ABSTRACT

The recent developments of shale gas in the US have encouraged exploration for shale gas resource in WA. In the largely unexplored Merlinleigh Sub-basin, within the Carnarvon Basin, Western Australia, which is predominately of Permian strata, geochemical data has shown the potential to contain high-quality gas-prone source rocks. Three main potential shale layers, the Gneudna Formation, Wooramel Group and the Byro Group, were identified with key intervals analysed for the type of kerogen, total organic content (TOC), generation potential and thermal maturity. These parameters enabled a gas-in-place resource estimation to be made for each of these formations. The TOC data from various wells were validated by using petrophysical logs and the ΔlogR method. The log approach produced results consistent with the geochemical data. The three layers were ranked according to their geochemical parameters, as well as by any petrophysical or geomechanical characteristics. This analysis showed that the Wooramel Group contained the best quality source rocks, followed by the Byro Group. The Gneudna Formation was found to have poor quality source rocks. The Monte Carlo method by Crystal Ball was selected to estimate the probabilistic resources contained within these three layers. According to the P50 estimations, the Byro Group, Wooramel Group and the Gneudna Formation contain resources of 51.6 Tcf, 40.1 Tcf and 1.4 Tcf, respectively.

Source Potential and Maturity of the Merlinleigh Sub-basin

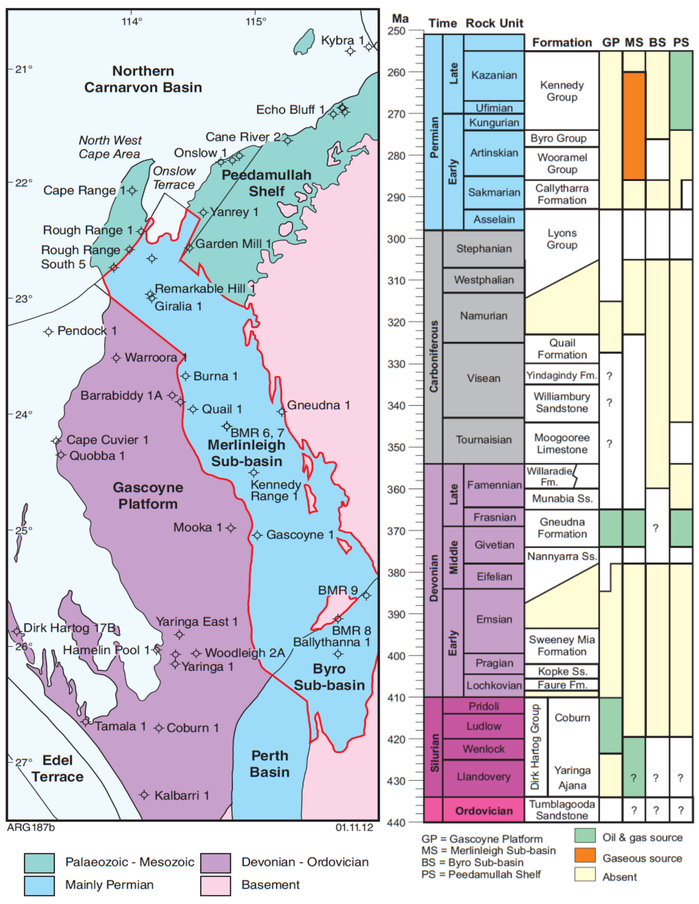

Figure 1: Generalised Stratigraphy and source rock locations of the onshore Carnarvon Basin, WA (Ghori, 2013)

The Lower Permian section of the Merlinleigh Sub-basin contains the best gas-prone source beds in the Carnarvon Basin. Geochemical data from four wells were used to analyse the basins' generation potential.

Three distinct formations were identified to contain high levels of organic richness, vitrinite reflectance and generation potential. Source maturity ranges from immature along the margins of the sub-basin to over-mature towards the centre (*Figure 3*).

