There has been very limited burial history modelling on the Mesoproterozoic Roper Group succession (referred to hereafter as Roper Basin); as a result the impact of major burial events and heat flow on the timing of hydrocarbon generation from the middle Velkerri Formation source rocks has been very poorly understood. Most recently, Silverman et al (2007) published burial history models for the McManus-1 and Jamison-1 wells, located in the central and northern portions of the Beetaloo Sub-basin respectively (Figure 1). Both of these models showed two burial events, one during the Mesoproterozoic associated with the deposition of the Roper Basin, and another

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during the Cambrian associated with the deposition of the Georgina Basin (part of the Centralian A Superbasin). The two models also show that the middle Velkerri Formation source rocks commence generation during the deposition of the Hayfield mudstone in both well locations, while the Kyalla Formation shale commenced generation during the later stage of Roper Basin deposition (timing not specified) in Jamison-1 and during the Cambrian in McManus-1.

While the Silverman et al (2007) basin models are useful as a guide to the possible timing of generation from the Roper Basin source rocks, recent seismic and well data collected by Pangaea (NT) Pty Ltd, age dating and province work by Carson (2013) and Munson (in press), along with the other more recent mapping and improved correlation of the Proterozoic sequences across northern Australia, allow more detailed burial history models to be constructed. Based on this work, Pangaea produced a number of burial history models for petroleum wells that Pangaea drilled in the western Roper Basin succession (west of the Daly Waters Arch), and for other pre-existing wells in the Beetaloo Sub-basin region.

This abstract presents details on the burial history results for one of Pangaea’s wells, Tarlee-S3. Results include possible timing of hydrocarbon generation from the middle Velkerri Formation, along with the justification for the inputs to the models such as burial events and heat flow. For Tarlee-S3, two basin models are presented. Both models have the same heat flow applied over time, while the depth of burial events vary post the deposition of the Roper Basin during the Mesoproterozoic.

**Mesoproterozoic burial event**

The burial history during the Mesoproterozoic is relatively well constrained due to the limited amount of likely uplift and erosion interpreted away from the basin margins, and due to the timing of major structural features that occurred post deposition (eg Daly Waters Arch). For both of the basin models produced by Pangaea, only a few hundred metres of erosion has been modelled for the end of the Mesoproterozoic (Figure 2 and 3). Both of the burial history models are the same in terms of sedimentation and heat flow during the Mesoproterozoic.

**Evidence for a Neoproterozoic burial event**

The Silverman et al (2005) burial history models grouped the Jamison sandstone and the Hayfield mudstone into the Mesoproterozoic Roper Basin depositional event; increasing the amount of sedimentation and hydrocarbon generation at this time. However, seismic data, well correlations and detrital zircon geochronological studies indicate that grouping the Jamison sandstone and Hayfield mudstone into the Mesoproterozoic Roper Basin is likely incorrect. Carson (2013) interprets the Jasper Gorge Sandstone in the Victoria Basin to the west of the study area as being the basal unit of the Supersequence 1 of the Neoproterozoic Centralian A Superbasin, based on detrital zircon geochronological data compared to the Heavitree Quartzite in the Amadeus Basin. Detrital zircon geochronology conducted by Munson (in press) on the Jamison sandstone and Hayfield mudstone also appear very similar to the Jasper Gorge Sandstone and other Neoproterozoic Supersequence 1 basal units. Other evidence indicating that the Jamison sandstone and Hayfield mudstone are part of the Neoproterozoic Centralian Basin system is the striking similarity in wireline character between the Jasper Gorge Sandstone and the overlying Angalarri Siltstone in the Bullo River-I well in the Victoria Basin with the Jamison sandstone and Hayfield mudstone log response from wells in the Beetaloo Sub-basin region (Figure 4). There is also seismic evidence that a regional unconformity exists at the base of the Jamison sandstone. This unconformity is more easily observed around the basin margins and structural highs, particularly at McManus-1 and Walton-2 where the unconformity has removed the upper Roper Basin sequences down to the lower Kyalla Shale/Moroak sandstone in McManus-1, and down to the middle Velkerri Formation in the structurally higher Walton-2. The truncation of folds in the underlying Mesoproterozoic sequence at Walton-2 and other areas within the basin by the Jamison unconformity provides evidence that a significant regional tectonic event and hiatus occurred towards the end of the Mesoproterozoic. This deformation event may be related to the Musgrave Orogeny (~1200 Ma–1050 Ma). In addition, the onset of oil window maturity at ~400 m in Walton-2 and McManus-1 (based on Rock-Eval pyrolysis data) suggests that the maximum maturity/burial event had to occur after the Mesoproterozoic deposition in this area, either in the Neoproterozoic or Cambrian.

