The APPEA Journal 2020, **60**, 685–690
https://doi.org/10.1071/AJ19059

Extended abstract

The Paleozoic prospectivity of the Browse Basin, Australia

Said Amiribesheli[A,D], *Joshua Thorp*[B] and *Julia Davies*[C]

[A]KUFPEC Australia Pty Ltd, Alluvion, 58 Mounts Bay Rd, Perth, WA 6000, Australia.
[B]Searcher Seismic Pty Ltd, Level 1/15 Rheola St, West Perth, WA 6005, Australia.
[C]Discover Geoscience, Level 1/15 Rheola St, West Perth, WA 6005, Australia.
[D]Corresponding author. samiribesheli@kufpec.com

Abstract. Most of the discovered hydrocarbons in the Browse Basin occurred within the Mesozoic intervals, while deeper Paleozoic sequences have been seldom explored. Lack of Paleozoic exploration in the Browse Basin has been attributed to the lack of well penetrations, poor understanding of the petroleum systems and paucity of seismic data. The onshore Canning Basin with several commercial fields and discoveries is the most appropriate analogue for understanding the Paleozoic sequences in the region. With the integration of geophysical data (i.e. gravity, magnetic and seismic), well data and geology, the Paleozoic prospectivity of the Browse Basin can be further enlightened. Modern long offset (8 m) Vampire 2D seismic data were acquired by Searcher to address some of the complex challenges in the Browse Basin. Reservoir quality of the Brewster Formation, volcanic discrimination within the Plover Formation and identification of deeper Triassic and Paleozoic plays are some examples of these challenges in the Browse Basin. Recently Searcher reprocessed this regionally important Vampire 2D seismic dataset that ties to 60 wells. The broadband pre-stack depth migration reprocessed data were inverted to extract three petro-elastic properties of acoustic impedance, Vp/Vs and density by three-term amplitude versus offset inversion algorithm to improve imaging of deeper plays and delineate reservoir properties. This paper discusses how several potential Paleozoic reservoir-seal pairs can be identified in the Browse Basin by utilising the integration of Vampire 2D seismic data, quantitative interpretation products, regional geology and knowledge of the Canning Basin's fields and discoveries. Previously there was little exploration of Paleozoic plays because they could not be imaged on seismic data. The potential Paleozoic reservoirs identified in this study include Permo-Carboniferous subcrop, Carboniferous-Devonian anticline and Carboniferous-Devonian rollover plays.

Keywords: Canning Basin, carbonate, Carboniferous play, Paleozoic play, Permian, S**ai**smic™, Vampire 2D seismic.

Accepted 30 March 2020, published online 15 May 2020

Introduction

The Browse Basin hosts major hydrocarbon fields and discoveries. The Browse Basin was initiated as an intra-cratonic failed rift basin during episodes of extensional tectonic regime in the Late Carboniferous-Early Permian. Rob Roy 1 penetrated into upper Carboniferous deltaic and shallow marine sediments on the Prudhoe Terrace and Yampi Shelf. Seismic data indicate that older Palaeozoic sediments are present beneath the central Browse Basin and the Scott Plateau (Lavering and Pain 1991) (Fig. 1). Similar to the Canning and Bonaparte Basins, the Permian sequence in the Browse Basin is likely to be predominantly clastic with glacial or glacio-marine facies at the base, overlain by shallow marine, deltaic and terrestrial sandstone and shale sequences (Lavering and Pain 1991). It is also postulated that a Permian carbonate may be present in the area.

During the Late Triassic there was a period of compression, inversion and uplift (Struckmeyer *et al*. 1998; Lawrence *et al*. 2014), during which sediments from the Early Triassic were eroded and transported into the Caswell Sub-basin. In the Early to Middle Jurassic, the Plover Formation fluvio-deltaics were deposited at the same time as extension continued the development of the north-easterly structural trend (Amiribesheli *et al*. 2019). By the Middle Jurassic, Argo Land had completely separated from the Australian Plate followed by a subsequent period of rifting during the Callovian to Oxfordian (Symonds *et al*. 1994; Blevin *et al*. 1997). The Brewster Formation submarine fans were deposited into the basin from the eastern margin in the Late Jurassic to

