The Application Area (L12-4) is underlain by the western Officer Basin, beneath the Gunbarrel Basin. The general basin architecture is outlined in Figure 1, which shows a northwest trending trough approximately 6 km deep. The relative depth contours (from the FrOG Tech SEEBASE database: courtesy of FrOG Tech Pty Ltd) are approximate base MesoProterozoic sediments of the Gunbarrel Basin and western Officer Basin.

**Figure 1: SEEBASE interpretive basement depth in relation to the Application Area**

Figure 1 also shows the approximate location of the Western Australian Release Areas L12-3, -4 and -5 (red lines). The basin outlines (blue lines) are derived from P. Haines (2012) - *Geology and petroleum prospectivity of State Acreage Release Areas L12-3, L12-4 and L12-5, Officer Basin, Western Australia*. 
Geological Setting and Stratigraphy

The extent of the western Officer Basin, beneath the Gunbarrel Basin, is also shown in Figure 2, which includes the basin outlines and location of Officer Basin release areas, also taken from P. Haines (2012). This application is for Area L12-4.
Figure 3 shows the regional stratigraphy of the Officer and Gunbarrel basins in South Australia and Western Australia. The area of interest is shown by the blue box.
Figure 4 shows simplified stratigraphy and petroleum systems of the Neoproterozoic (Supersequence 1) of the western and central Officer Basin across the Release Areas (modified after Grey et al., 2005 and Haines et al., 2008). This is a detail of the previous Figure (3). The key source rock intervals lie in the Steptoe Formation, the Hussar Formation and the Browne Formation. Other authors include horizons within the Kanpa Formation as source intervals (see previous Figure). These formations also have indicator hydrocarbon shows, suggesting limited migration, which the Applicants further suggest makes these zones suitable shale gas/oil targets.
Table 1 shows petroleum exploration and stratigraphic wells within, and select wells and mineral drill holes adjacent to State Acreage Release Areas L12-3, L12-4 and L12-5. Shows relevant to this Application are highlighted in yellow. Data extracted from Western Australian Petroleum and Geothermal Information Management System (WAPIMS) and well completion reports and included in the Release Package.

The Applicants note the strong presence of hydrocarbon shows in and around the Application Area L12-4 from within the Neoproterozoic section. These hydrocarbon occurrences provide the backbone of this Application.

Figure 5 also shows the stratigraphy, but in relation to the tectonic movements in the southern Central Australia region, as well as the known distribution of hydrocarbon source, seal and reservoir rocks (from G.M. Carlsen, A.P. Simeonova and S.N. Apak, 2003). The most consistent distribution of both shows and source rocks is from Supersequence 1 (SS1) in the mid Neoproterozoic.
Figure 6 shows the detailed gamma log and lithology from GSWA Empress – 1/1A (38kms west of Release Area L12-4).

Whilst there are no reports of hydrocarbon shows in this particular well, the target shale horizons, for the purpose of this Application, are shown by the oil/gas symbol in the:

- lower Kanpa Formation;
- lower Hussar Formation; and
- mid to lower Browne Formation.

The Lupton Formation (Supersequence 3) is shown in cross section B-B’ (below; Figure 13) as unconformably overlying a thinner Steptoe Formation, which in this figure would appear to have been included with the Kanpa Formation.

The Applicants identify almost 400m of net shale in this well section, which will thicken in the troughs to the northeast.

**The Applicants are led to conclude that the shale gas/oil model is applicable in this basin.**
The presumed or interpreted environments of deposition of the Kanpa and Browne Formations, in particular, are shown in Figure 7. The presence of anoxic zone shales and mudstones is of particular relevance to this Application.

Source rock models are shown for the Neoproterozoic Kanpa and Browne formations, western Officer Basin, modified after Elphinstone and Gorter (1991) and Stein et al (1986) indicating: 1) preservation of organically rich laminae (volumetrically minor); 2) thick mudstone deposition (significant clastic dilution and oxidation); 3) proposed site of thick source rock deposition; and 4) deep water anoxic deposits. In summary, the slowly subsiding ramp margin setting of the Browne, Hussar and Kanpa formations, with widespread shallow-marine to sabkha depositional environments, was an area of high organic productivity. Rapid transport of organic matter into dysoxic to anoxic waters is critical to entrain hydrogen-rich organic material.
Basin Structure

Figure 8
Kanpa 1A (projected)

Figure 9

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Figure 8 shows a NE-SW seismic line passing near to Kanpa 1A. It shows the general trough structure and the salt-lubricated thrust fault in the Browne Formation, and erosion of Supersequence 1 strata. Supersequence 3 strata (Wahgu Fm) is absent and Supersequence 4 strata unconformably overlies the Supersequence 1.

Figure 9 shows a composite seismic section through Yowalga 3 and Browne 2 wells and erosion of Supersequence 1 strata between salt emplacements in the Yowalga area.

Figure 10 shows the location of two orthogonal interpretive cross sections (Figures 11 & 12), in relation to existing seismic data and wells, as well as the Application Area L12-4. The oil and gas symbols on the cross sections shows where the Applicants will target the shale gas/oil approach to exploring this Permit.

