



Lady Penrhyn 2 Interpretive Summary

Upper Velkerri – Middle Velkerri Interval

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PETROLEUM GEOCHEMISTRY

INTRODUCTORY NOTE

A geochemical investigation has been conducted to assess hydrocarbon prospectivity of the Upper and Middle Velkerri Formations in the Lady Penrhyn 2 well located in the McArthur Basin, Northern Territories, Australia. Six (6) core chip samples from this well were analyzed by a variety of geochemical techniques, including total organic carbon (TOC, LECO®), programmed pyrolysis (SRA) and organic petrology with measured maceral reflectance (R_o). In addition, client supplied published geochemical data for 85 samples were also incorporated into the interpretive evaluation. The complete results of these analyses are documented in this report along with an integrated geochemical interpretation that is summarized in the following table.

Well Name	Formation	Main Product	Thermal Maturity	Source Rock Richness	Organic Matter Type	Shale Oil Risk
Lady Penrhyn 2	Upper Velkerri	Estimated Original →		Fair (0.85% TOC)	Oil-prone Type II	High
		Oil	Peak Oil Window	Fair (0.60% TOC)	Gas-prone Type III	
Lady Penrhyn 2	Middle Velkerri	Estimated Original →		Very Good (3.09% TOC)	Oil-prone Type II	Low
		Oil	Peak Oil Window	Very Good (2.50% TOC)	Mixed Type II/III	

Current TOC averages represent all data available; Original TOC averages are only high graded samples that have PPY data

Table 1. Geochemical Summary

UPPER VELKERRI FORMATION

Two (2) samples from the Upper Velkerri Formation were analyzed for LECO TOC content and programmed pyrolysis, with the remaining data set (20 samples) composed of client supplied public data (Fig. 1). TOC contents ranged from 0.26 to 0.92 wt.% and averaged 0.60 wt.% (fair). None of these samples have TOC contents above the minimum requirement of 1 wt.% for *effective* petroleum source rocks, nor do they have TOC content above the minimum requirement of 2 wt.% for *economic* petroleum source rocks. Highest TOC content is near the base of the designated Upper Velkerri interval (240.81 m depth) and increases dramatically at the contact with the underlying Middle Velkerri Formation (Fig. 1).

The S1 values of the Upper Velkerri source rock samples average 0.18 mg HC/g rock (4 bbl oil/acre-ft) and S2 values average 1.06 mg HC/g rock (23 bbl oil/acre-ft). The S1 and S2 values imply poor in-situ hydrocarbon saturation and poor remaining generative potential (Fig. 1). The normalized oil content (NOC) in the Upper Velkerri samples, $(S1/TOC) \times 100$, averages 27 (Fig. 1). NOC values of 20 to 50 are typical of low maturity source rocks, whereas values of 50 to 100 indicate possible oil staining or shows in thermally mature, tight petroleum source rocks. $NOC > 100$ are often associated with conventional oil reservoirs and indicate good prospectivity in unconventional shale oil plays. Jarvie (2012) has utilized a depth comparison of TOC versus programmed pyrolysis S1 yields as a potential indicator of producible hydrocarbon saturation in unconventional source rocks. When the S1 yields (reported as mg HC/g rock) exceed or “cross-over” the measured TOC content (reported as wt.%), this would be interpreted to represent zones with good potential for containing producible hydrocarbon saturation (or zones of possible contamination). In the present study, there are no samples where S1 crosses over TOC within the Upper Velkerri Formation (Fig. 1).

Measured Hydrogen Index (HI) values in the Upper Velkerri average 160 mg HC/g TOC, indicating gas-prone Type III kerogen quality in these source rocks at present day. Original HI_o of these samples are estimated to average 450 mg HC/g rock, which indicate oil-prone Type II kerogen. Transformation Ratios

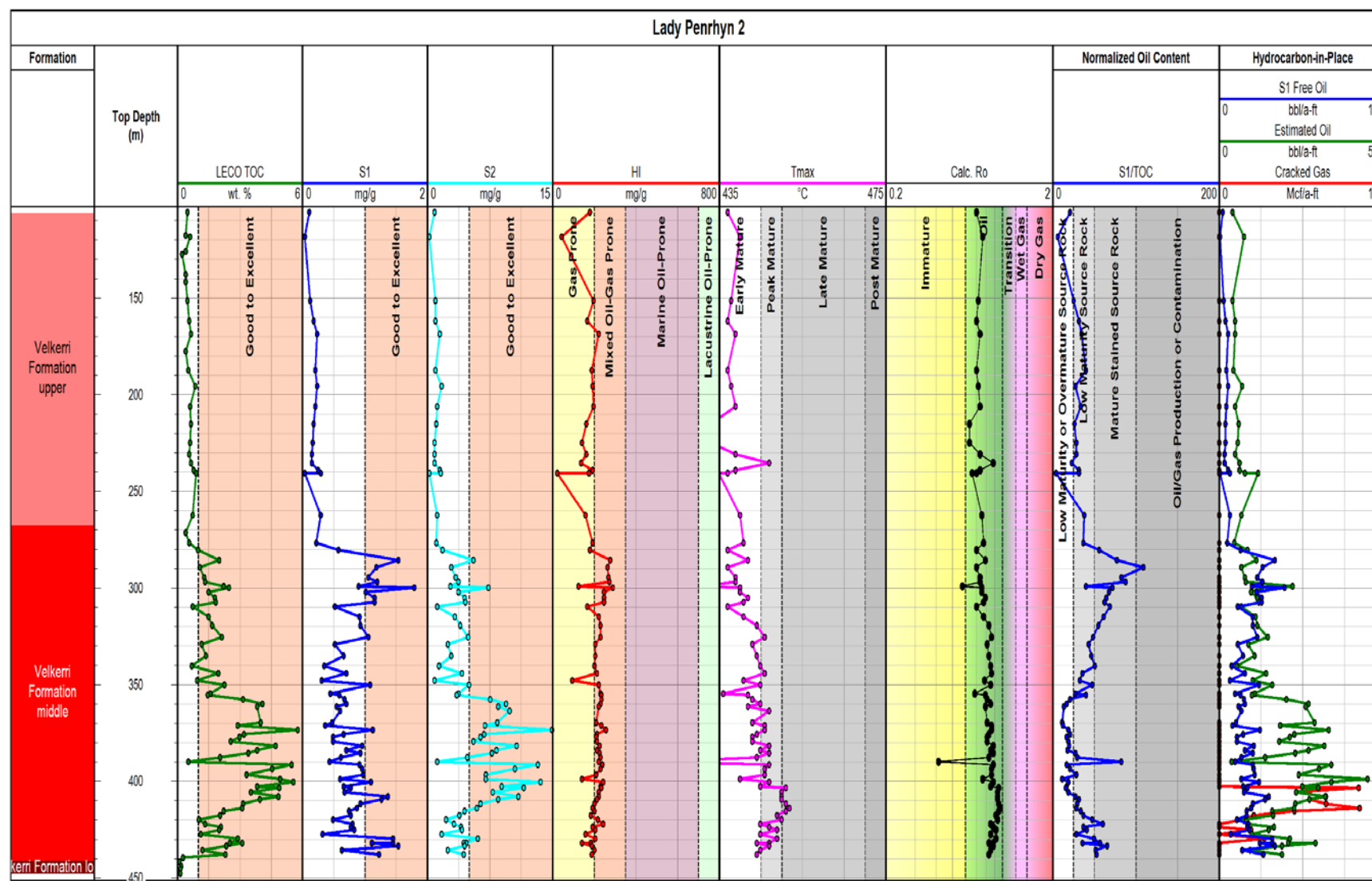


Figure 1. Geochemical depth plots for the Lady Penrhyn 2 well.

