

Reservoir Modelling, Structural History and Volumetrics of the Jerboa Area, Eyre Sub-Basin

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SUMMARY

The Eyre Sub-basin is situated in the Bight Basin in the Southern Margin. It covers an area of approximately 8,000km². It is one of several half-graben in the Bight Basin that formed during the initial rifting between Australia and Antarctica. Sediments have accumulated in these depocentres from the Middle Jurassic to present. The initial environments of deposition were a series of fluvial, lacustrine and floodplain sequences before becoming open marine environments in the Cretaceous to Recent. Structural, Property and Reservoir Facies Models were created using the seismic interpretation and well logs from Jerboa-1. The models suggest the sequences on the Jerboa high thicken down-flank away from the well. Source rocks capable of generating hydrocarbons complete with oil stains and oil inclusions were found in the Middle Jurassic-Early Cretaceous non-marine sequences. There are several potential stacked reservoir sections in the sequences from the Middle Jurassic to the Berriasian. These have high porosities between 14-30% and clean channel sands as indicated on the Jerboa-1 logs. The Valanginian-Barremian shale dominated sequence is mapped as laterally extensive and has the best potential of sealing the underlying reservoirs. Across fault seal assessment indicates the fault throws potentially seal the reservoirs, although fault reactivation in the Late Cretaceous resulted in a collapsed graben complex along the apex of the Jerboa high and is potentially the cause of the hydrocarbons escaping. Sections in the Eyre Sub-basin that have stacked channel reservoirs, source rocks with adequate burial and traps that have not been breached have the potential to hold an accumulation of hydrocarbons. The Eyre Sub-basin is a working petroleum system.

Key words: Eyre Sub-basin, Bight Basin, modelling, petroleum potential, volumetrics.

1.0 INTRODUCTION

The Southern Margin of Australia is an area of significant interest for the exploration of hydrocarbons (Figure 1). The separation of Australia and Antarctica formed several sedimentary basins along the Southern Margin from the Middle Jurassic to Cenozoic. These

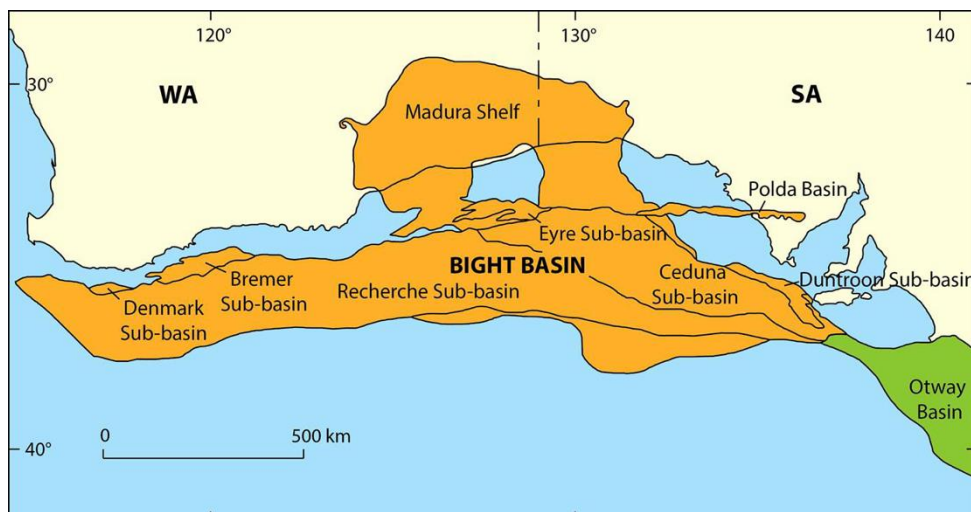


Figure 1. Location map of the basins and sub-basins of the Southern Margin (After Bradshaw, 2007).

basins include: the Bight, Otway, Gippsland, Bass and the Sorell Basins (Blevin and Cathro, 2008), which together stretch over 4,000km (Totterdell et al., 2014). The basin of interest is the Bight Basin and more specifically the Eyre Sub-basin. The large fault blocks contain thick packages of sediments with the potential to produce hydrocarbons. The Jerboa-1 well is the only exploration well in the sub-basin and contained oil inclusions and oil stains along with a 15m palaeo-oil column (Ruble et al., 2001). This indicates a working petroleum system and suggests there could potentially be an economic hydrocarbon accumulation in the basin.

STRUCTURE

The Eyre Sub-basin covers an area of approximately 8,000km² (Bein and Taylor, 1981; Brown et al., 2001; Stagg and Willcox, 1991). Two major extension events control the structural orientation of the sub-basin. The oblique active rifting in the Jurassic resulted in large fault blocks which are the major controls on the basin as it is separated into two depocentres trending NE-SW (Figure 2). Reactivation of the faults in the Early Cretaceous was driven by plate reconfiguration and separation of Australia and Antarctica (Totterdell and Bradshaw, 2004). The sub-basin is bounded by the Northern Platform of Precambrian age to the north and the west while the Southern Basement High, also probably Precambrian, bounds the basin to the south (Stagg and Willcox, 1991). The Eyre Sub-basin trends ENE and two major half-grabens divide it into southern and northern parts. The southern half-graben is structurally complex with minor ENE-WSW faulting throughout producing narrow normal fault blocks, on one of which the Jerboa-1 well was drilled (Huebner, 1980). The southern half-graben has around 4,500m of sediment while the northern half-graben has approximately 3,000m and is much narrower.

