



Alexander 1 Interpretive Summary

Upper Velkerri – Lower Velkerri Interval

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PETROLEUM GEOCHEMISTRY

INTRODUCTORY NOTE

A geochemical investigation has been conducted to assess hydrocarbon prospectivity of the Upper, Middle and Lower Velkerri Formations in the Alexander 1 well located in the McArthur Basin, Northern Territories, Australia. Ten (10) core chip samples from this well were analyzed by a variety of geochemical techniques, including total organic carbon (TOC, LECO®) and programmed pyrolysis (SRA). In addition, client supplied published geochemical data for 60 samples was 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
Alexander 1	Upper Velkerri	Estimated Original →		Good (1.82% TOC)	Oil-prone Type II	Moderate
Measured Currently →		Oil	Early Oil Window	Good (1.42% TOC)	Gas-prone Type III	
Alexander 1	Middle Velkerri	Estimated Original →		Excellent (5.30% TOC)	Oil-prone Type II	Low
Measured Currently →		Oil	Peak Oil Window	Excellent (4.31% TOC)	Mixed Type II/III	
Alexander 1	Lower Velkerri	Estimated Original →		Poor (0.48% TOC)	Oil-prone Type II	High
Measured Currently →		Light Oil Wet Gas	Wet Gas Window	Poor (0.35% TOC)	Gas Prone Type 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

Four samples (4) from the Upper Velkerri Formation were analyzed for LECO TOC content and programmed pyrolysis, with the remaining data set (16 samples) composed of client supplied public data (Fig. 1). TOC contents ranged from 0.58 to 3.03 wt.% and averaged 1.42 wt.% (good). Twelve (12) of these samples have TOC contents above the minimum requirement of 1 wt.% for *effective* petroleum source rocks, while five (5) samples 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 (278.02 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 1.29 mg HC/g rock (28 bbl oil/acre-ft) and S2 values average 2.36 mg HC/g rock (52 bbl oil/acre-ft). The S1 and S2 values imply good 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 91 (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, S1 crosses over TOC at 112 m and most of the interval between 193–278 m (Fig. 1) in the basal Upper Velkerri Formation.

Measured Hydrogen Index (HI) values in the Upper Velkerri average 173 mg HC/g TOC, indicating gas-prone Type III kerogen quality in these source rocks at present day. This is consistent with elemental analyses of select kerogen samples from the Upper Velkerri that have average H/C ratios of 0.89, which is typical for Type III kerogen. Original HI_0 of these samples are estimated to average 454 mg HC/g rock, which indicate oil-prone Type II kerogen. Transformation Ratios (TR) based upon HI average 73%, which is consistent with a peak to late oil window thermal maturity. T_{max} values in the Upper Velkerri samples average 432°C. T_{max} between 425 and 435°C typically indicate early oil window, while values < 425°C are considered immature with regard to the 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 early 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 432°C is equivalent to a Calc. % R_o value of 0.62%. 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 0.33. These elevated PI values are consistent with source rocks in the late oil window, which typically have PI values between ~0.25 to 0.35. It is noteworthy that samples in the depth range of ~193-278 m appear to have the most elevated PI values and this is consistent with their elevated NOC, which suggests possible producible in-situ oil saturation within this horizon.

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 (24 samples) composed of client supplied public data (Fig. 1). The Middle Velkerri Formation in the Alexander 1 well exhibits excellent generative potential for petroleum source rocks based on TOC content values (Fig. 1). TOC content ranges from 1.03 to 7.87 wt.% and averages 4.31 wt.%. All but two 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 303, 348 and 438 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 3.24 mg HC/g rock (71 bbl oil/acre-ft), indicating very good 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 lower in comparison to the overlying strata and average 75. Oil cross over (NOC > 100) was observed for many samples in the middle of this unit between the depths of 363-413 m (Fig. 1), which suggests possible producible hydrocarbons at these depths. The S2 values in this interval average 9.03 mg HC/g rock (198 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 205 mg HC/g TOC, which indicate mostly mixed oil/gas-prone Type II/III kerogen quality in these source rocks at present day. This is consistent with elemental analyses of select kerogen samples from the Middle Velkerri that have average H/C ratios of 1.00, which is typical for mixed Type II/III kerogen. Estimated original HI_0 values in these samples average 453 mg HC/g TOC, which indicate oil-prone Type II kerogen quality. Transformation Ratios (TR) based upon HI average 67%, which is consistent with a peak oil window thermal maturity.