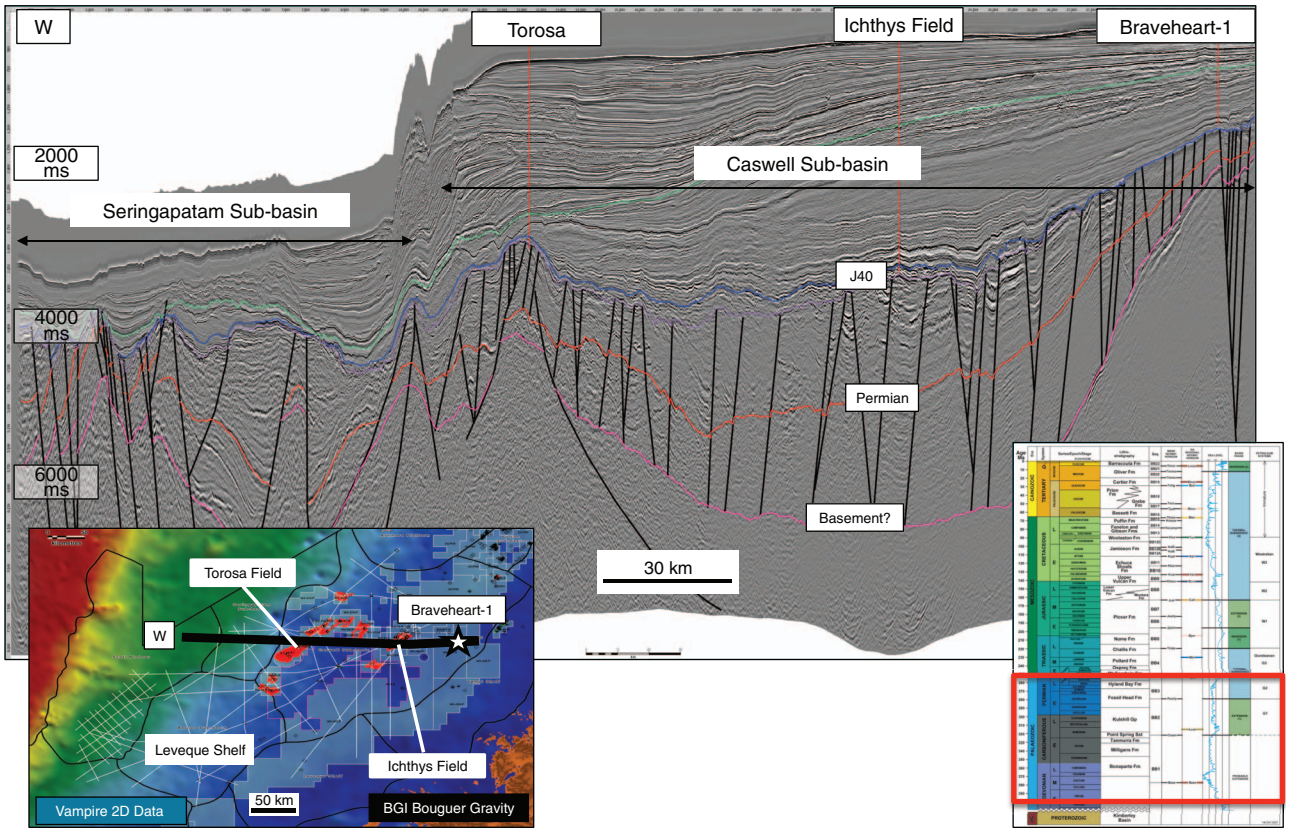

Fig. 1. The Vampire 2D PSDM full stack seismic line tied to the Braveheart-1 well and main fields in the Browse Basin. The Paleozoic section is highlighted between red and pink horizons. The left-hand inset shows the structural elements overlaying the BGI Bouguer Gravity where relative highs are in red and lows in blue. The right-hand inset shows the generalised stratigraphy of the Browse Basin and is modified after Geoscience Australia. (Seismic courtesy of Searcher's S**ai**smic platform).