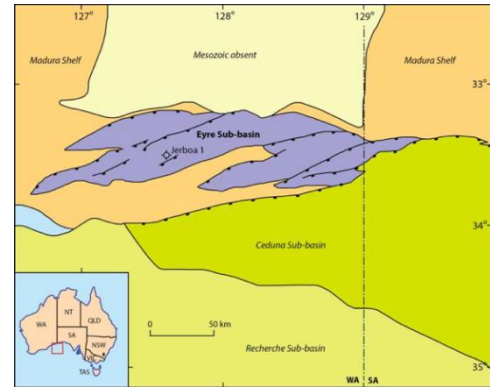


Figure 2. Location map of the structural aspects of the Eyre Sub-basin (After Totterdell et al., 2014).

STRATIGRAPHY AND SEDIMENTATION

Sedimentation began in the Eyre Sub-basin in the Late Jurassic and has continued up to present (Figure 3). The first sediments were syn-rift in nature, deposited in the Middle Jurassic to Berriasian (Stagg and Willcox, 1991; Longley et al., 2001). Accumulation of sediments occurred within the two depocentres with possible connection in the east. The first sediment to be deposited was the Middle Jurassic-Early Cretaceous (MJEC) Sequence (Sea Lion and Minke equivalent). This is interpreted to be a fluvio-lacustrine environment which is known to contain good source rocks (Stagg and Willcox, 1991). The subsequent mid-Berriasian to early Valanginian sediments were deposited in a non-marine fluvial environment, comprising the Lower Berriasian (Southern Right equivalent) and Upper Berriasian (Lower Bronze Whaler equivalent) Sequences. These sediments consisted of poorly sorted sandstones derived locally, progressing upwards into lacustrine and fluvial channel sands with interbedded shales.

The Late Jurassic to Valanginian non-marine section represents the main exploration target especially the sandstones that prograded to the south-east. The Valanginian-Barremian (Upper Bronze Whaler equivalent) is a thick shale package that unconformably overlies the earlier sediments. It is interpreted as being deposited in a fresh to brackish lake system. The Eyre Sub-basin in the mid-Albian underwent a major marine transgression with deposition of thin shale packages with another 3Ma hiatus afterwards in the late Albian (Stagg and Willcox, 1991). Espurt et al., (2009) describes a restricted marine seaway with fluvial to deltaic sediments that include coals passing laterally into marine claystone and siltstones. Marine conditions, but more specifically near-shore sediments (Stagg and Willcox, 1991), continued to dominate in the Cenomanian with deposition of interbedded shale, sandstone and claystone.

Seismic interpretation of the Eyre Sub-basin indicates there are no Tiger Super-sequence sediments. Uplift and erosion in the Turonian to the Santonian could explain why they do not occur within the depocentres of the Eyre sub-basin, whereas they can be seen to the east of the sub-basin where they become progressively thicker into the Ceduna Sub-basin. Similarly, seismic interpretation indicates the Hammerhead Sequence, is also missing in the Eyre Sub-basin, whereas it is a thick delta package found throughout the Ceduna Sub-basin where it is of exploration interest. It is unclear whether both these units were deposited and eroded or were not deposited in the Eyre Sub-basin.

The breakup of Gondwana occurred between the Campanian to the Selandian and during this time there was a possible non-depositional phase with a period of fault reactivation. Ocean levels rose and a marine transgression in the Eyre Sub-basin occurred (Totterdell and Bradshaw, 2004) followed by a series of prograding carbonate foresets deposited between the late Palaeocene to the early Eocene, known as the Wobbepong Super-sequence. The prograding strata were only deposited on the northern part of the Eyre