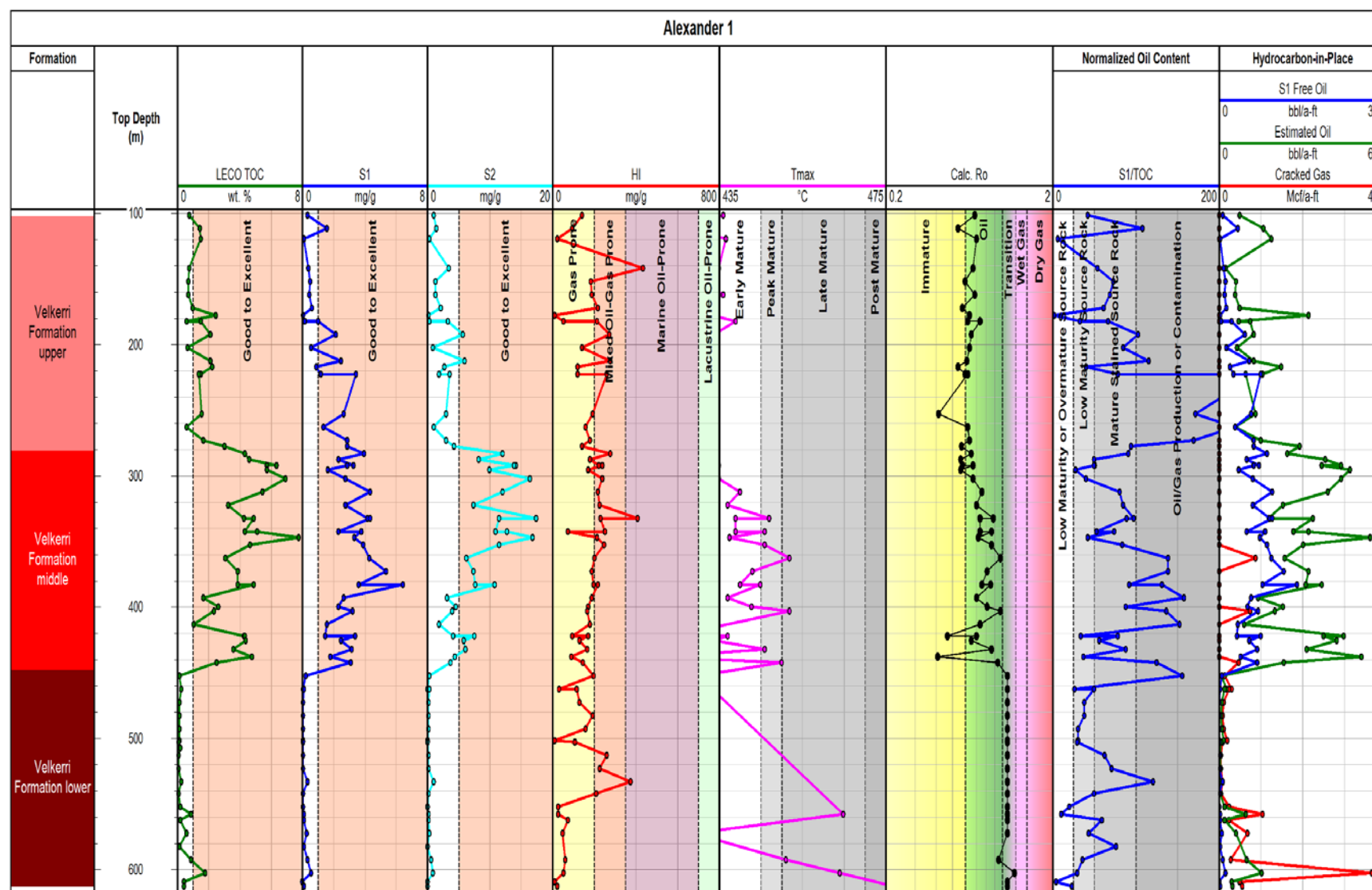


Figure 1. Geochemical depth plots for the Alexander 1 well.

The organic-matter in the Middle Velkerri interval in the Alexander 1 well is thermally mature and is interpreted to be in the peak oil window. Programmed pyrolysis T_{max} values average 439°C (Fig. 1). Using the formula published by Jarvie et al. (2007) for Type II kerogen ($\text{Calculated } R_o = (0.0180)(T_{max}) - 7.16$), the average measured T_{max} value of 439°C is equivalent to a Calc. % R_o value of 0.74%. 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 0.29. These elevated PI values are consistent with source rocks in the late oil window. The PI values tend to increase toward the base of the Middle Velkerri interval and are generally elevated in the same zone where NOC values are also highest. This suggests possible producible in-situ oil saturation within this horizon.

LOWER VELKERRI FORMATION

Two (2) samples from the Lower Velkerri Formation were analyzed for LECO TOC content and programmed pyrolysis, with the remaining data set (19 samples) composed of client supplied public data (Fig. 1). TOC contents ranged from 0.07 to 1.79 wt.% and averaged 0.35 wt.% (poor). Only one (1) of these samples have TOC contents above the minimum requirement of 1 wt.% for *effective* petroleum source rocks, and no samples exceeds the minimum requirement of 2 wt.% for *economic* petroleum source rocks. The highest measured TOC content is near the base of the designated Lower Velkerri interval (603 m depth) (Fig. 1). Most of this interval has TOC content < 0.5 wt. % and is considered to have only poor source potential (Fig. 1).