Early Cretaceous. During the Early Cretaceous, thermal subsidence continued, which overtook the rate of sediment supply in the Valanginian causing a marine transgression and an increase in argillaceous sediment input (Radlinski *et al.* 2004). The Aptian was a time of regression and tectonic stability when clastic sediments were deposited during passive thermal subsidence. In the Cenozoic, tectonic stability was interrupted by the collision of Australia and Asia, resulting in compressional uplift along the North West Shelf margin (Longley *et al.* 2002; Lawrence *et al.* 2014).

Seismic data through the Saismic platform

In this study, Searcher provided seismic data through Searcher's S**ai**smic cloud-based data platform. Searcher's large seismic database in the Browse Basin was used for this study, including the 8-km long offset Vampire 2D pre-stack depth migration (PSDM) survey, multi-vintage pre-stack time migration reprocessed Supertie 2D data and the proprietary Openseis data. The cloud-based S**ai**smic platform allows mapping, visualisation and easy export of data. The S**ai**smic platform has been designed to implement large-scale analytics and machine learning functionality with Python API functions.

To uncover the Paleozoic potential of the Browse Basin, long offset seismic data are required. Searcher acquired the Vampire 2D Seismic Survey in 2011 to address the issues and concerns associated with the legacy data in the Browse Basin (Fig. 1). The Vampire 2D data were acquired with 6-m source depth, 25-m shot point interval and 8-km steamer. This acquisition setting ensured that the trace length would image all the play levels and deeper structures within the basin while still providing sufficient fold in the shallow section for velocity modelling. Modelling of the known geophysical and geological issues in the area indicated that an 8-km streamer would sufficiently image the primary Mesozoic and deeper Palaeozoic targets. Modelling also suggested the 8-km streamer provides enough angle coverage (beyond 50°) for a three-term amplitude versus offset (AVO) inversion technique at the Mesozoic level (Amiribesheli *et al.* 2019).

In 2018, Searcher decided to apply broadband PSDM seismic processing to the Vampire 2D data. The detailed interpretation and wealth of well information allowed for a high-resolution velocity model that incorporated localised velocity features through the tomographic inversion. The final processing result offered significantly improved bandwidth throughout the section and improved the stability of the far and ultra-far offset stacks such that they could be

used in a three-term AVO and quantitative interpretation analysis.

From onshore Canning Basin to offshore Browse Basin

To unravel the Paleozoic sequences in the Browse Basin, regional analogue data are required. The onshore Canning Basin with several commercial hydrocarbon fields is the best-known Paleozoic basin in the region. In the onshore Canning Basin area, the Precambrian crystalline basement of the Pilbara and Kimberley Cratons is overlaid by the Paleozoic sequences (Amiribesheli and Weller 2019). The thickest part of the onshore Canning is placed in the Fitzroy Trough, in which sediment thickness exceeds 11 000 m. The marine shales, carbonates and evaporates with minor sandstones of Lower Ordovician to Silurian are the oldest recorded sedimentary interval in the onshore area (Insight Petroleum and Searcher Seismic 2015). Theia-1 (2015) discovered oil and gas in the Middle Ordovician Goldwyer Formation. The exploration potential of the Carboniferous (and older) sedimentary units in the onshore Canning area have been largely ignored and unimaged. This has mostly been due to lack of seismic data in the offshore Canning Basin and further to the north in the Leveque Shelf of the Browse Basin. Analogues for the Paleozoic prospectivity of the Browse Basin are therefore best appraised from the onshore Canning Basin.

Lower Devonian compressional Prices Creek Movement has generated regional angular unconformity for the base Devonian. Followed by the Price Creek unconformity, the Upper Devonian syn-rift succession has been deposited by the Pillara Extension. The Upper Devonian reef complex, which is the main reservoir in the Blina oil field, is also believed to have been initiated at this time (Insight Petroleum and Searcher Seismic 2015). It has also been postulated that the reef complex is present in the offshore area (Playford 1982). The main source rock of the Carboniferous Laurel Formation is understood to be responsible for most of the oil and gas occurrences in the Lennard Shelf (e.g. Kingsley and Streitberg 2013). From organic carbon richness prospective, the Lower Carboniferous shows reasonable-quality source rock (Ghori 2013).