(TR) based upon HI average 74%, which is consistent with a peak to late oil window thermal maturity. T_{\max} values in the Upper Velkerri samples average 438°C, on the basis of select samples determined to have reliable S2 peak shape. T_{\max} between 435 and 445°C typically indicate peak oil window, while values between 425 and 435°C indicate early oil window (Type II kerogen). On the basis of these guidelines, the average Upper Velkerri T_{\max} values in this well would be interpreted to be in the peak oil window. Using the formula published by Jarvie et al. (2007) for Type II kerogen (Calculated $R_o = (0.0180)(T_{\max}) - 7.16$), the average measured T_{\max} value of 438°C is equivalent to a Calc. % R_o value of 0.72%. It is important to note that T_{\max} is only a crude measure of thermal maturation (Peters, 1986) and it can be compromised by a variety of pyrolysis artifacts and caveats.

Production Index (PI) values in these Upper Velkerri samples average 0.14. These moderate PI values are more consistent with source rocks in the early oil window, which typically have PI values between ~0.10 to 0.15. The PI values in the peak oil window are generally higher between ~0.15 to 0.25.

The thermal maturity of the Upper Velkerri source rocks was also assessed using measured Kübler Index values from XRD, which are based upon illite crystallinity. These values can be used as maturity indicator when samples contain sufficient high quality clays (Abad, 2008). One sample from the Upper Velkerri (40% clays) has a measured Kübler Index of 0.076, which is equivalent to a measured vitrinite reflectance of > 4% (late stage metagenesis). This interpretation is inconsistent with other geochemical maturity ratios evaluated in this study and suggests the Kübler Index should be used with caution to evaluate thermal maturity in Mesoproterozoic aged source rocks

MIDDLE VELKERRI FORMATION

Four samples (4) from the Middle Velkerri Formation were analyzed for LECO TOC content and programmed pyrolysis, with the remaining data set (61 samples) composed of client supplied public data (Fig. 1). The Middle Velkerri Formation in the Lady Penrhyn 2 well exhibits very good generative potential for petroleum source rocks based on TOC content values (Fig. 1). TOC content ranges from 0.29 to 5.79 wt.% and averages 2.50 wt.% (very good). Thirty-nine (39) of these samples analyzed exceed the minimum value of 2.0 wt.% for *economic* petroleum source rocks (Lewan, 1987). There are three distinct cycles of TOC within this interval with maxima occurring at depths of 300, 374 and 432 m (Fig. 1). These three organic rich intervals have been previously recognized within the Middle Velkerri (Lanigan et al, 1994) and could be associated with the base of transgressive systems tracts (TST) in a series of platform/ramp parasequences (Bohacs et al., 2013). These stepwise changes in TOC and corresponding minimal change in Hydrogen Index values (HI) suggests that production was the major control on organic richness along with auto-dilution by pelagic carbonate (Bohacs et al., 2013).

The S1 values in the Middle Velkerri average 0.85 mg HC/g rock (19 bbl oil/acre-ft), indicating fair in-situ hydrocarbon saturation (Fig. 1) and are consistent with a thermal maturity in the peak oil window. These values should be considered a minimum for in-situ oil saturation since they do not account for potential loss of volatile components during sample collection and analysis. NOC values in the Middle Velkerri interval are overall slightly higher in comparison to the overlying strata and average 33. Oil cross over (NOC > 100) was observed for only one sample (290.03 m) in the upper portion of this unit (Fig. 1), which suggests possible producible hydrocarbons at this depth. The S2 values in the Middle Velkerri average 5.62 mg HC/g rock (123 bbl oil/acre-ft), which indicates good remaining generative potential and is consistent with a peak oil window thermal maturity.

Measured HI values in these samples average 216 mg HC/g TOC, which indicate mostly mixed oil/gas-prone Type II/III kerogen quality in these source rocks at present day. Estimated original HI_o values in these samples average 450 mg HC/g TOC, which indicate oil-prone Type II kerogen quality. Transformation Ratios (TR) based upon HI average 64%, which is consistent with a peak oil window thermal maturity.

The organic-matter in the Middle Velkerri interval in the Lady Penrhyn 2 well is thermally mature and is interpreted to be in the peak oil window. Programmed pyrolysis T_{\max} values average 444°C (Fig. 1). Using

the formula published by Jarvie et al. (2007) for Type II kerogen ($\text{Calculated } R_o = (0.0180)(T_{\text{max}}) - 7.16$), the average measured T_{max} value of 444°C is equivalent to a Calc. % R_o value of 0.83%. It is important to note that T_{max} is only a crude measure of thermal maturation (Peters, 1986) and it can be compromised by a variety of pyrolysis artifacts and caveats.

Production Index (PI) values in these Middle Velkerri samples average 0.16. These elevated PI values are consistent with source rocks in the peak oil window. The PI values tend to decrease toward the middle of the Middle Velkerri interval and are generally elevated in the same zones where NOC values are also highest in both the upper and lower sections. This suggests possible producible in-situ oil saturation within these horizons.

Organic petrology was performed on one (1) sample from the Middle Velkerri interval (398.9 m) in the Lady Penrhyn 2 well (Fig. 2). The results from these analyses show distributions that consist of macerals identified as either fluorescing Alginite or low reflecting solid bitumen. The low reflecting solid bitumen population has reflectance values that average 0.78% R_o (Fig. 2) and are considered the most representative indigenous kerogen population for thermal maturity assessment. This group of organic macerals is thought to possibly represent fine grained migrabitumen, although they could also represent preserved original cyanobacterial kerogen that has subsequently undergone thermal conversion to form a dispersed solid bitumen network within these Velkerri Formation source rocks. The maturity assessment from this maceral group would be consistent with the peak oil window, which is also supported by the presence of dull orange to light brown algal fluorescence colors in this same sample. The fluorescing Alginite maceral group had an average reflectance value of 0.64% R_o , which is also consistent with a peak oil window thermal maturity.