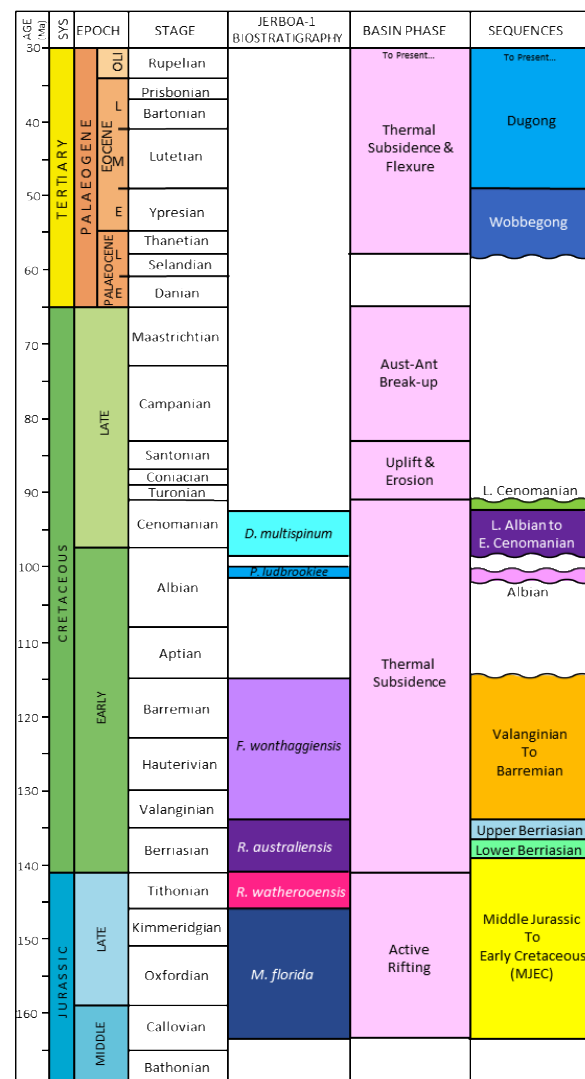


Figure 3. Stratigraphic column of the Eyre Sub-basin (Modified from Totterdell and Bradshaw, 2004).

Sub-basin, comprising a thin layer of carbonates of the same age. The middle Eocene to Recent Dugong Super-sequence is dominated by shelf carbonates and covers the older sequences.

2.0 METHODS

2.1 Data & Limitations

This project relies on several seismic surveys and the Jerboa-1 well which are all open file data. The surveys utilised were the E79A M.S.S, E82A M.S.S and the Offshore Eucla 1990 M.S.S. The E79A and E82A surveys were shot in 1979 and 1982 respectively by ESSO Exploration & Production Australia Inc. (ESSO). The line spacing for both surveys varies from 2km to 15km. They have recently been reprocessed by Santos as part of their commitment to permit WA-517P and were kindly made available for the interpretation. The Offshore Eucla 1990 M.S.S survey was shot in 1990 by Japan National Oil Company (JNOC) with line spacing of approximately 40km. The Eyre Sub-basin has a sparse coverage of 2D seismic lines (Figure 4) that do not allow mapping of fine scale features.

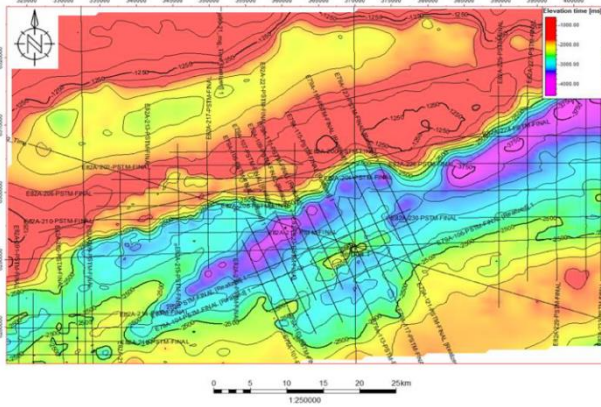


Figure 4. Survey map with the location of the seismic lines used in the study. A depth map of the basement is underlying.

The area only contains one exploration well, Jerboa-1. Jerboa-1 was drilled in 1980 by ESSO and is the main well utilised in this study to tie the seismic data. The basic well logs used are open file. However, the estimated volume of shale, total porosity, effective porosity and permeability were supplied courtesy of Santos (Figure 5). Stratigraphic descriptions of the different formations in the Eyre-Sub-basin have been made using the well logs, cuttings, sidewall cores, conventional cores, biostratigraphy, seismic characteristics and isopachs. Schlumberger software, PETREL was used for the project. Seismic interpretation of a targeted area of the sub-basin was undertaken focused on the horizons which have the greatest impact on the potential reservoir section. Horizons including the basement, MJEC, Lower Berriasian, Upper Berriasian, Valanginian-Barremian and seabed were mapped with more detail. The large scale basement faults control the basin formation and the reactivation of these faults and the younger faults are important influences on the petroleum system in the area.

2.2 Reservoir Modelling Methods

Facies and petrophysical property models were added to the structural model based on the Jerboa-1 well logs, the core and seismic data. The Facies Model is based mainly on the detailed lithofacies log interpreted at Jerboa-1 (Figure 5). This log classifies the lithofacies into channel sands, fine sands, sand, shale, mudstone and siltstone based on the core interpretation and calibrated to the gamma ray, porosity and sonic logs. The well log was first scaled-up or blocked to layer thickness prior to being extrapolated over the model, concentrating on the reservoir sections. A variogram indicated the direction and scale for extrapolating the sedimentation in the model. This was assumed from the seismic character and direction of the inferred channel systems indicating that the sediment came from a NNW direction. The NNW anisotropy was assumed to be twice the NE-SW variance by inference for channel systems.