Byro Group

- Early Permian strata up to 700m thick.
- Good to fair gas-prone layers are present in the Byro Group through a 700 m thick interval in Kennedy Range 1.
- It is immature and incomplete in the studied wells, except in Kennedy Range 1 where it ranges from mature to over-mature.

Table 1: Summary of potential source rock layers (Ghori 1996)

Formation	Organic Richness	Generating Potential	Kerogen Type
Gneudna Formation	Good to Fair	Good to Fair	Oil and gas
Wooramel Group	Very good to Fair	Very good to Fair	Mainly gas
Byro Group	Very good to Fair	Good to Fair	Mainly gas

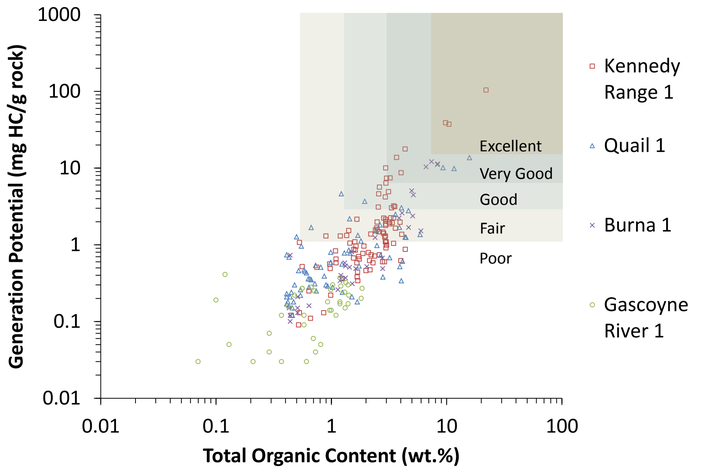

Figure 2: Generation Potential of the Merlinleigh Sub-basin

Wooramel Group

- Early Permian strata up to 380m thick.
- Interbedded organic-rich shales.
- Thermal maturities range from immature in all studied wells except Kennedy Range 1 where it is over-mature.
  - Understood to be from a local intrusion.

Gneudna Formation

- Devonian strata up to 50m thick.
- Thin yet excellent oil-prone source beds.
- Generation potential and maturity varies considerably; vertically and laterally.

