New insights into the Exmouth Sub-basin: tectono-stratigraphic evolution

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SUMMARY

The Exmouth Sub-basin forms one of several Jurassic depocentres in the greater Carnarvon Basin and has been prolific in terms of hydrocarbon production with approximately 1 Bbbls of oil and over 1 Tcf of gas discovered/produced to date. The sub-basin was recently covered for the first time with a contiguous, high quality, deep record 3D seismic survey that has enabled detailed structural and stratigraphic mapping over its full extent, providing new insights into the tectono-stratigraphic history of the area. These interpretations along with those incorporating the sub-basins thermal history and gross depositional environments were used to constrain an integrated petroleum systems model with the ultimate aim of representing hydrocarbon distribution and future exploration potential.

Key words: Exmouth Sub-Basin, seismic interpretation, basin evolution

INTRODUCTION

The Exmouth Sub-basin forms one of several Jurassic depocentres in the greater Carnarvon Basin (Figure 2). To date, significant hydrocarbon resources have been discovered and produced along the southern margin, mainly within the late Jurassic and early Cretaceous sequences. The sub-basin has recently been covered for the first time with a contiguous high quality, deep record 3D seismic survey that has enabled detailed structural and stratigraphic mapping over its full extent. This paper presents new understandings and insights gained from an integrated basin wide study, including the basin’s tectono-stratigraphic history, revisions to the timing of active extension and volcanism, and subsequent implications for petroleum systems.

STRUCTURAL AND STRATIGRAPHIC OBSERVATIONS

Historically the Exmouth Sub-basin has been covered by a patchwork of 3D seismic with limited record lengths too short to image the deeper Jurassic and Triassic intervals. Additionally, very few wells have been drilled to test the deeper Jurassic section and thus the reservoir and source potential has remained relatively enigmatic. In 2017, WesternGeco acquired the 12,500 km$^2$ long offset broadband Exmouth MC3D seismic survey which covers the entire Exmouth Sub-basin. This dataset together with on-board gravity and magnetic data provides new understandings into the tectono-stratigraphic history of the area and has implications for future exploration.

The deeper seismic imaging (and gravity/magnetic data) provides for the first time a clear definition of the Triassic section through the central, thick portion of the basin (Figure 3). Basin-wide mapping of the Triassic sequences has shown that following late Paleozoic extension (Gartrell et al., 2016), the next phase of active extensional growth faulting is restricted to a short period within the late Triassic. The seismic traverse in Figure 3 shows clear growth relationships of the late Triassic within the NE-SW oriented depocentre, mainly along the major N-S trending faults. This is in contrast to observations made in previous studies (Jitmahantakul and McClay, 2013) which describes extension initiating somewhere in the late Triassic continuing through to the mid-Jurassic.

Structural and stratigraphic seismic mapping in the Jurassic sequences of the Exmouth Sub-basin shows different thickening relationships during subsequent phases of basin evolution. Rather than being controlled by large growth faults, deposition appears to have been more uniform, with shallow marine Jurassic sequences (Murat/Athol, Calypso and Dingo Formations) thickening gradually from the basin margins into the depocentre, suggesting a more passive phase of subsidence. Regional mapping shows that active extension and growth faulting continued inboard in the adjacent Barrow Sub-basin during the early-middle Jurassic. Thickness maps from the Exmouth Sub-basin show the evolution of the basin morphology during this period (Figure 4), with the basin depocentre migrating to the northeast through time.

A series of Tithonian through Berriasian low-standing canyon incisions and basin floor fans have been mapped in the southern area of the basin. This is followed by deposition of the greater
Barrow Delta through the Berriasian and Valanginian, recorded as a series of third order proradational and aggradational sequences. This system is truncated by an angular uniformity associated with mild folding and uplift along the Novara and Resolution Arches (Tindale et al., 1998; Smith et al., 2002). Final phases of deposition are represented by the shaledominated transgressive Muderong and Gearle sequences that grade into carbonate-dominated Late Cretaceous to Cenozoic passive margin sediments.

**LATE JURASSIC IGNEOUS ACTIVITY**

A series of ring dikes and other intrusions are observed across the basin and have previously been interpreted to be of middle Jurassic age (Symonds et al., 1998). However, a series of fluid escape features associated with these intrusions are observed to terminate at a common reflector (Figure 5), constraining the timing of emplacement of this suite of intrusions to approximately 145-150 Ma. Extrusive sequences are also mappable within the new 3D dataset (Figure 6), and seismic stratigraphic relationships again show the timing of these igneous events to be ~145-150 Ma (O’Halloran et al., 2019).