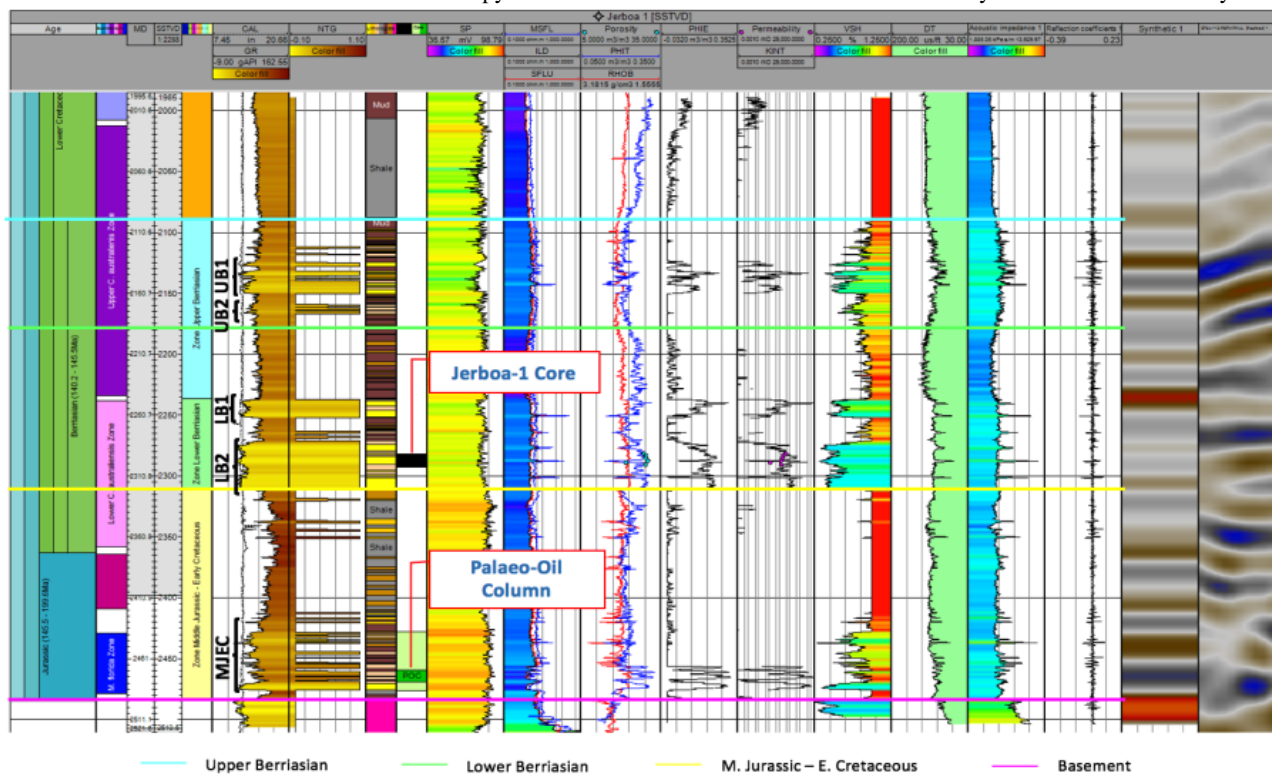


Figure 5. Jerboa-1 log panel showing the reservoir sections: Upper Berriasian 1 (UB1), Upper Berriasian 2 (UB2), Lower Berriasian (LB1), Lower Berriasian 2 (LB2) and Middle Jurassic-Early Cretaceous (MJEC).

These settings were applied to all the reservoir zones and for each of the lithologies since they were all non-marine. The Porosity Model was conditioned to the facies model to make sure the mud, silt and shale had low porosity values correctly assigned to each model cell with high porosity values assigned to the sands. More sophisticated facies and property models could be generated by guiding the facies and property distributions with seismic attributes but data quality is not sufficient to do this given the wide 2D seismic line spacing.

2.3 Structural History Methods

A structural model was created in PETREL using the interpreted seismic surfaces in TWT discussed earlier and the large scale faults. The workflow involved in summary:

- Building a Velocity Model for each interval between the horizons using the interval velocities from the sonic log from the Jerboa-1 well.
- Using the ‘Corner Point Gridding’ process modelling each fault using the ‘Fault Modelling’ and ‘Pillar Gridding’ to create the 3D framework.
- Inserting the surfaces from the interpretation into the ‘Make Horizons’ process tied to the well tops. This tied the surfaces to the well and created the main zones of the model.
- The TWT model was then converted to depth using the velocity model.
- Reservoir zones and layers were added from the sequence well tops shown in the well panel. These zones were chosen from the logs to discriminate between the reservoir sequences of sand and shale.
- Finally, layers were inserted to capture small lithological changes based mainly on the gamma ray and total porosity logs.

