised depocentres (Figure 8) have the potential to contain thicker Permian accumulations including reservoirs such as the Irwin River and High Cliff sandstones as shown on an interpreted section from the Houtman sub-basin (Figure 8). These sands have the potential to receive charge from sources within the lower Permian succession (e.g. Irwin River coals, Holmwood Shale) or the overlying Kockatea Shale. The regionally sealing Kockatea shale may preserve charge in the up-dip sections of the Permian sediments, far from major bounding faults that may be at risk of reactivation.



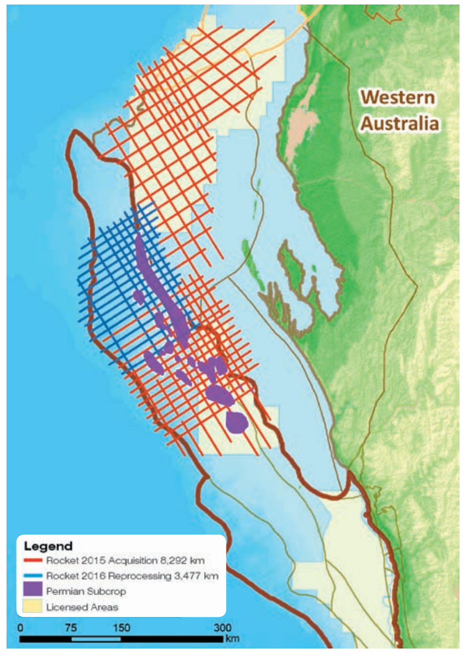


Figure 8: *Rocket Phase 2 seismic confirming a new untested play in which Permian reservoirs and source rock deposited in growth wedges are overlain by the Kockatea Shale regional source. The map shows the possible distribution of the localised depocentres.*

Geology	Average VR	VR Samples	Petroleum Generation	Average Tmax	S1 avg (mg/g)	S2 avg (mg/g)	S1avg + S2avg (mg/g)	No of samples	Depositional Environment	Oil/Gas Prone
Valanginian	0.38	4	Immature	421.20	0.37	7.81	8.18	10	N/A	N/A
Yarragadee	0.47	61	Immature	427.02	1.18	30.07	31.26	141	Fluvial	N/A
Cadda.	0.59	18	Early Oil Generation	430.42	0.47	5.35	5.82	138	Marine shales	Oil
Cattamarra	0.58	51	Early Oil Generation	437.14	0.43	5.93	6.36	122	Deltaic	Gas
Eneabba	0.64	19	Early Oil Generation	459.59	0.88	14.53	15.40	70	Sabkha	Oil/Gas
Lesueur	0.46	21	Immature	458.00	0.13	0.78	0.91	18	Fluvial with marine in north	N/A
Woodada	0.56	27	Early Oil Generation	435.57	0.18	2.55	2.72	72	Marine and fluvial	Oil
Kockatea	0.65	80	Early Oil Generation	436.01	0.20	1.53	1.73	121	Marine shales	Oil
Hovea Member	0.70	21	Early Oil Generation	431.06	0.62	12.33	12.95	67	Marine shales	Oil
Wagina	0.94	1	Early Condensate	456.42	0.26	1.16	1.42	4	Marine Mudstones	Oil
Dongara	0.98	10	Early Condensate	445.75	0.50	4.84	5.35	16	Terrestrial	N/A
Caryngina	0.91	21	Early Condensate	457.04	0.27	1.48	1.75	28	Marine mudstones	Oil
Irwin River	0.85	28	Early Condensate	438.22	0.95	8.27	9.22	55	Coals	Gas
Holmwood	0.54	3	Early Oil Generation	435.33	0.10	0.99	1.09	3	Marine shales	Oil

Table 2: *Geochemistry data summarised from the compilation in Jorgensen et al (2011).*

NORTH PERTH BASIN PETROLEUM SYSTEM

The numerous hydrocarbon shows and palaeo-oil columns identified through the Permo-Jurassic basin fill demonstrate that a source kitchen has developed in the basin resulting in secondary charge migration. Geochemical data (Table 2) summarised by O'Neill (2016) from data compiled in Jorgensen et al (2011) demonstrates that maturity generally increases with depth with the potential for oil and gas charges to develop.

A key factor in understanding the North Perth Basin petroleum system is that hydrocarbon generation and migration commenced early, in the Jurassic (Jones and Hall 2002). As such, many early filled pools will have held their oil reserves for over 100 million years. In this time, as discussed above, the margin has been subject to numerous periods of extension, transpression and inversion, giving much opportunity for trap breach and re-migration of hydrocarbons. Identification of early formed structures that have not subsequently been reactivated (such as Cliff Head and the Permian growth wedge play in (Figure 8), are key to risk reduction in this basin. Geomechanical modelling (Langhi et al, 2012) provides a method of ranking the reactivation risk of untested prospects and derisking the effects of these reactivation events.

Good reservoir quality is common in the Permo-Jurassic succession with porosities of up to 30% measured within the shallower, less compacted Triassic and Jurassic sands (Table 1). Permeabilities above 1 Darcy have been measured in the relatively shallow Yarragadee Sandstone and the Permian Irwin River Coal Measures, host to the Cliff Head field.

TECH TALK

CONCLUSIONS

Review of the 22 exploration wells drilled in the Offshore Northern Perth Basin provides a wealth of evidence for a viable petroleum system upon the West Australian continental margin. Good reservoir quality is demonstrated by many wells at Upper Permian play level and at Triassic-Jurassic Play levels. Evidence for oil generation and successful migration is again manifest by both discoveries at Cliff Head-1, Frankland-1, Perserverance-1, Dunsborough-1 and numerous oil and gas shows.

Generation modelling suggests oil is generated early in this basin (in the Jurassic), and residual oil based palaeo-oil column interpretations in many wells provide evidence of trap breach. This highlights fault reactivation as the key basin exploration risk. Geomechanical modelling may provide the key to understanding reactivation risk prior to drilling of future leads.

Exploration has focussed on testing of reservoirs below the regional Kockatea Shale upon fault-bounded structural highs within the Abrolhos Sub-basin. There is potential for many similar structures to exist within the largely untested Houtman Sub-basin, similar to the success at Cliff Head-1. Additionally, Permian growth wedges (Figure 8), sealed by the regional Kockatea Shale offer an untested play concept that is worthy of further investigation. Integration of the well data, the understanding of the key risk to prospectivity in this early charged basin, with modern long offset seismic broadband data such as Rocket 2D, designed specifically to boost low frequencies and image the deeper plays in this frontier area (Figure 7b), will provide the fuel needed to re-energize exploration and maximise the potential to reduce risk within this exciting underexplored basin. ◗

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