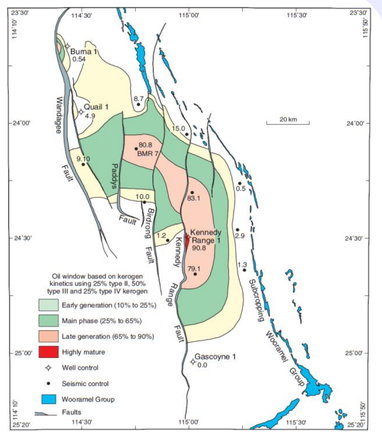

Figure 3: Maturity Map – Wooramel Group

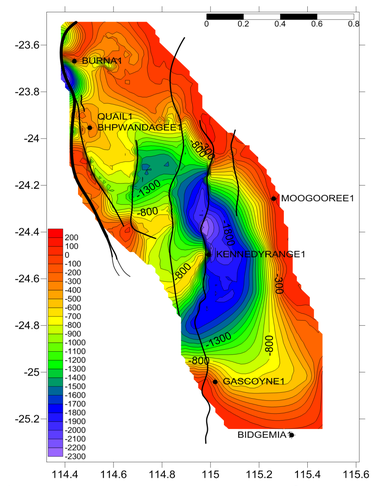

Figure 4: Contour Map – Moogooloo Sst

Modeling

TOC calculation from logs and shale thickness identification

Table 2: Shale Layer Rankings

Shale Gas Ranking Parameter Ranges - Merlinleigh Sub-basin							FORMATION SCORE		
Ranges	Geochemistry						Gneudna	Wooramel	Byro
1-10 wt.%	TOC Class	<1.0	1.0-3.0	3.0-6.0	6.0-9.0	>9.0	0.39	3.89	2.95
	Points	0	4	6	8	10	0	6	4
0.5-2.0 R_o	R_o Class	<0.5	0.5-1.0	1.0-1.5	1.5-2.0	>2.0	1.73	1.33	0.79
	Points	0	4	6	8	10	8	6	4
0<S2<30	Rock Potential	<2	2.0-5.0	5.0-10.0	10.0-20.0	>20.0	1.33	2.62	2.06
	Points	0	4	6	8	10	0	4	4
	Shale Thickness								
50-300ft	Thickness (ft.)	<50	50-100	100-200	200-300	>300	164	673	898
	Points	0	4	6	8	10	6	10	10
	Gas Field Porosity								
2-8%	Porosity (%)	<2.0	2.0-4.0	4.0-6.0	6.0-8.0	>8.0	2.4	13.7	8.6
	Points	0	4	6	8	10	4	10	10
					TOTAL/50		18	36	32

After identifying potential source rock layers, each formation was analysed and ranked according to the quality of their geochemical and petrophysical data. The results are summarised in the table above.

Out of 50 points, it is clear to see that the **Wooramel Group** is ranked the highest with 36 points; followed by **Byro Group** with 32 points; and the **Gneudna Formation** with 18 points.

Testing the 'ΔlogR' method

- Passey (et al. 1990) formed an alternative method to TOC geochemical analysis.
- Organic-rich intervals can be identified by the separation between **resistivity** and **porosity** logs (*Figure 5*) called the 'ΔlogR' method.
- When applied to wells with known geochemical data, both the data (blue circles) and the 'ΔlogR' values (red shaded area) were found to produced results that were consistent with each other.

Thickness Identification

The thickness of shale layers are usually estimated by analyzing geochemical TOC values where zones of a consistently high reading (>2% TOC) are identified. However, this becomes problematic with high risk and uncertainties for wells with limited amounts or no data.

By calibrating the petrophysical logs of wells with known geochemical TOC values using Passey's (et al. 1990) method, shale thicknesses of wells with no TOC data available can be identified.

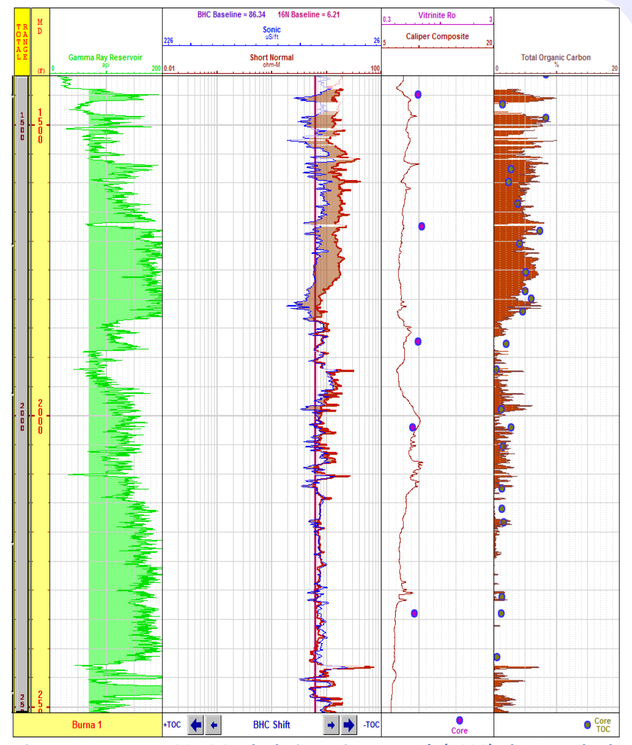

Figure 5: Burna 1 – GS TOC calculation using Passey's (1990) ΔlogR method

GS Software was used to overlay Resistivity and Sonic Porosity logs from wells in the Merlinleigh sub-basin

Resource estimations

Conclusions

Resource estimations of shale gas volumes in all three formations were performed using both a deterministic and probabilistic approach. A risk analysis of ultimate recovery was also performed using 15%, 20% and 30% recovery scenarios. The information has been summarized in *Table 1* below.