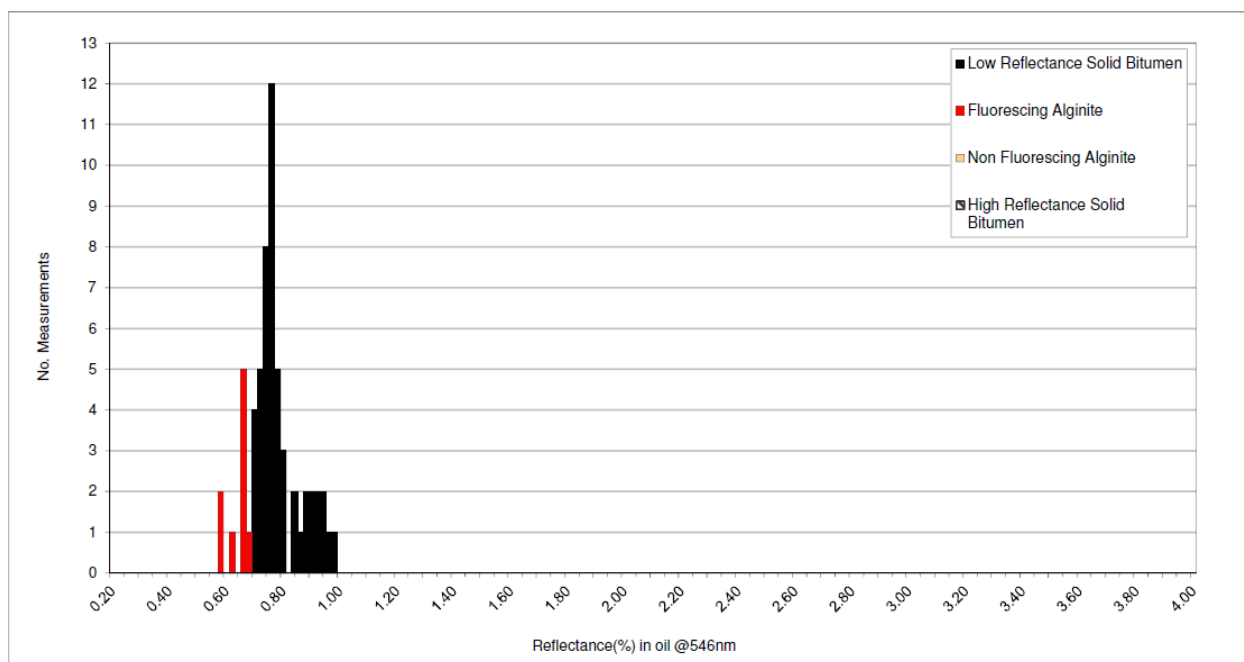


Figure 2. Organic petrology of the Middle Velkerri (398.9 m) in the Lady Penrhyn 2 well. Mean maceral reflectance of fluorescing Alginite is 0.64% R_o . Mean maceral reflectance of low reflecting solid bitumen is 0.78% R_o .

ORIGINAL GENERATIVE POTENTIAL AND HYDROCARBON YIELD CALCULATIONS

Petroleum generative capacity depends on the original quantity of organic matter (TOC_o) and the original type of organic matter (HI_o) (Peters et al., 2005, p. 97). The petroleum generation process has likely decreased the remaining generative potential as measured by TOC_{pd} and HI_{pd} in the Velkerri source rock samples examined in this study. We can estimate the extent of the petroleum generation process, the volume of expelled oil and the expulsion efficiency by making some reasonable assumptions based on the core geochemical data and published regional information (Jarvie et al., 2007; Peters et al., 2005).

HI_o values can be computed from visual kerogen assessments and assigned kerogen-type HI_o average values using the following equation (Jarvie et al., 2007):

$$HI_o = \left(\frac{\% \text{Type I}}{100} \times 750 \right) + \left(\frac{\% \text{Type II}}{100} \times 450 \right) + \left(\frac{\% \text{Type III}}{100} \times 125 \right) + \left(\frac{\% \text{Type IV}}{100} \times 50 \right) \quad (1)$$

This equation requires the input of maceral percentages from visual kerogen assessment of a source rock. For the present study, only limited kerogen data were available. Where available, these kerogen data sets were used. In the absence of other measured kerogen data original kerogen type were interpreted in the context of measured present day TOC, HI and OI values to arrive at an appropriate kerogen mix for each sample examined in this investigation. All samples were modeled using appropriate kerogen mix to maintain an appropriate transformation ratio consistent with the interpreted thermal maturity. The average maceral percentage in the various formations evaluated in the current study are shown in Table 2, along with the resultant average original HI_o values calculated using equation (1) above. The kerogen estimations used in this study are generally in agreement with other published values that suggest Type II to a mixed Type I/II kerogen assemblage (Law et al., 2010; Crick et al., 1988; Taylor et al., 1994).

Formation	%Type I 750 HI _o	%Type II 450 HI _o	%Type III 125 HI _o	%Type IV 50 HI _o	HI _o
Upper Velkerri	0	100	0	0	450
Middle Velkerri	0	100	0	0	450

Table 2. Average Kerogen Estimations for Lady Penrhyn 2 well.

The extent of the petroleum-generation process, or transformation ratio (TR) which is also called fractional conversion, is calculated as follows (Jarvie et al., 2007, p. 497):

$$TR_{HI} = 1 - \frac{HI_{pd}[1200 - HI_o(1 - PI_o)]}{HI_o[1200 - HI_{pd}(1 - PI_{pd})]} \quad (2)$$

HI_{pd} and PI_{pd} are the measured HI and PI values for the various source rock samples in this well. The average HI_{pd} and PI_{pd} for the formations evaluated in the current study are shown in Table 3. HI_o and PI_o are the original HI and PI values for immature organic matter in the rocks. For this calculation using the assumptions described previously results in an average HI_o values of 450 mg HC/g TOC (Table 2). We assume a PI_o of 0.02 (see Peters et al., 2005). Using these values in equation 2, the extent of fractional conversion of HI_o to petroleum varies from 0.64 to 0.74 (Table 3), i.e., on average an estimated 64 to 74% of the petroleum generation process has been completed.

The original TOC_o in the source rocks before burial and thermal maturation is constrained by mass balance considerations as follows (corrected from Jarvie et al., 2007):

$$TOC_o = \frac{HI_{pd} \left(\frac{TOC_{pd}}{1+k} \right) (83.33)}{\left[HI_o (1 - TR_{HI}) \left(83.33 - \left(\frac{TOC_{pd}}{1+k} \right) \right) \right] + \left[HI_{pd} \left(\frac{TOC_{pd}}{1+k} \right) \right]} \quad (3)$$

In this equation k is a correction factor based on residual organic carbon being enriched in carbon over original values at high maturity (Jarvie et al., 2007, p. 497). For Type II kerogen the increase in residual carbon C_R at high maturity is assigned a value of 15% (whereas for Type I, it is 50%, and for Type III, it is 0%) and the correction factor k is then $TR_{HI} \times C_R$. The kerogen mix for each individual sample was used in this calculation.

Using equation 3, the average estimated original TOC_o for the source rock samples in this well before petroleum generation varies from 0.85 to 3.09 wt.% (Table 3).