The S1 values in the Lower Velkerri source rock samples average only 0.13 mg HC/g rock (3 bbl oil/acre-ft) and S2 values are also very low with an average 0.27 mg HC/g rock (6 bbl oil/acre-ft). The S1 and S2 values imply generally poor in-situ hydrocarbon saturation and generative potential, with the exception of the single sample at 603 m depth (Fig. 1). The normalized oil content (NOC) in the Lower Velkerri samples average 37 (Fig. 1) and there is oil “cross-over” in only one sample from 533 m depth. This is interpreted to represent zones with low potential for containing producible hydrocarbon saturation.

Measured Hydrogen Index (HI) values in the Lower Velkerri average only 118 mg HC/g TOC, indicating gas-prone Type III kerogen quality in these source rocks at present day (Fig. 1). This is consistent with elemental analyses of select kerogen samples from the Lower Velkerri that have average H/C ratios of 0.87, which is typical for Type III kerogen. Original HI_o of these samples are estimated to average 450 mg HC/g rock, which indicate oil-prone Type II kerogen. Transformation Ratios (TR) based upon HI average 81%, which is consistent with a wet gas/condensate window thermal maturity. T_{max} values in the Lower Velkerri samples are generally considered to be unreliable for maturity assessment due to low S2 yields. Using select data deemed valid gives an average 458°C. T_{max} between 450 and 470°C typically indicate condensate/wet gas window, while values > 470°C are considered post-mature dry gas window (Type II kerogen). On the basis of these guidelines, the average Lower Velkerri T_{max} values in this well would be interpreted to be in the condensate/wet gas window. Using the formula published by Jarvie et al. (2007) for Type II kerogen ($\text{Calculated } R_o = (0.0180)(T_{max}) - 7.16$), the average measured T_{max} value of 458°C is equivalent to a Calc. % R_o value of 1.08%. 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 the Lower Velkerri samples average 0.33. These elevated PI values are consistent with source rocks in the late oil to early wet gas/condensate window, which typically have PI values between ~0.25 and 0.40.