The present-day preserved thickness of the interpreted Neoproterozoic sequence (Jamison sandstone and Hayfield mudstone) varies significantly across the basin. The sequence is 539 m thick in Balmain-1 in the central Beetaloo Sub-basin while only a 142 m thick in Tarlee-S3. The cross-section in Figure 4 shows that the equivalent sequence in Bullo River-I is presently 850 m thick. The Jasper Gorge Sandstone and the lower Angalarri Siltstone have very similar thickness to the equivalent markers in Shortland-I. This implies that at least in some areas overlying the Roper Basin, greater than 800 m of sediment was likely deposited during the early Neoproterozoic. For the Tarlee-S3 burial history models, 700 m of Neoproterozoic deposition was used in Model 1 and 1000 m in Model 2 (Figure 2 and 3).

**Evidence for a significant Cambrian-Ordovician burial event**

A possible third significant burial event occurred during the deposition of the Cambrian–Ordovician Daly/Georgina Basin (Centralian B Superbasin). In the Silverman et al (2007) burial models, approximately 400–700 m of Cambrian deposition was used, close to the present-day thickness of the Cambrian sequence in the Beetaloo Sub-basin. However, regionally thick sequences of Cambrian to Ordovician rocks are preserved in the Daly Basin (~1000 m) to the northwest of Tarlee-S3 and in the Wiso Basin to the south. These rock sequences are significantly thicker than the 234 m at Tarlee-S3 possible due to uplift and erosion around the Tarlee-S3 location as this area lies along a present-day saddle between the Daly and Wiso basins.
Figure 2. Model 1- (a) Modelled temperature over time. (b) Thermal maturity over time.
Figure 3. Model 2- (a) Modelled temperature over time. (b) Thermal maturity over time.
To help determine the impact of burial thickness on hydrocarbon generation at this time, Tarlee-S3 burial history Model 1 uses 1200 m of Cambrian-Ordovician sediment deposition and Model 2 uses 900 m.

**Heat flow and thermal history**

McLaren *et al* (2003) show that almost all Australian Proterozoic terranes are characterised by anomalous concentrations of heat-producing elements. Most terranes have experienced very low average levels of denudation (~10–15 km) consequently most of the enriched granitic mid-upper crust is preserved. Hence, the Roper Basin region shows some of the highest present-day heat flow in Australia. McLaren *et al* (2003) have also shown that the present-day Proterozoic terrane heat flow is around 80–85 mWm\(^{-2}\) with the crustal contribution averaging 50–70 mWm\(^{-2}\). During the Proterozoic, this crustal contribution was likely to have been greater.

Based on work by McLaren *et al* (2003), a 112 mWm\(^{-2}\) heat flow was applied to both models during the Mesoproterozoic with the heat flow decreasing over time (*Figure 5*). An additional heat flow pulse was assumed to have occurred during the Cambrian associated with a large continental hot spot during the extrusion of the Antrim Plateau Volcanics over a large portion of northern Australia. An additional heat flow pulse was also applied to the late Mesoproterozoic to correspond with the Derim Derim Dolerite sill emplacement (1324 Ma); however, this appeared to have less of an impact on the final modelled heat flow (*Figure 5*).