From the deterministic approach, the resource estimations for the Gneudna Formation, Wooramel Group and Byro Group were found to be 40.5 Gm3 (1.43 Tcf), 1167 Gm3 (41.21 Tcf) and 1476 Gm3 (52.14 Tcf), respectively.

Table 3: Total Gas-Initially-in-Place estimates (GIIP, in Gm^3 and tcf) for Merlinleigh Sub-basin formations

	Gneudna Formation	Wooramel Group	Byro Group
GIIP	40.5 (1.43)	1167 (41.21)	1476 (52.14)
Recoverable Resource	6.3 (0.22)	175.0 (6.18)	221.4 (7.82)
Risked GIIP (30%)	12.2 (0.43)	350.0 (12.36)	442.9 (15.64)
RRR (15%)	1.7 (0.06)	52.4 (1.85)	66.5 (2.35)
RRR (20%)	2.5 (0.09)	70.0 (2.47)	88.6 (3.13)
RRR (30%)	3.7 (0.13)	105.0 (3.71)	132.8 (4.69)
Crystal Ball Prediction			
P90	32.5 (1.15)	902.2 (31.86)	1182.5 (41.76)
P50	40.2 (1.42)	1152.5 (40.70)	1460.2 (51.57)
P10	49.0 (1.73)	1449.2 (51.18)	1786.2 (63.08)

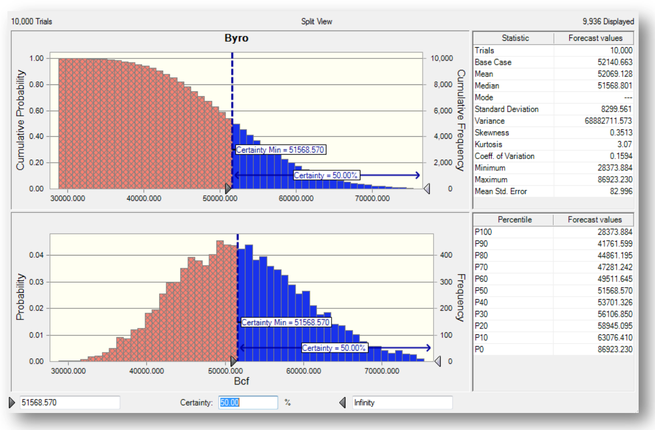

Figure 6: Crystal Ball prediction of the Byro Group

A Monte Carlo method in Crystal Ball used probabilistic estimates to obtain P10, P50 and P90 values.

In comparison, the P50 values of each formation was very similar to the values estimated from the deterministic method, providing increased confidence in our volumetric assessment.

Shale gas exploration within the onshore Carnarvon Basin is still very limited and highly uncertain; however, the available data shows great potential for large shale plays.

It was identified within the Merlinleigh Sub-basin that the Wooramel Group contained the best quality source rocks, followed by the Byro Group. The Gneudna Formation however, was found to have poor quality source rocks. The Monte Carlo method by Crystal Ball was selected to estimate the probabilistic resources of the three layers. According to the P50 estimations, the Byro Group, Wooramel Group and the Gneudna Formation contained resources of 51.6tcf, 40.1tcf and 1.4tcf respectively.

The evaluation of the shale gas potential in other sub-basins within the onshore Carnarvon Basin requires additional data acquisition and exploration. The results of the current study indicate, however, that substantial potential is likely to be present throughout the Carnarvon Basin. These resources, when combined with the existing large resource estimates for shale gas plays in the Canning and Perth Basins, indicates that an exciting future exists for shale gas exploration and development in Western Australia.

Government of **Western Australia**
Department of **Mines and Petroleum**