The original generation potential $S2_o$ can be calculated using the following equation:

$$S2_o = \left(\frac{HI_o \times TOC_o}{100} \right) \quad (4)$$

For the Velkerri source rocks examined in the Lady Penrhyn 2 well, the average $S2_o$ values vary from 3.8 to 13.9 mg HC/g rock or approximately 83 to 304 bbl/acre-ft (multiply $S2_o$ by 21.89 to calculate barrels/acre-ft, Jarvie and Tobey, 1999) (Table 3).

Knowing the measured remaining generation potential $S2$ from programmed pyrolysis and using the calculated original generation potential $S2_o$ enables a determination of the amounts of hydrocarbons generated. A VR_o algorithm can then be applied to estimate fractional oil cracking thereby converting yields to estimated oil and cracked gas (reported as Mcf/acre-ft or thousand cubic feet/acre-ft).

$$\text{Original } (S2_o) - \text{Remaining } (S2) = \text{Generated HCs} \quad (5)$$

Using this methodology for the Middle Velkerri samples analyzed in the current study, the generated oil yields average 180 bbl/acre-ft and there is a minor amount of secondary cracked gas that averages 8 Mcf/acre-ft. The generated oil yield from overlying Upper Velkerri was lower with an average value of 60 bbl/acre-ft.

Formation	TOC_{pd}	HI_{pd}	$S2_{pd}$ bbl/a-ft	HI_o	TR	TOC_o	$S2_o$ bbl/a-ft	S1 Free Oil bbl/a-ft	Est. Oil bbl/a-ft	Cracked Gas Mcf/a-ft
Upper Velkerri	0.67	160	23	450	0.74	0.85	83	4	60	0
Middle Velkerri	2.57	216	123	450	0.64	3.09	304	19	180	8

Table 3. Hydrocarbon Yields average data for Lady Penrhyn 2 well.

The amount of hydrocarbons (oil + gas) expelled from the rocks can be estimated as the difference between the amount of residual oil measured via programmed pyrolysis ($S1$) and the amount of estimated generated hydrocarbon yields determined above (equation 5). The expulsion efficiency ($ExEf$) can then be calculated as a direct proportion of the measured retained oil saturations and the average generated hydrocarbon yields. Thus, the resulting expulsion efficiency for the Velkerri intervals varies from 93% in the Upper unit to 90% in the Middle Velkerri interval.

The Upper and Middle Velkerri source rock intervals in the Lady Penrhyn 2 well are interpreted to be in the peak oil window and hydrocarbon yield calculations suggest moderate to significant amounts of

generation have occurred (predominantly oil with some associated and secondary cracked gas). From an exploration risk perspective, this is favorable. However, it is useful to relate these hydrocarbon yields to other productive unconventional US Shale plays (Table 4). In doing so, the potential critical value is not necessarily the generated oil and gas yields, but also the original (S_{2o}) generation potential of the source rocks. These values related to the ultimate volumes of hydrocarbon that could be generated at depth in the basin. For the Middle Velkerri original generation potential (S_{2o}) averages 304 bbl oil/acre-ft, this is on the low side but compares favorably to the list of unconventional US Shale plays shown below. For the Upper Velkerri, original generation potential is much lower 83 bbl oil/acre-ft and this unit do not compare favorably with other unconventional US Shale plays.

Sample Database Averages TOC >1%	HI ^o mg/g TOC	TR	TOC ^o wt%	S ₂ ^o mg/g Rock	Remaining Potential bbl/a-ft	Original Potential bbl/a-ft	Oil Cracked %	S1 Free Oil bbl/a-ft	Estimated Oil bbl/a-ft	Cracked Gas Mcf/a-ft
Barnett Shale Ft. Worth Basin	435	0.84	5.38	23.40	94	513	0.40	33	251	1005
Barnett Shale Delaware Basin	435	0.91	5.25	22.84	52	500	0.80	32	90	2149
Woodford Shale Delaware Basin	480	0.89	6.41	30.79	139	674	0.89	46	60	2854
Haynesville Shale E. Texas Basin	400	0.98	3.93	15.73	7	344	1.00	3	0	2022
Fayetteville Shale Arkoma Basin	435	0.95	3.34	14.53	15	318	1.00	10	0	1820
Woodford Shale Arkoma Basin	520	0.87	5.15	26.80	12	587	0.70	87	170	2431
Eagle Ford Shale Gulf Coast Basin	520	0.85	3.19	16.61	61	364	0.47	22	161	848
Marcellus Shale Appalachian Basin	600	0.97	6.44	38.66	34	847	1.00	24	0	4875
Utica Shale Appalachian Basin	450	0.98	2.74	12.32	6	270	1.00	12	0	1585
Barnett Shale Oil	450	0.47	5.47	24.64	326	540	0.00	79	213	0
Barnett Shale Gas	450	0.96	5.58	25.13	23	550	0.87	7	68	2751
Upper Velkerri	450	0.74	0.85	3.81	23	83	0.00	4	60	0
Middle Velkerri	450	0.64	3.09	13.90	123	304	0.01	19	180	8

Table 4. Geochemical Properties and Generation Potential for US Shale plays and current study.

HYDROCARBON SATURATIONS

A comparison was made between oil saturations based upon shale rock properties (SRP) analyses and those determined via programmed pyrolysis for a single sample from the Upper Velkerri Formation (149.85 m depth). In this instance the measured SRP oil saturations are significantly higher than those determined by SRA methods using the S1 yields. The saturation determined by SRP was 1.05 mg oil/g AR Rock (23 bbl oil/acre-ft), while that determined from S1 yields on a nearby sample is 0.13 mg oil/g AR Rock (3 bbl oil/acre-ft). This suggests that the S1 is significantly underestimating the total hydrocarbons extracted using Dean-Stark methods (toluene). The likely cause of this is undoubtedly related to the in-situ hydrocarbon saturation. Lower maturity oils generally contain relatively high abundances of non-volatile polar and asphaltene components associated with the in-situ oil/bitumen saturation and while this interval is generally considered to be in the peak oil window it may still contain some of these non-volatile components. Further evaluation of the extractable hydrocarbons by liquid chromatography and gas chromatography is warranted to fully evaluate the nature of these apparent discrepancies between SRP and S1 saturations.

UNCONVENTIONAL OIL & GAS RISK ASSESSMENT

The Mesoproterozoic Velkerri Formation source rocks in the Lady Penrhyn 2 well have been evaluated for unconventional oil and gas potential. These source rock samples are presented in a modified geochemical risk assessment diagram (Fig. 3) based upon published results from the Barnett Shale in the Fort Worth Basin. The data illustrated in the star plot represents average values for all four diagnostic ratios where available. Also shown are the recommended areas for unconventional oil (in green) and gas (in red). Data that lies above the minimum threshold and within the shaded areas indicates samples with low geochemical risk for either thermogenic oil or gas production. Data that lie below the minimum threshold and fall in the immature region (in gray) indicate a high risk for commercial shale oil or gas production. Transformation ratios (TR) were calculated based upon HI_o estimates using measured and interpreted fractional composition of kerogen macerals.