**Figure 10: Location Map – Interpretive Cross Sections**
Petroleum Source Potential


Thin but organic-rich beds with excellent to fair oil generating potential (together with good reservoir and seal rocks) are present in the basin. Oil and gas prone source beds with fair to excellent hydrocarbon-generating potential are found in Browne 1 and 2, Empress 1/1A, Hussar 1, Kanpa 1A, LDDH 1, NJD 1, and Yowalga 3, as indicated by total organic carbon, Rock-Eval pyrolysis and rock extract analyses. Source rocks are generally mature, with the measured maturity ranging from immature to over-mature as indicated by organic petrology and Rock-Eval pyrolysis. A significantly thick part of the Neoproterozoic succession in Yowalga 3 (1500-3000m) is presently within the oil window. The present-day depth to the top of the oil window in Kanpa 1A and Yowalga 3 (Yowalga area) is about 1000 m deeper than in Hussar 1 (Gibson area; Ghori, 1998a, b).

Figure 13 (from G.M. Carlsen, A.P. Simeonova and S.N. Apak, 2003) shows source rock characterisation: a) Petroleum generating potential as a function of organic richness versus potential yield, for samples interpreted as reliable; b) type of kerogen as a function of Tmax vs hydrogen index, from Rock-Eval pyrolysis; c) type of kerogen as a function of oil proneness (C5-C31 alkanes + alkenes) versus gas-oil generation index (C1-C5)/C6+ from pyrolysis-gas chromatography, (from Ghori, 2002).
Hydrocarbon Maturity in WA Release Area L12-4

The petroleum maturity of the western Officer Basin has been modelled by Ghori (2002; *Modelling the hydrocarbon generative history of the Officer Basin, Western Australia*). Geohistory modelling was used to analyse different geological and thermal scenarios for the evolution of the Officer Basin. It is important to determine the timing of hydrocarbon generation and the sensitivity to variations in thermal and erosional history.

The Applicants have selected the Kanpa-1A model as indicative of the Application Area L12-4. This is shown in Figure 14. Maturation stages and their corresponding vitrinite reflectance values are as follows:

- immature zone, less than 0.5% Ro;

![Figure 13](image-url)
• early mature for oil, 0.5% to 0.7% Ro;
• mid mature for oil, with some gas, 0.7% to 1.0% Ro;
• late mature, for oil with gas, 1.0% of 1.3% Ro; and
• mainly gas generation, over 1.3% Ro.

The deepest equivalent vitrinite reflectance value is considered to represent the maximum maturity attained in the wells because the $T_{\text{max}}$ values are consistently lower than the equivalent vitrinite reflectance values in this area. The modelling suggests that the lower Kanpa Formation, and the underlying Hussar and Browne formations in Kanpa-1A, are within the mature zone for oil and gas generation.

Geohistory diagram: KANPA-1A

At this stage in the data review, the Applicants cannot reconcile the difference in indicative maturity between measured vitrinite reflectance and $T_{\text{max}}$ values.

Conclusion: Summary of Petroleum Prospectivity in WA Release Area L12-4

The petroleum prospectivity of the western Officer Basin has been discussed by Perincek (1998), Ghori (1998, 2002, 2007), Carlsen et al. (1999, 2003), Apak and Moors (2000), Apak et al. (2002), D’Ercole et al. (2005), and Simeonova and Lasky (2005). In particular, the following summary is drawn from Haines (2012) - Geology and petroleum prospectivity of State Acreage Release Areas L12-3, L12-4 and L12-5, Officer Basin, Western Australia.
Based on these studies, the Applicants assess the key prospectivity of the Release Areas, particularly Area L12-4, as largely restricted to sources in the early to middle Neoproterozoic Buldya Group.

Although hydrocarbon shows have been small, the Neoproterozoic of the western Officer Basin shows similarities to Neoproterozoic Basins in Oman and Russia (Ghori et al., 2009). As part of the former Centralian Superbasin, the succession is also very similar to the nearby Amadeus Basin, which has recorded more significant Neoproterozoic oil and gas occurrences, including the sub-economic Dingo gasfield. There may also be similarities to the indicative shale gas/oil plays in the McArthur Basin, Northern Territory.

Potential source rocks have been identified within the Browne, Kanpa, and Hussar Formations, and possibly the Steptoe Formation. If the richest of these, as identified in WMC NJD 1, thickens northeast and extends into deeper and more mature locations within the Release Areas, where it has the potential to source volumes of hydrocarbons.

The widespread, though minor, hydrocarbon shows in wells across the western Officer Basin (including Kanpa 1/1A in the Application Area, L12-4) indicate that “some” volumes of hydrocarbons have been generated. There may have been some migration, although the Applicants do not consider this to be highly significant. Much may have remained in source shales – the basis for the shale gas/oil concept being pursued by the Applicants. Maturity modelling suggests that the most significant hydrocarbon traps formed before most of the potential source rocks entered the oil window, and much of the prospective section within the thicker parts of the western Officer Basin remains in the oil-maturation window today (Ghori, 1998, 2002). The northeastern third of the Release Areas (north and east of the Western Platform Zone) is likely to be more prospective due to somewhat thicker successions.

Clearly, a contingent resource assessment is virtually impossible on the limited data available. However, a basic review of the parameters suggests a resource in the range of 5 to 10tcf of gas, possibly larger.