3.0 RESULTS

3.1 Reservoir Modelling Results

3.1.1. Middle Jurassic - Early Cretaceous (MJEC) Sequence Facies

The Middle Jurassic-Early Cretaceous (MJEC) appears to represent a single stratigraphic sequence as seen on logs and seismic (Figure 5). The base of the sequence is a lowstand series of fining-up sand packages indicating stacked channels that pass conformably upwards to interbedded mud, silt and shale beds suggesting the channels have migrated elsewhere or represent a period of transgressive to highstand levees, flood plains and lacustrine sediments. Inspection of the layer slices in the facies model shows that channel migration can be depicted in the lower sandy section. The sands intersected in Jerboa-1 in the MJEC are thin, have slightly high gamma ray and are interbedded with silts. This suggests that the well was not drilled in the middle of the channel but off to the side in the channel margins and if the well was drilled more to the east off the high, a thicker more complete channel system could be found. Looking at the seismic lines and the intersection lines in the model, the MJEC thins out completely just to the west of the well and looks as though it is truncated by the overlying Lower Berriasian. On the eastern flank of the high, the MJEC thickens into what look on seismic like a series of stacked channel sands. The channel sands are potentially sealed by the eastern fault and the adjacent basement rocks. Oil stains, inclusions and a palaeo-oil column were found in the Middle Jurassic - Early Cretaceous sequence.

3.1.2. Lower Berriasian Sequence Facies

The Lower Berriasian facies is made up of two stacked channel sands with interbedded mud, silt and sand beds between them. The lower of the sand units was cored. The lower sands are the thickest of the channel sands in Jerboa-1 and are a prime target for exploration with high porosity values between 14-30%. The base of the zone in the facies model infers the channels to have amalgamated with a large area covered in channel sands with two feeder channels coming in from the NW (Figure 6). Moving upwards through the model, the channels separate and migrate across the area and then gather once again. Mud, silt and fine sands indicating a series of flood plains, occur increasingly upwards as in Jerboa-1. The channels reappear towards the top showing a migrating pattern, gathering and separating representing the upper sand units. The Lower Berriasian sands also thin out completely over the Jerboa high on the western side of the well. These missing sequences could be because of erosion on top of the structures or the basement high was restricting and controlling the flow of the channel systems. This facies sequence is considered one of the primary potential reservoir sections.

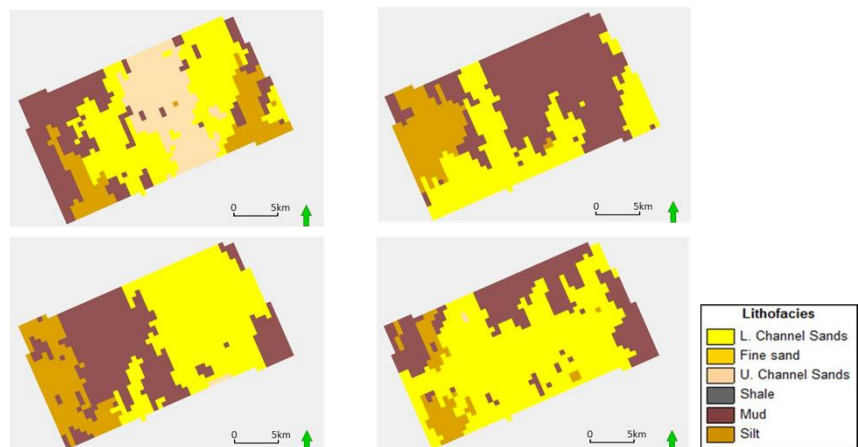


Figure 6. Dated depth surfaces in the Lower Berriasian reservoir showing the migration and gathering of channel systems.

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3.1.3. Upper Berriasian Sequence Facies

The stacked channel sands in the Lower Berriasian pass upwards into another series of flood plains and lacustrine silts and muds with some thin sandstones. These flood plains occupy most of the Upper Berriasian as seen in the seismic, the model and the log. In the model the channel sands begin to appear in the upper layers indicating more stacked channels which can be seen in the model above the flood plain sequence as multiple channels. Moving up through the sequence, the channels are realistically modelled as switching

and migrating across the area and coming together at the top of the sequence. Before the next period of flood plain sediments appear, the channels come together. The well appears to be drilled mainly within the channel margins as the gamma ray values are higher than those found in the Lower Berriasian channel sands (Figure 5). Unlike the Lower Berriasian and MJEC sequences, the Upper Berriasian does not thin out on top of the basement high but stays a relatively consistent thickness throughout the area. This is the first post-rift sequence to be deposited after the rift extension event in which Gondwana began to break up.