The Middle Velkerri source rock interval in the Lady Penrhyn 2 well is interpreted to represent a low geochemical risk for in-situ shale oil production. The average TOC content of 2.50 wt.% is above the generally accepted minimum value of 1% TOC to be considered an *effective* source rock for hydrocarbon generation/expulsion (Fig. 3). It is also above the minimum requirements of 2 wt.% for *economic* petroleum source rocks. Original organic matter type is interpreted to be predominantly oil-prone Type II marine algal kerogen. Thermal maturity parameters from programmed pyrolysis place the Middle Velkerri source interval in peak oil window. The average Tmax value of 444°C is above the recommended minimum value of 435°C for shale oil, but below the minimum of 455°C for shale gas (Fig. 3). This amount of conversion would likely be sufficient to generate/expel significant amounts of hydrocarbons from this organic-rich, oil prone source facies. Transformation Ratios (TR), the least constrained risk parameter, average 64% and fall above the recommended minimum of 50% for shale oil systems (Fig. 3). On the basis of all of these measured geochemical risk parameters, the Middle Velkerri source interval would be considered a low risk for shale oil and a high risk for shale gas since all of the thermal maturity risk parameters do fall well below recommended minimum thermogenic shale gas thresholds (Fig. 3).

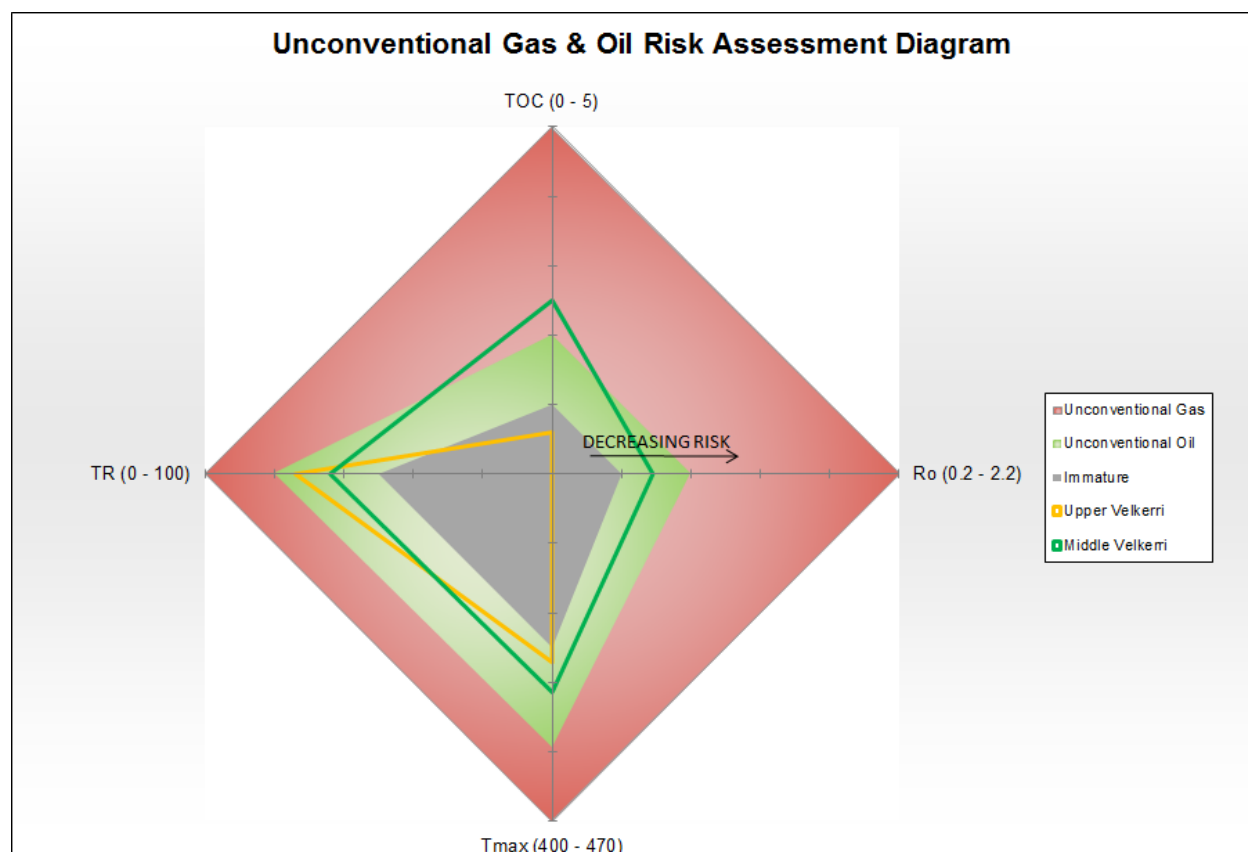


Figure 3. Geochemical Risk Assessment diagram for Mesoproterozoic Velkerri Formation source rocks in the Lady Penrhyn 2 well.

In contrast, the Upper Velkerri source rock interval in the Lady Penrhyn 2 well is interpreted to represent a high geochemical risk for in-situ shale oil production. The Upper Velkerri samples have an average TOC of only 0.60 wt.% and no samples exceed the recommended minimum threshold of 1% TOC for shale oil systems (Fig. 3). Thermal maturity indicators suggest peak window maturity. On the risk assessment diagram, average Tmax value of 438°C is above the recommended minimum value of 435°C for shale oil and the Transformation Ratio of 74% is also above the minimum threshold (Fig. 3). On the basis of all of these measured geochemical risk parameters, the Upper Velkerri source interval would be considered a high risk for shale oil because despite having sufficient thermal maturity it has insufficient organic richness (Fig. 3).

In the Middle Velkerri source interval, measured in-situ oil saturation determined by programmed pyrolysis S1 yields is fair (avg. 19 bbl oil/acre-ft) (Fig. 4), but zones in both the upper and lower intervals have generally higher saturations (20-40 bbl oil/acre-ft) suggesting low risk for shale oil development. Hydrocarbon yield calculations on as-received samples show estimates of average generated oil from the Middle Velkerri at 180 bbl oil/acre-ft, along with 8 Mcf/acre-ft of secondary cracked gas. As a comparison, a representative example from the core area of Barnett Shale oil production in the Fort Worth Basin has an estimated generated oil yield of 213 bbl/a-ft with a measured in-situ oil saturation of 79 bbl/a-ft. These values are somewhat higher in comparison to the Middle Velkerri due primarily to differences in organic richness (Barnett Shale oil example has avg. 4.70 wt.% TOC). The relatively large differences in in-situ hydrocarbon saturation could reflect dissimilar retention/expulsion efficiency possibly related to differences in geologic age of these formations.