The significant Meda Transpression event marks Carboniferous angular unconformity (Apak and Backhouse 1998) in which the basin architecture allows deposition of the fluvial and glaciogenic (Grant Group), shallow marine sandstone (Poole Formation) and marine shale (Noonkanbah Formation) (Insight Petroleum and Searcher Seismic 2015). The Upper Grant Group with organic-rich marine shales acts as the main source rock interval within the Upper Carboniferous and Lower Permian. Mory (2010) also

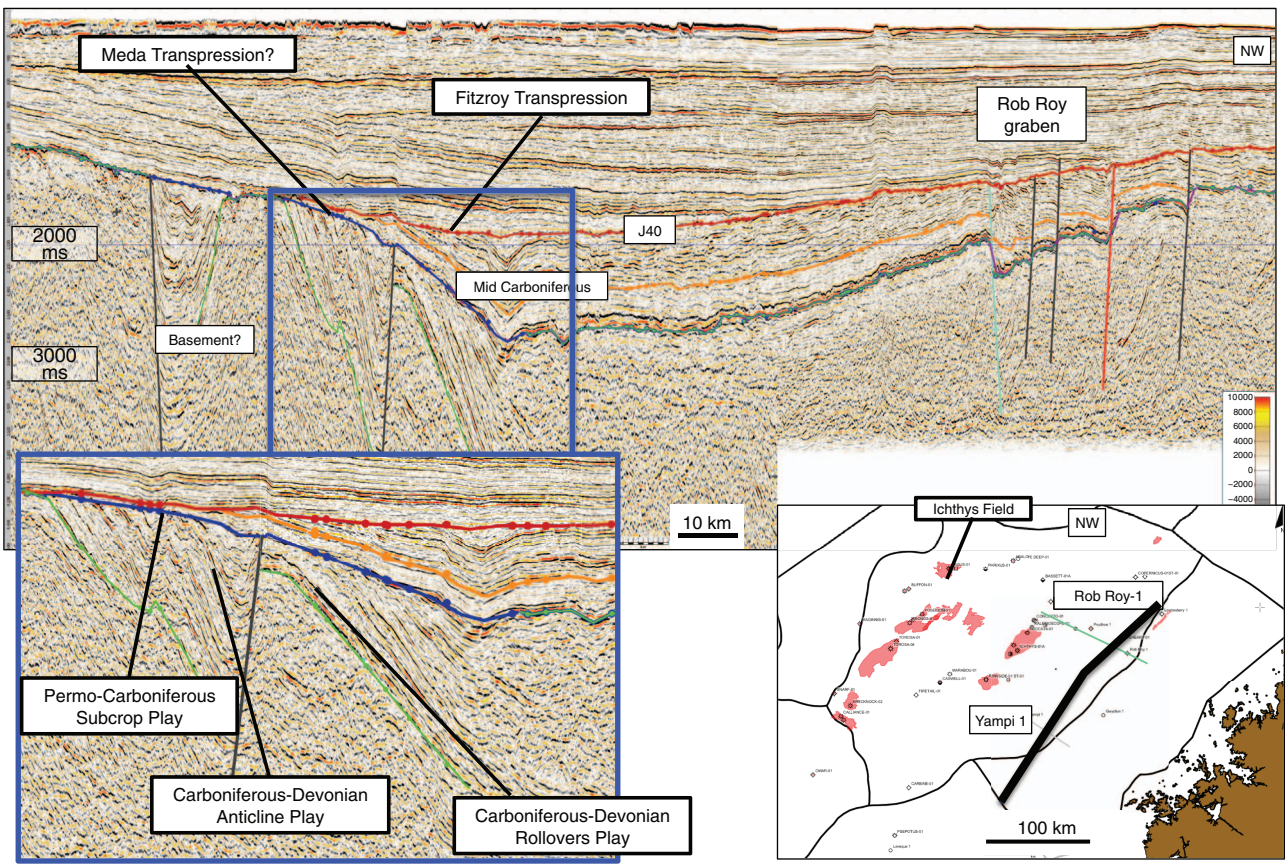

Fig. 2. The seismic line is a SSW–NNE transect along the Yampi Shelf. This line shows several Paleozoic grabens in the Browse Basin. Examples of Permo-Carboniferous subcrop, Carboniferous- Devonian anticline and Carboniferous-Devonian rollover plays are highlighted in the blue frame. (Seismic courtesy of Searcher's **Sai**smic platform).

suggested that the Permian Noonkanbah Formation could contain good source potential in the basin. It is important to note that the Meda Transpression event in the onshore Canning Basin is associated with uplift and erosion and reactivation of older strike–slip faults resulting in the generation of faults and fractures which provide vertical conduits for hydrocarbon migration (Fig. 2).