3.2 Structural History Results

The detailed structural model covers the Jerboa area which consists of a composite basement high that was initiated by the extensional rifting between Australia and Antarctica. The structural framework of the Jerboa area model consists of five main faults (Figure 7). The largest of the faults (F1) runs NE-SW with a maximum displacement of approximately 1.3km. The other four faults are connected to F1. Faults F2 and F3 are orientated WNW-ESE and faults F4 and F5 are orientated almost N-S. The smaller faults have maximum displacements ranging from 650m to 200m. As F1 grew, the stress was accommodated by the stair-stepping character of F2 and F3 on the west and F4 and F5 on the east side. The isopachs show that the subsidence and deposition was greatest down flank from the basement highs which did not subside as fast, resulting in thinner sediments over the highs, which at times probably were sites of non-deposition or erosion. The isopachs indicate that the sediments are thinnest on top of the Jerboa structure from the Jurassic to Early Cretaceous (MJEC is a syn-rift package) as shown in Figure 8. The post-rift sediment packages, including the Lower and Upper Berriasian, Valanginian-Barremian, have more continuous and constant isopachs and are only slightly thinner over the high due to the more even subsidence across the area and probably some differential compaction (Figure 8). The break-up of Antarctica and Australia began in the Late Cretaceous (~85Ma) and a new extensional phase resulted in the reactivation of the faults in the Eyre-Sub-basin. The effects of the reactivation can be seen over the older structural highs. A collapsed graben has developed along the apex of the Jerboa structure sub-parallel to F1. The collapsed grabens are structurally complex with many small faults splaying from F1. After the breakup was complete there was a time of non-deposition followed by deposition of the calcareous Wobbegong and Dugong sequences from the Palaeogene to present.

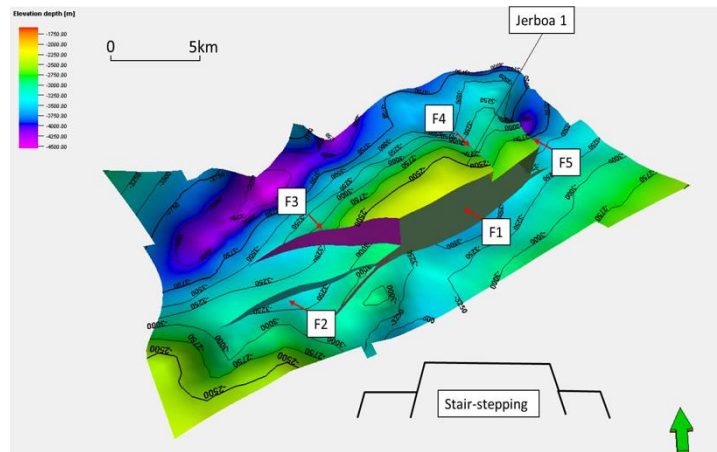


Figure 7. Structural Model of the Jerboa area showing the fault geometries (north indicated by green arrow).