In the Upper Velkerri source interval, measured in-situ oil saturation determined by programmed pyrolysis S1 yields is poor (avg. 4 bbl oil/acre-ft), suggesting high risk for shale oil development (Fig. 4). Although the in-situ hydrocarbon saturations determined from SRP analysis are higher (23 bbl oil/acre-ft), this single sample may not be representative of the entire interval and does not necessarily alter the high risk assessment. Hydrocarbon yield calculations on as-received samples show estimates of average generated oil from the Upper Velkerri at 60 bbl oil/acre-ft. These low values suggest a high risk for shale oil and shale gas within the Lower Velkerri interval.

It is important to note that the quantity of oil generated from a potential source rock is only one geochemical factor to consider in regard to risk assessment. Equally important is the quality of the oil generated, since this factor can be a critical element in assessing the movability and ultimate recovery. The interpreted thermal maturity of the Upper and Middle Velkerri source intervals in this well is in the peak oil window and hydrocarbon saturation is likely to be relatively light and mobile. However, differences between SRP oil saturation and S1 yields in the Upper Velkerri suggest the possibility of a heavy non-volatile component. The presence of heavy oil and/or bitumen could also indicate a source interval with restricted microporosity. Such microporosity is considered necessary for recovery of in-situ oil saturation and can be better assessed using scanning electron microscopy (SEM). Source rock extract fingerprints and bulk fractional compositional analyses from select Velkerri samples would also aid in the determination of the quality of the in-situ hydrocarbon saturation and provide a better assessment of their movability and ultimate recovery potential.

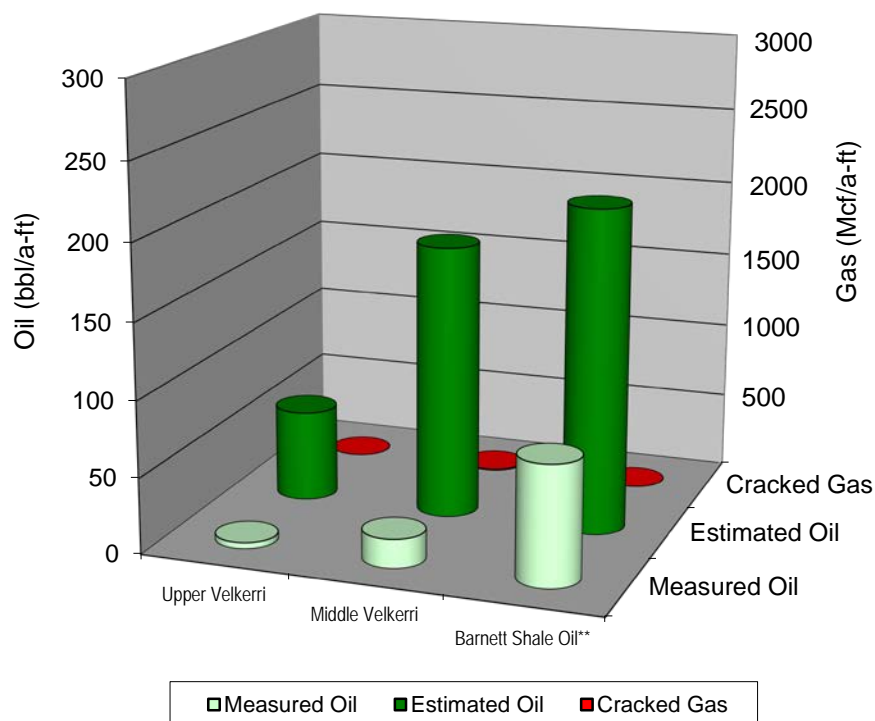


Figure 4. Hydrocarbon yield estimates for the Mesoproterozoic source rocks in the Lady Penrhyn 2 well compared to Barnett Shale in the oil window.

GEOCHEMICAL SUMMARY

The Middle Velkerri source interval in the Lady Penrhyn 2 well is interpreted to represent low geochemical risk for unconventional shale oil development. It clearly has elevated organic richness (avg. 2.50 wt.% TOC) and is considered a very good source rock with dominantly oil-prone Type II kerogen. Thermal maturity parameters indicate that the source interval is in the peak oil window, 0.83% Calc. R_o and measured 0.78% R_o , and all key risk ratios are above recommended minimum thresholds for shale oil systems. The Middle Velkerri has likely generated significant amounts of oil (avg. 180 bbl oil/acre-ft) and comparison to other systems such as the Barnett Shale show in-situ oil saturations (avg. 19 bbl oil/acre-ft) are much lower for the Middle Velkerri. Risk criteria like the S1 versus TOC show some oil cross-over and generally more elevated values of hydrocarbon saturation in both the upper and lower zones of this unit. Further evaluation of in-situ oil characteristics would be required to fully evaluate potential oil mobility and recovery risk.

The Lower Velkerri source rock interval evaluated in the Lady Penrhyn 2 well generally has higher risk in comparison to the Middle Velkerri. This horizon has marginal organic richness, with the average 0.60 wt.% TOC being well below the minimum threshold for shale oil. The estimated generated oil is low (avg. 60 bbl oil/acre-ft) in the Lower Velkerri and measured in-situ oil saturation determined by S1 yields is low (avg. 4 bbl oil/acre-ft), although SRP data suggests in-situ saturations may be somewhat higher. This unit is considered a high risk for shale oil development.