Figure 2 shows several Paleozoic grabens in the Browse Basin. The seismic line is a SSW–NNE transect along the Yampi Shelf. Note the Rob Roy graben on the northern (right) end of the section. The dark blue event is the mid-Carboniferous compressional event, perhaps equivalent of the Meda Transpression in the onshore Canning Basin. The main Paleozoic extensional faults create NNW–SSE trending grabens. Evidence of a possible Devonian extension can be seen on the southern end of the line, inboard of Yampi-1. The structuring due to the subsequent compression during the Late Triassic (Fitzroy Transpression) also can be identified in the image.

Paleozoic play concept in the Browse Basin

With the recognition of the main unconformity in the Browse Basin by long offset Vampire 2D data and seismic data from the S**ai**smic platform, some speculative play concepts have been developed. Figure 2 shows a section near the Yampi Shelf where numerous NNW–SSE trending grabens have been identified. Within these grabens several play concepts are interpreted including (not limited to) Permo-Carboniferous subcrop, Carboniferous-Devonian anticline and Carboniferous-Devonian rollover plays. Regional seismic interpretation and mapping of structural features highlights the variation of sedimentary thickness. Figure 3 is the isochron (in ms) between top Permian to basement and indicates thickness variation of the Paleozoic section. It is postulated that Palaeozoic source rock is preserved within this unit. The overlain grid shows the area of possible source rock deposition and their migration pathway. As per the onshore Canning Basin analogue, liquid-rich hydrocarbon is expected to fill traps in the shelfal part of the Browse Basin.

Conclusion

Most of the discovered hydrocarbons in the Browse Basin occurred within the Mesozoic intervals, whereas deeper Paleozoic sequences are seldom explored. Lack of Paleozoic exploration in the Browse Basin has been attributed to the lack of well penetrations, poor understanding of the petroleum systems and paucity of seismic data. Integration of the onshore data, regional geology and the modern Vampire data reveals several potential reservoir-seal pairs in the Paleozoic section, which previously was unimaged. With modern long offset seismic and knowledge of tectono-stratigraphic framework and seismic interpretation of the onshore Canning Basin, in this paper it is demonstrated that the Paleozoic section of the