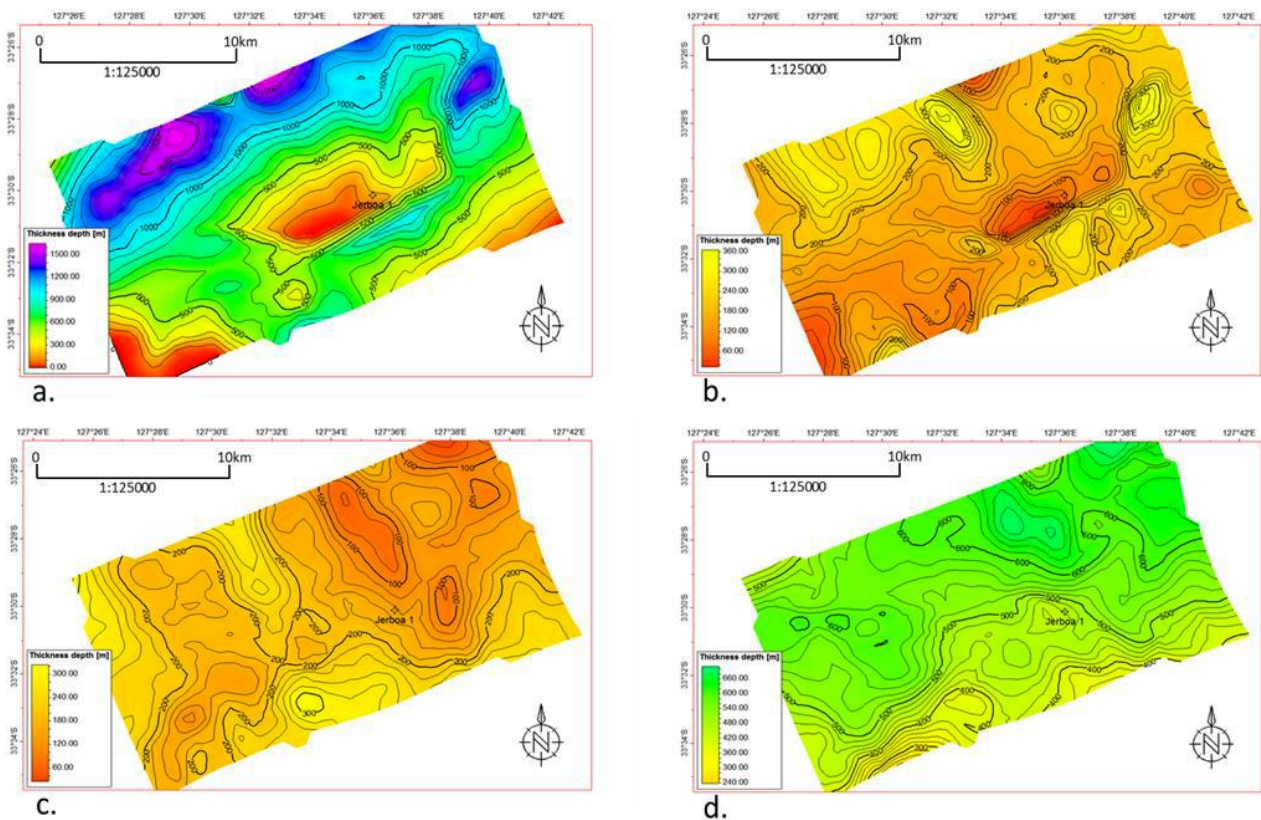


Figure 8. Isopach maps of the Jerboas area. a.) Middle Jurassic-Early Cretaceous, b.) Lower Berriasian, c.) Upper Berriasian, d.) Valanginian-Barremian.

3.2.1. Fault Seal Assessment

The complete Reservoir Model was used to conduct the fault seal assessment of the Jerboa structure. The assessment assists understanding the validity of the petroleum system allowing to check if the hydrocarbons in the trap could leak through the faults by cross-fault movement within juxtaposed sandstones. Faults F3 and F4 seal the reservoir sands on top of the Jerboa high and also the smaller fault block to the east. The F3 fault seals the reservoir sands on the Jerboa high with muds and silts acting as a seal above and adjacent to the fault (Figure 9). On F4, the sands are sealed with the silts and muds from above and also adjacent across the fault. The reservoir sands initially were adjacent to each other before F4 began moving as can be seen from datumed sections. The F5 fault also has a similar scenario with silts and muds sealing the reservoir sands on the east side of the fault and this is also the case at F1. Above the Upper Berriensian sediments, the Valanginian-Barremian shale sequence is a thick laterally extensive seal. Although the faults are suggested to be sealing the reservoir sequences around the Jerboa high, the reactivation of the faults in the Late Cretaceous results in a collapsed graben, probably linking to the reservoir sequences. Hence, when Jerboa-1 was drilled, there were no live oil shows, only a remnant oil column.

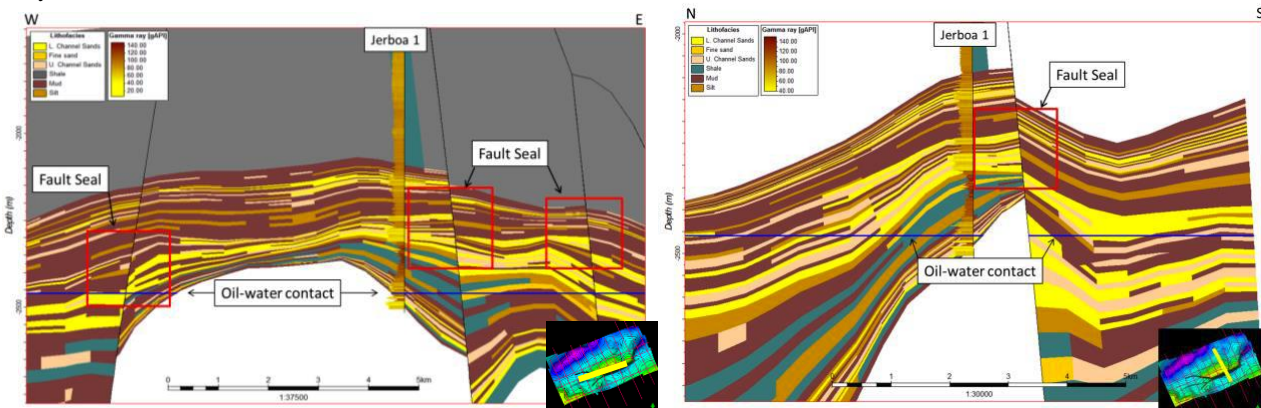


Figure 9. General intersection across the Jerboa high showing the facies, oil-water contact and potential fault seal areas.

3.3 Volumetrics

The location of the palaeo-oil column has been used to calculate the volume of hydrocarbons that could have been trapped in the Jerboa structure (Figure 10). A contact set was created in the model using closing contours on the reservoir surfaces guided by the location of the palaeo-oil column. The net to gross (NTG) log was created from the Facies Model through the calculator and together with the porosity model, were used in the 3D volume calculations. A hydrocarbon saturation value was used for the sandstones of 0.75. The results estimate that the STOIP for the MJEC palaeo-oil column was approximately 21 million stbbls.