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Appendix I

Hydrocarbon Yield Calculation

Shelf Group

Lady Penrhyn 2

McArthur Basin Integrated Petroleum Geochemistry, 2016

Northern Territory Geological Survey - Australia



Lady Penrhyn 2
Hydrocarbon Yield Calculation

																S2 (meas)	S2 (orig)				
Sample	Top Depth	TOC*	HI*	S1*	S2*	Calc.Ro	PI*	%Type IV 50 HIº	% Type III 125 HIº	%Type II 450 HIº	%Type I 750 HIº	HIº	TR	TOCº	S2º	Remaining Potential	Original Potential	Oil Cracked	S1 Free Oil	Estimated Oil	Cracked Gas
Lady Penrhyn 2	(m)	wt%	mg/g TOC	mg/g Rock	mg/g Rock	%						mg/g TOC		wt%	mg/g Rock	bb/a-ft	bb/a-ft	%	bb/a-ft	bb/a-ft	Mcf/a-ft
1408477	106	0.51	180	0.11	0.92	0.71	0.11	0	0	100	0	450	0.71	0.63	2.83	20	62	0.00	2	42	0
HD14DJR022	118	0.62	45	0.04	0.28	0.76	0.13	0	0	100	0	450	0.93	0.82	3.71	6	81	0.00	1	75	0
1408483	152	0.51	198	0.13	1.01	0.72	0.11	0	0	100	0	450	0.67	0.62	2.81	22	61	0.00	3	39	0
1408484	162	0.57	170	0.18	0.97	0.71	0.16	0	0	100	0	450	0.73	0.71	3.21	21	70	0.00	4	49	0
1408485	169	0.68	224	0.24	1.52	0.74	0.14	0	0	100	0	450	0.63	0.82	3.70	33	81	0.00	5	48	0
1408487	188	0.52	188	0.21	0.98	0.71	0.18	0	0	100	0	450	0.70	0.65	2.91	21	64	0.00	5	42	0
1408488	196	0.88	194	0.24	1.71	0.72	0.12	0	0	100	0	450	0.68	1.08	4.86	37	106	0.00	5	69	0
1408489	207	0.62	198	0.21	1.23	0.74	0.15	0	0	100	0	450	0.68	0.76	3.43	27	75	0.00	5	48	0
1408490	216	0.68	165	0.18	1.12	0.63	0.14	0	0	100	0	450	0.74	0.85	3.83	25	84	0.00	4	59	0
1408491	225	0.60	145	0.17	0.87	0.63	0.16	0	0	100	0	450	0.77	0.76	3.43	19	75	0.00	4	56	0
1408492	231	0.56	164	0.16	0.92	0.74	0.15	0	0	100	0	450	0.74	0.70	3.16	20	69	0.00	4	49	0
1408494	236	0.65	137	0.15	0.89	0.89	0.14	0	0	100	0	450	0.79	0.83	3.72	19	81	0.00	3	62	0
1408493	239	0.79	195	0.25	1.54	0.74	0.14	0	0	100	0	450	0.68	0.97	4.37	34	96	0.00	5	62	0
1408495	241	0.92	176	0.29	1.62	0.71	0.15	0	0	100	0	450	0.72	1.15	5.15	35	113	0.00	6	77	0
HD14DJR023	241	0.92	24	0.04	0.22	0.66	0.15	0	0	100	0	450	0.97	1.24	5.57	5	122	0.00	1	117	0
1408496	263	0.75	160	0.29	1.20	0.76	0.19	0	0	100	0	450	0.75	0.95	4.27	26	93	0.00	6	67	0
Upper Velkerri (Avg)		0.67	160	0.18	1.06	0.72	0.14	0	0	100	0	450	0.74	0.85	3.81	23	83	0.00	4	60	0
1408498	277	0.59	195	0.22	1.15	0.78	0.16	0	0	100	0	450	0.68	0.73	3.28	25	72	0.00	5	47	0
1408499	281	1.02	181	0.58	1.85	0.71	0.24	0	0	100	0	450	0.71	1.28	5.78	41	127	0.00	13	86	0
1408500	286	2.00	280	1.54	5.60	0.80	0.22	0	0	100	0	450	0.52	2.38	10.72	123	235	0.00	34	112	0
1408501	290	1.09	268	1.19	2.92	0.71	0.29	0	0	100	0	450	0.55	1.33	6.00	64	131	0.00	26	67	0
1408502	295	1.28	270	1.06	3.45	0.74	0.24	0	0	100	0	450	0.54	1.54	6.94	76	152	0.00	23	77	0
1408503	297	1.36	274	1.20	3.72	0.74	0.24	0	0	100	0	450	0.54	1.64	7.38	81	162	0.00	26	80	0
HD14DJR025	299	2.24	126	0.90	2.83	0.58	0.24	0	0	100	0	450	0.81	2.88	12.94	62	283	0.00	20	221	0
1408504	300	2.50	293	1.80	7.33	0.76	0.20	0	0	100	0	450	0.49	2.94	13.22	161	290	0.00	39	129	0
1408505	303	1.50	249	1.02	3.73	0.76	0.21	0	0	100	0	450	0.58	1.82	8.17	82	179	0.00	22	97	0
1408506	305	1.80	250	1.16	4.50	0.80	0.20	0	0	100	0	450	0.58	2.17	9.77	99	214	0.00	25	115	0
1408507	308	1.85	247	1.16	4.57	0.78	0.20	0	0	100	0	450	0.58	2.23	10.05	100	220	0.00	25	120	0
1408508	310	0.75	167	0.52	1.25	0.71	0.29	0	0	100	0	450	0.74	0.96	4.32	27	95	0.00	11	67	0
1408509	315	1.50	223	0.92	3.34	0.78	0.22	0	0	100	0	450	0.63	1.84	8.28	73	181	0.00	20	108	0
1408510	320	1.68	233	0.93	3.92	0.83	0.19	0	0	100	0	450	0.61	2.04	9.17	86	201	0.00	20	115	0
1408511	326	2.15	230	1.06	4.95	0.87	0.18	0	0	100	0	450	0.62	2.60	11.70	108	256	0.00	23	148	0
1408512	329	1.18	207	0.52	2.44	0.81	0.18	0	0	100	0	450	0.66	1.45	6.52	53	143	0.00	11	89	0
1408513	335	1.40	207	0.66	2.90	0.83	0.19	0	0	100	0	450	0.66	1.72	7.75	64	170	0.00	14	106	0
1408514	341	0.69	203	0.35	1.40	0.85	0.20	0	0	100	0	450	0.67	0.85	3.85	31	84	0.00	8	54	0
1408515	345	1.96	215	0.70	4.22	0.87	0.14	0	0	100	0	450	0.64	2.37	10.68	92	234	0.00	15	142	0
HD14DJR026	348	0.95	96	0.31	0.91	0.78	0.25	0	0	100	0	450	0.86	1.24	5.60	20	123	0.00	7	103	0
1408516	351	2.26	224	1.09	5.06	0.85	0.18	0	0	100	0	450	0.63	2.74	12.34	111	270	0.00	24	159	0
1408517	355	1.60	233	0.45	3.72	0.69	0.11	0	0	100	0	450	0.60	1.91	8.59	81	188	0.00	10	107	0
1408518	356	1.48	236	0.60	3.49	0.80	0.15	0	0	100	0	450	0.60	1.78	8.00	76	175	0.00	13	99	0
1408519	358	3.17	238	0.68	7.53	0.81	0.08	0	0	100	0	450	0.59	3.73	16.78	165	367	0.00	15	203	0
1408520	360	4.11	230	0.71	9.45	0.85	0.07	0	0	100	0	450	0.61	4.83	21.73	207	476	0.00	16	269	0
1408521	362	3.85	222	0.55	8.54	0.80	0.06	0	0	100	0	450	0.62	4.54	20.44	187	448	0.00	12	261	0
1408523	370	4.02	209	0.48	8.39	0.81	0.05	0	0	100	0	450	0.65	4.77	21.47	184	470	0.00	11	287	0
1408524	372	2.91	237	0.37	6.90	0.87	0.05	0	0	100	0	450	0.59	3.40	15.31	151	335	0.00	8	184	0
1408525	374	5.79	258	1.13	14.95	0.87	0.07	0	0	100	0	450	0.55	6.66	29.95	327	656	0.00	25	328	0
1408526	376	3.20	213	0.67	6.83	0.83	0.09	0	0	100	0	450	0.64	3.82	17.21	150	377	0.00	15	227	0
1408527	378	3.00	212	0.50	6.35	0.81	0.07	0	0	100	0	450	0.64	3.58	16.11	139	353	0.00	11	214	0
1408528	380	2.57	215	0.49	5.52	0.81	0.08	0	0	100	0	450	0.64	3.07	13.82	121	303	0.00	11	182	0
1408529	382	4.75	227	0.96	10.76	0.89	0.08	0	0	100	0	450	0.61	5.59	25.18	236	551	0.00	21	316	0
1408530	384	3.83	215	0.70	8.25	0.85	0.08	0	0	100	0	450	0.64	4.55	20.48	181	449	0.00	15	268	0
1408531	386	3.41	228	0.93	7.77	0.89	0.11	0	0	100	0	450	0.61	4.05	18.23	170	399	0.00	20	229	0
1408532	388	2.06	232	0.62	4.78	0.83	0.11	0	0	100	0	450	0.61	2.46	11.06	105	242	0.00	14	137	0
1408533	390	0.53	223	0.44	1.18	0.42	0.27	0	0	100	0	450	0.64	0.66	2.97	26	65	0.00	10	39	0
1408534	392	5.49	242	0.92	13.31	0.89	0.06	0	0	100	0	450	0.58	6.37	28.65	291	628	0.00	20	336	0
1408535	394	4.58	230	0.96	10.55	0.87	0.08	0	0	100	0	450	0.61	5.39	24.24	231	531	0.00	21	300	0
1408536	397	3.32	212	0.97	7.05	0.87	0.12	0	0	100	0	450	0.65	3.99	17.96	154	393	0.00	21	239	0
HD14DJR027	399	4.94	143	0.61	7.05	0.77	0.08	0	0	100	0	450	0.77	6.10	27.45	154	601	0.00	13	447	0
1408537	401	5.56	244	1.10	13.59	0.89	0.07	0	0	100	0	450	0.58	6.45	29.04	298	636	0.00	24	338	0
1408538	403	3.85	233	0.67	8.98	0.85	0.07	0	0	100	0	450	0.60	4.52	20.33	197	445	0.00	15	249	0