The timing of this phase of igneous activity as well as the observation of late Triassic active extension has important implications for thermal modelling and petroleum systems within the basin (Schenk et al., 2019).

**SUMMARY**

The early history of the greater Exmouth-Barrow area was one of a long-lived Palaeozoic to Triassic intra-cratonic setting (Tindale et al., 1998). The evolution of the Exmouth Sub-basin as a discrete depocentre initiated during the latest Triassic with a pulse of active extensional faulting, with the Brigadier Fm. deposited in actively growing half-grabens. Subsequent to this, it developed primarily as a small passively subsiding depocentre through the early/middle Jurassic, outboard of the Barrow Sub-basin, which was the main focus of active extensional faulting at this time. Deposition during this period is characterised by the shale dominated shallow marine sequences of the Murat/Atlth, Calypso and Dingo formations. Continued rifting in the late Jurassic/early Cretaceous which was accompanied by magmatic activity (both intrusive and extrusive) lead to the final separation of the Australian and Indian plates. Deposition during this phase of basin development is characterised initially by lowstand canyon/turbidite systems (Eskdale/Macedon Member), followed by the deposition of the Barrow deltaic sequences onto the evolving and subsiding passive margin (Figure 7). Gross depositional environment (GDE) maps have been generated for these Jurassic sequences incorporating 3D seismic attribute analysis and spectral decomposition. These have been used to constrain an integrated petroleum systems model which provides new insights into remaining hydrocarbon potential of the Exmouth Sub-basin (Schenk et al., 2019).

**CONCLUSIONS**

This paper has shown the value of large, basin-wide seismic surveys in fully understanding the complex evolutionary history and petroleum systems of a given basin. The main findings from this study are:

1. The age of active extensional/growth faulting in the Exmouth Sub-basin has been constrained to latest Triassic
2. Subsequent phases of Jurassic deposition appear to have been more uniform, with sequences thickening gradually from the basin margins into the depocentre, suggesting a more passive phase of subsidence
3. Timing of igneous activity (intrusive and extrusive) has been more tightly constrained to ~145-150 Ma.

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**REFERENCES**


Figure 1. Simplified stratigraphic column of the Exmouth Sub-basin (Schenk et al., 2019)
Figure 2. Map showing location of the Exmouth Sub-basin and Exmouth MC3D seismic survey (courtesy of WesternGeco). Area A (Figure 5), Area B (Figure 6).
Figure 3. Seismic traverse (Exmouth MC3D, courtesy of WesternGeco) through centre of the Exmouth Sub-basin, showing the thickening nature of the late Triassic against the hanging-walls of the N-S trending extensional faults (highlighted in purple).
Figure 4. TWT thickness maps for (a) Late Triassic, (b) Early Jurassic, (c) Middle Jurassic and (d) Late Jurassic illustrating migration of the basin axis through time.
Figure 5. (a) is a seismic traverse (Exmouth MC3D, courtesy of WesternGeco), Area A (Figure 2) illustrating an intrusive tied to fluid escape features terminating at a common seismic event (flattened) at approximately 145 Ma. (b) and (c) is a time-slice and variance-slice respectively illustrating pock marks and radial faults associated with igneous activity at approximately 145 Ma.
Figure 6. Seismic Traverse (Exmouth MC3D, courtesy of WesternGeco) illustrating volcanism tied to tuff intersections (Top Volcanics) in Stybarrow wells, Area B (Figure 2).
Figure 7. Tectono-stratigraphic evolution schematic of the Exmouth Sub-basin. (a) Latest Triassic: Onset of extension - Formation of proto Exmouth and Barrow Sub-basins: Localised growth wedges within L.Tr77-100 intervals (“Brigadier Formation”) - “Brittle” mode of extension. (b) Early - Mid - Late Jurassic: Ongoing extension and outboard rifting - Main active extensional fault system was along eastern margin of Barrow Sub-basin, with subsidence in Exmouth focussed upon older late Triassic fault systems. Late Jurassic magmatic activity (intrusions, volcanics) associated with outboard rifting. (c) Latest Jurassic – Cretaceous: Late - Post rift sequences - Proven reservoirs of latest Jurassic age (lowstand “Macedon/Eskdale Mbrs”) with progadation of large Barrow delta system.