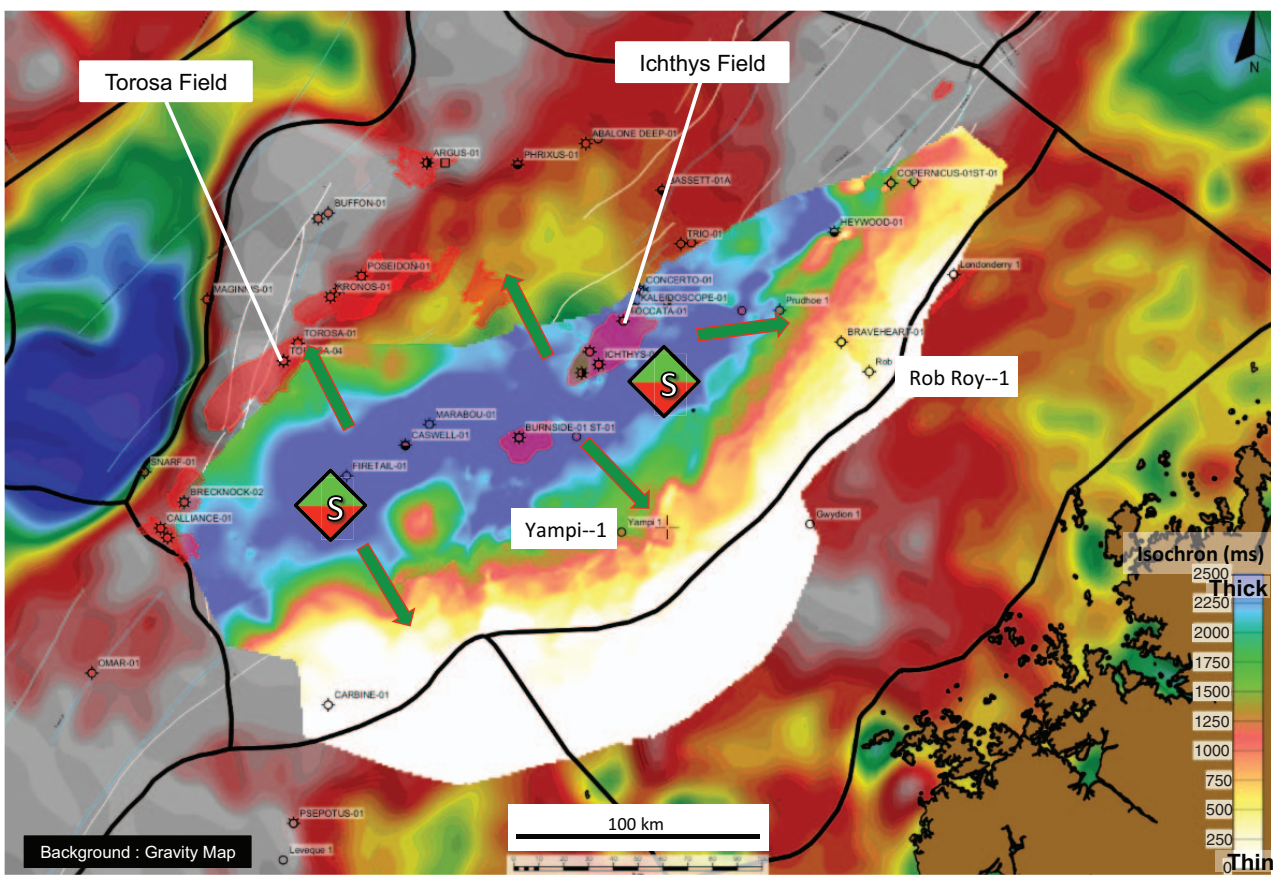

Fig. 3. Top Permian to Basement Isochron map (in ms). The isochron indicates thickness variation of the Paleozoic section in the basin. The map also shows the area of possible source rock accumulation and the migration pathway.

onshore Canning Basin and the Browse Basin are comparable. Integration of onshore data, regional geology and the seismic data reveals several potential reservoir intervals in the Palaeozoic section of the Browse Basin. Possible Palaeozoic play concepts in the Browse Basin include Permo-Carboniferous subcrop, Devonian anticline, Carboniferous-Devonian rollovers and Devonian reefs, as well as Permian carbonates.

Conflicts of interest

The authors are unaware of any conflicts of interest.

Acknowledgements

The authors thank KUFPEC Australia Pty Ltd, Discover Geoscience and Searcher Seismic for permission to publish this paper, as well as their colleagues for fruitful discussion while preparing this paper. This research did not receive any specific funding.

References

Amiribesheli, S., and Weller, A. (2019). The Paleozoic prospectivity of the Offshore Canning area, Australia. *ASEG Extended Abstracts* **2019**, 1–6. doi:10.1080/22020586.2019.12072974

Amiribesheli, S., McGlew, J., and Thorp, J. (2019). Dude, where's my AVO? A case study from the Browse Basin, North West Shelf, Australia. *ASEG Extended Abstracts* **2019**, 1–5. doi:10.1080/22020586.2019.12073041

Apak, S. N., and Backhouse, J. (1998). Re-interpretation of the Permo-Carboniferous Succession, Canning Basin, Western Australia. In 'The Sedimentary Basins of Western Australia 2. Proceedings, PESA Symposium, Perth, August 30–September 2 1998'. (Eds P.G. Purcell and, R.R. Purcell.), pp. 667–682. (PESA: Perth)

Blevin, J.E., Struckmeyer, H.I.M., Boreham, C.J., Cathro, D.L., Sayers, J. and Totterdell, J.M. (1997). Browse Basin high resolution study. Interpretation report, North West Shelf, Australia. AGSO Record, 38.

Ghori, K. A. R. (2013). Petroleum geochemistry and petroleum systems modelling of the Canning Basin, Western Australia. Geological Survey of Western Australia, Report 124.

Insight Petroleum and Searcher Seismic (2015). Prospectivity study of the offshore Canning Area, Western Australia (unpublished).