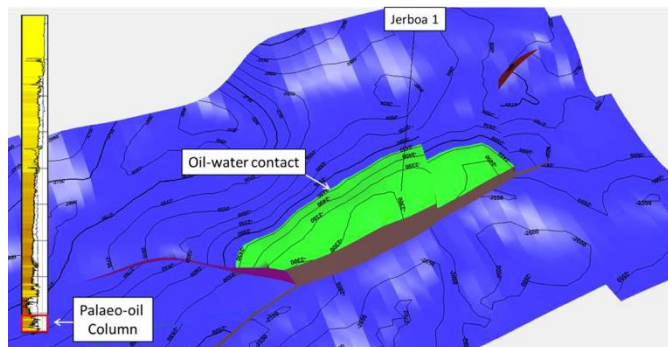


Figure 10. Surface map of the top of the reservoir section in the Middle Jurassic-Early Cretaceous indicating the estimated oil-water contact at the palaeo-oil column.

4.0 CONCLUSIONS

The detailed study on the petroleum potential of the Eyre Sub-basin found that there is a working petroleum system in the sub-basin. This is seen through the presence of oil stains and oil inclusions in the lower sequences of Jerboa-1. The sequence with the best potential to be a source rock is the Middle Jurassic-Early Cretaceous (MJEC) Sequence. It was deposited in fluvial, lacustrine and floodplain environments and is consistent with the source rock facies type suggested by the geochemical results. Thin mud and shale beds occur below the stacked channels in the MJEC at Jerboa-1. The seismic data and Reservoir Model suggest this unit becomes thicker further into the sub-basin and is at the right depth to generate hydrocarbons. The thicker floodplain sequence above the MJEC reservoir also has the potential to generate hydrocarbons away from Jerboa-1. The best quality reservoir section intersected at Jerboa-1 is the Lower Berriensian stacked channel sequences. These channel sequences contain the highest porosity and permeability values. The best potential for an extensive seal is the regional Valanginian-Barremian shale section overlying the Upper Berriensian reservoirs.

The shale sequence is thick and laterally extensive although it begins to thin out towards the edges of the sub-basin. The structural and facies modelling suggest there is a combination of stratigraphic and structural traps at Jerboa-1. A shale drape trap was the target for exploration and the faults surrounding the Jerboa high at times have been adequately sealed. The trap at the Jerboa high probably was breached in the Late Cretaceous during the break-up of Australia and Antarctica. This caused the faults to be reactivated resulting in a collapsed graben running along the apex of the high. Several potential reservoir units exist in the Jerboa area. The original in-place volumes in the MJEC sandstones, which represents the deepest of these reservoirs, was probably in the order of 21 MMSTB. Sections in the Eyre sub-basin that have stacked channel reservoirs, source rocks with adequate burial and traps that have not been breached have the potential to hold an accumulation of hydrocarbons. The Eyre Sub-basin is a working petroleum system.

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REFERENCES

- Bein, J., and Taylor, M., 1981, The Eyre Sub-basin: recent exploration results. *The APEA Journal* 21, 91-98.
- Blevin, J., and Cathro, D., 2008, Australian southern margin synthesis. Project GA707, Client report to Geoscience Australia. froG Tech Pty Ltd, Canberra.
- Brown, B., Müller, R., and Struckmeyer, H., 2001, Anomalous tectonic subsidence of the southern Australian passive margin: response to Cretaceous dynamic topography or differential lithospheric stretching, PESA Eastern Australian Basins Symposium, Melbourne, Vic. Citeseer, pp. 563-570.
- Huebner, P (compiler)., 1980, Jerboa-1 Well Completion Report. ESSO Exploration and Production Australia Inc.
- Espurt, N., Callot, J.P., Totterdell, J., Struckmeyer, H., and Vially, R., 2009, Interactions between continental breakup dynamics and large-scale delta system evolution: Insights from the Cretaceous Ceduna delta system, Bight Basin, southern Australian margin. *Tectonics* 28.
- Longley, I.M., Bradshaw, M.T., and Heberger, J., 2001, AAPG Memoir 74, Chapter 15: Australian petroleum provinces of the twenty-first century.
- Norvick, M., Smith, M., and Power, M., 2001, The plate tectonic evolution of eastern Australasia guided by the stratigraphy of the Gippsland Basin, Eastern Australasian Basins Symposium, A Refocused Energy Perspective for the Future, Petroleum Exploration Society of Australia, Special Publication, pp. 15-23.
- Ruble, T., Logan, G., Blevin, J., Struckmeyer, H., Liu, K., Ahmed, M., Eadington, P., and Quezada, R., 2001, Geochemistry and charge history of a palaeo-oil column: Jerboa- 1, Eyre Sub-basin, Great Australian Bight.
- Stagg, H.M.J. and Willcox, J.B., 1991, Eyre Sub-basin: structural framework and hydrocarbon potential. *BMR Research Newsletter* V15, pp.8-9.
- Totterdell, J., and Bradshaw, B., 2004, The structural framework and tectonic evolution of the Bight Basin, Eastern Australasian Basins Symposium II. Petroleum Exploration Society of Australia, Special Publication, pp. 41-61.
- Totterdell, J., Hall, L., Hashimoto, T., Owen, K. and Bradshaw, M., 2014, Petroleum geology inventory of Australia's offshore frontier basins. Record 2014/009. Geoscience Australia, Canberra. *Journal* V 42, 405- 435.