**Hydrocarbon generation events**

There is evidence for multiple hydrocarbon generation events in the Roper Basin succession. Alkane ratios from extracts from the residual hydrocarbons in the Jamison-1 well show a mixture of two generations of oil, with one

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*Figure 4.* Interpreted Neoproterozoic correlation between Shortland-1 in the Beetalool Sub-basin and Bullo River-1 in the Victoria River Basin.
Figure 5. (a) Heat flow model input and (b) modelled heat flow.
being more biodegraded than the other (Lanigan and Torkington 1991). This suggests that multiple (at least two) hydrocarbon generation events have occurred in the basin within this area. Also, bitumen has been observed in the Antrim Plateau Volcanics (Mathews 2009) within the region of Tarlee-S3 well, which if sourced from the Proterozoic (Kyalla Formation shale or middle Velkerri Formation), would indicate a hydrocarbon generation event may have occurred during the Phanerozoic.

Based on the burial history models for Tarlee-S3, it likely that during the Mesoproterozoic, the middle Velkerri Formation source rocks possibly reached the oil to the wet gas maturity window (0.8–1.3 VRe) (Figure 2 and 3). Model 1 has less Neoproterozoic burial than Model 2 and would have had primary generation and secondary cracking oil and wet gas during this time. The middle Velkerri Formation has been modelled at ~1.0 VRe at the top of the unit and ~1.6 VRe at the base during the Neoproterozoic. For Model 1, at least 1200 m of burial had to occur during the Cambrian-Ordovician, along with a significant heat flow event, to match the present present-day maturity and temperature observed in the well (Figure 6).

For Model 2, additional burial (1000 m) was applied to the Neoproterozoic resulting in the top of the middle Velkerri reaching approximately 1.2 VRe and the base reaching approximately 1.75 VRe during this time. Model 2 had less deposition during the Cambrian-Ordovician (900 m) resulting in the model slightly underestimating the present-day thermal maturity (Figure 7).

For there to have been no Cambrian-Ordovician hydrocarbon generation event, an additional 550–600 m of deposition would need to have occurred during the Mesoproterozoic to reach the present-day maturity observed at Tarlee-S3. Alternatively, 250–300 m of additional basin fill would be required during the Neoproterozoic otherwise a significant increase in the heat flow (or in combination with additional deposition) during the Proterozoic would be required to reach the present-day thermal maturity observed in Tarlee-S3.

Conclusions

It is possible that middle Velkerri Formation source rocks at Tarlee-S3 and also other areas of the Roper Basin succession have undergone primary and secondary hydrocarbon generation across two or possibly three major burial events. It is likely that the middle Velkerri Formation source rocks reached the oil to wet gas window during the Mesoproterozoic depositional event with additional primary and secondary cracking of hydrocarbons during the Neoproterozoic and/or Cambrian-Ordovician. For hydrocarbon generation to have occurred during the Cambrian, at least 1200 m of Cambrian-Ordovician deposition had to occur along with an increase in heat flow associated with a continental hot spot related to the extrusion of the Antrim Plateau Volcanics.

Regardless of the timing of generation, large quantities of oil and gas are still present in the middle Velkerri Formation source rocks. This may be related to hydrocarbon generation occurring during the more recent burial event in

Figure 6. Model 1- (a) Modelled temperature versus depth matches with well temperature data. (b) Modelled maturity (VRe) matches the well data.
the Cambrian-Ordovician or the Neoproterozoic, and/or due to the thick (200–400 m) clay-rich upper and lower Velkerri Formation top and base seals.

The Tarlee-S3 burial history models show that even though the middle Velkerri source rocks were deposited ~1400 Ma years ago, final hydrocarbon generation (primary and secondary) could have occurred almost 900–1000 Ma year later in the Phanerozoic.

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References