Lady Penrhyn 2
Hydrocarbon Yield Calculation

																S2 (meas)	S2 (orig)				
Sample	Top Depth	TOC*	HI*	S1*	S2*	Calc.Ro	PI*	%Type IV 50 HIº	% Type III 125 HIº	%Type II 450 HIº	%Type I 750 HIº	HIº	TR	TOCº	S2º	Remaining Potential	Original Potential	Oil Cracked	S1 Free Oil	Estimated Oil	Cracked Gas
Lady Penrhyn 2	(m)	wt%	mg/g TOC	mg/g Rock	mg/g Rock	%						mg/g TOC		wt%	mg/g Rock	bbbl/a-ft	bbbl/a-ft	%	bbbl/a-ft	bbbl/a-ft	Mcf/a-ft
1408539	404	4.91	235	0.78	11.56	0.96	0.06	0	0	100	0	450	0.59	5.73	25.77	253	564	0.04	17	297	84
1408540	406	3.53	224	0.68	7.91	0.94	0.08	0	0	100	0	450	0.62	4.18	18.80	173	412	0.03	15	231	46
1408541	408	4.87	224	1.37	10.91	0.94	0.11	0	0	100	0	450	0.62	5.78	25.99	239	569	0.03	30	320	64
1408542	410	3.95	216	1.27	8.55	0.94	0.13	0	0	100	0	450	0.64	4.74	21.31	187	467	0.03	28	270	54
1408543	412	3.17	202	0.93	6.40	0.96	0.13	0	0	100	0	450	0.67	3.84	17.28	140	378	0.04	20	228	64
1408544	414	3.10	194	0.88	6.00	0.98	0.13	0	0	100	0	450	0.68	3.77	16.99	131	372	0.06	19	226	84
1408545	416	2.22	203	0.75	4.51	0.96	0.14	0	0	100	0	450	0.67	2.70	12.17	99	267	0.04	16	160	45
1408546	418	2.06	186	0.77	3.83	0.92	0.17	0	0	100	0	450	0.70	2.55	11.46	84	251	0.02	17	163	21
1408547	420	1.04	220	0.50	2.29	0.94	0.18	0	0	100	0	450	0.64	1.27	5.72	50	125	0.03	11	73	15
1408548	422	1.32	245	0.80	3.23	0.85	0.20	0	0	100	0	450	0.59	1.60	7.19	71	157	0.00	18	87	0
1408549	424	2.09	193	0.78	4.04	0.89	0.16	0	0	100	0	450	0.69	2.57	11.56	88	253	0.00	17	165	0
1408550	426	2.02	205	0.84	4.15	0.92	0.17	0	0	100	0	450	0.66	2.47	11.12	91	244	0.02	18	149	19
1408551	428	1.11	160	0.32	1.78	0.85	0.15	0	0	100	0	450	0.75	1.39	6.27	39	137	0.00	7	98	0
1408552	430	2.90	208	1.46	6.04	0.92	0.19	0	0	100	0	450	0.66	3.55	15.97	132	350	0.02	32	213	27
1408553	432	2.52	187	1.45	4.71	0.89	0.24	0	0	100	0	450	0.70	3.14	14.14	103	310	0.00	32	206	0
HD14DJR029	432	3.10	141	1.11	4.38	0.84	0.20	0	0	100	0	450	0.78	3.92	17.63	96	386	0.00	24	290	0
1408554	434	2.34	191	1.54	4.48	0.89	0.26	0	0	100	0	450	0.69	2.92	13.16	98	288	0.00	34	190	0
1408555	436	1.21	202	0.63	2.45	0.85	0.20	0	0	100	0	450	0.67	1.50	6.74	54	148	0.00	14	94	0
1408556	438	2.31	188	1.23	4.35	0.83	0.22	0	0	100	0	450	0.70	2.87	12.93	95	283	0.00	27	188	0
Middle Velkerri (Avg)		2.57	216	0.85	5.62	0.83	0.16	0	0	100	0	450	0.64	3.09	13.90	123	304	0.01	19	180	8
Barnett Shale Oil**		4.70	300	3.60	14.90	0.86	0.20	0	0	100	0	450	0.47	5.47	24.64	326	540	0.00	79	213	0
Barnett Shale**		4.21	26	0.33	1.07	1.66	0.24	0	0	100	0	450	0.96	5.58	25.13	23	550	0.87	7	68	2751

Notes: Calc.Ro values in **bold** are calculated from measured Tmax. Calc.Ro values in **red font** are intepreted from other geochemical maturity data because Tmax was considered unreliable. All other Calc.Ro values are formation specific averages because Tmax was considered unreliable.

Kerogen Type in **bold** have visual kerogen data for estimates TR = Transformation Ratio (fractional conversion) (Original Potential - Remaining Potential) = (Estimated Oil + Cracked Gas)

Estimated Oil and Cracked Gas yield data assume complete conversion and no expulsion of hydrocarbon products and the proportion between each is based on empirical Ro calculated % cracking.

Yields do not represent recoverable products and are intended primarily for comparison purposes, yield calculations based on carbon mass balance are likely to be overestimations.

**Estimated parameters for productive Barnett Shale in the Ft. Worth Basin

Hydrocarbon yield calculations and formulas are fully documented in the appendix section of Jarvie et al. (2007)