Kingsley, D., and Streitberg, E. (2013). The exploration history of the Laurel Basin-centred gas system Canning Basin, Western Australia. In 'West Australian Basins Symposium, Perth, WA, August 18–21, 2013'.

Lavering, I. H., and Pain, L. (1991). Australian Petroleum Accumulations Report 7, Browse Basin. Department of Primary Industries and Energy, Bureau of Mineral Resources, Geology and Geophysics, Australian Government Publishing Service: Canberra.

Lawrence, S., Thompson, M., Rankin, A., Alexander, J., Bishop, D., and Boterhoven, B. (2014). A new structural analysis of the Browse Basin, Australian North West Margin. *The APPEA Journal* **54**(1), 1–10. doi:10.1071/AJ13001

Longley, I. M., Buessenschuett, C., Clydsdale, L., Cubitt, C. J., Davis, R. C., Johnson, M. K., Marshall, N. M., Murray, A. P., Somerville, R., Spry, T. B., and Thompson, N. B. (2002). The North West Shelf of Australia–a Woodside perspective. In 'The Sedimentary Basins of Western Australia 3: Proceedings of the Petroleum Exploration Society of Australia Symposium, Perth, 2002.' (Eds M. Keep and S. J. Moss) (PESA: Perth)A.

Mory, A. J., (2010). A review of mid-Carboniferous to lower Triassic stratigraphy, Canning Basin, Western Australia. Geological Survey of Western Australia, Report 107.

Playford, P. E. (1982). Devonian reef prospects in the Canning Basin: implications of the Blina oil discovery. *The APPEA Journal* **22**(1), 258–272. doi:10.1071/AJ81021

Radlinski, A. P., Kennard, J. M., Edwards, D. S., Hinde, A. L., and Davenport, R. (2004). Hydrocarbon generation and expulsion from Early Cretaceous source rocks in the Browse Basin, North West Shelf, Australia: a small angle neutron scattering study. *The APPEA Journal* **44**(1), 151–180. doi:10.1071/AJ03005

Struckmeyer, H. I., Blevin, J. E., Sayers, J., Totterdell, J. M., Baxter, K., Cathro, D. L., Purcell, P. G., and Purcell, R. R. (1998). Structural evolution of the Browse Basin. North West Shelf. New concepts from deep seismic data. In 'The sedimentary basins of Western Australia 2: Proceedings of the Petroleum Exploration Society of Australia Symposium, Perth, 1998.' Eds P. G. Purcell and R. R. Purcell) pp. 345–367. (PESA: Perth)

Symonds, P. A., Collins, C. D. N., Bradshaw, J., Purcell, P. G., and Purcell, R. R. (1994). Deep structure of the Browse Basin: implications for Basin development and petroleum exploration. In 'Proceedings of Petroleum Exploration Society of Australia Symposium, Perth, 1994'.

The authors

Said Amiribesheli has over 20 years of experience with major operating exploration and production (E&P) companies covering new ventures through to exploration and development. His focus regions include Australia, SE Asia, PNG, Barents Sea, Gulf of Mexico and the Middle East. Said's expertise includes seismic interpretation, play analysis, rock physics and reservoir characterisation, 4D seismic interpretation and monitoring, and he has extensive experience in play, lead and prospect generation, evaluation, volumetrics and risk analysis. Said holds a PhD in Exploration Geophysics from Curtin University, Australia.

Joshua Thorp is the Geoscience Manager at Searcher Seismic based in Perth, Australia. He has a BSc in Pure Mathematics from the University of Calgary and started his career at CGG in 2007. He worked as an expat in Houston, France, Angola and Brazil with CGG as a project leader on time processing and PSDM seismic processing projects. In 2012, Joshua joined Searcher to manage and QC the seismic processing projects and implement quantitative interpretation and amplitude versus offset analysis workflows. As Geoscience Manager, Joshua has led the development of the Saismic platform which has been purpose built for training and applying deep learning algorithms on global seismic datasets. Joshua is a member of EAGE, SEG and PESA.

Julia Davies has over 30 years within the E&P petroleum industry with experience in a broad range of geologic provinces and technical disciplines including initiating, evaluating and promoting new E&P opportunities to mature field redevelopment and improved oil recovery enhancement projects.