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	1	99	0	0	454
Middle Velkerri	1	99	0	0	453
Lower Velkerri	0	100	0	0	450

Table 2. Average Kerogen Estimations for Alexander 1 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 ranging from of 450 to 454 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 0.67 to 0.81 (Table 3), i.e., on average an estimated 67 to 81% 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 0.48 to 5.30 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 Alexander 1 well, the average $S2_o$ values vary from 2.2 to 24.0 mg HC/g rock or approximately 48 to 525 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 326 bbl/acre-ft and there is a minor amount of secondary cracked gas that averages 7 Mcf/acre-ft. The generated oil yield from overlying Upper Velkerri was lower with an average value of 128 bbl/acre-ft. The average generated oil yield from the Lower Velkerri averaged 34 bbl/acre-ft along with 44 Mcf/acre-ft of secondary cracked gas (Table 3) in this relatively higher thermal maturity zone.

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	1.42	173	52	454	0.73	1.82	180	28	128	0
Middle Velkerri	4.31	205	198	453	0.67	5.30	525	71	326	7
Lower Velkerri	0.36	118	6	450	0.81	0.48	48	3	34	44

Table 3. Hydrocarbon Yields average data for Alexander 1 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 78% in the Upper unit, 78% in the Middle and 93% in the Lower interval. This is likely to be a consequence of increased thermal maturity resulting in more volatile in-situ oil compositions and higher gas/oil ratios, both of which would tend to enhance expulsion in the deeper source rock intervals.

The Upper and Middle Velkerri source rock intervals in the Alexander 1 well are interpreted to be in the early to peak oil windows 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. In the Lower Velkerri, hydrocarbon yield estimates suggest minor amounts of oil and some secondary gas have been generated due to the relatively higher

interpreted thermal maturity. 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 ($S2_o$) 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 ($S2_o$) averages 525 bbl oil/acre-ft, which compares favorably to the list of unconventional US Shale plays shown below. For the Upper and Lower Velkerri, original generation potential is much lower from 180 to 48 bbl oil/acre-ft and these two units do not compare favorably with other unconventional US Shale plays.

Sample Database Averages TOC >1%	H ^o mg/g TOC	TR	TOC ^o wt%	S2 ^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	454	0.73	1.82	8.22	52	180	0.00	28	128	0
Middle Velkerri	453	0.67	5.30	23.98	198	525	0.01	71	326	7
Lower Velkerri	450	0.81	0.48	2.18	6	48	0.16	3	34	44

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

UNCONVENTIONAL OIL & GAS RISK ASSESSMENT

The Mesoproterozoic Velkerri Formation source rocks in the Alexander 1 well have been evaluated for unconventional oil and gas potential. These source rock samples are presented in a modified geochemical risk assessment diagram (Fig. 2) based upon published results from the Barnett Shale in the Fort Worth Basin. The data illustrated in the star plot represents average values for three of the four diagnostic ratios (no measured R_o data 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 H_i estimates using measured and interpreted fractional composition of kerogen macerals.

The Middle Velkerri source rock interval in the Alexander 1 well is interpreted to represent a low geochemical risk for in-situ shale oil production. The average TOC content of 4.31 wt.% is above the generally accepted minimum value of 1% TOC to be considered an *effective* source rock for hydrocarbon generation/expulsion (Fig. 2). 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 439°C is above the recommended minimum value of 435°C for shale oil, but below the minimum of 455°C for shale gas (Fig. 2). 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 67% and fall above the recommended minimum of 50% for shale oil systems (Fig. 2). 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. 2).

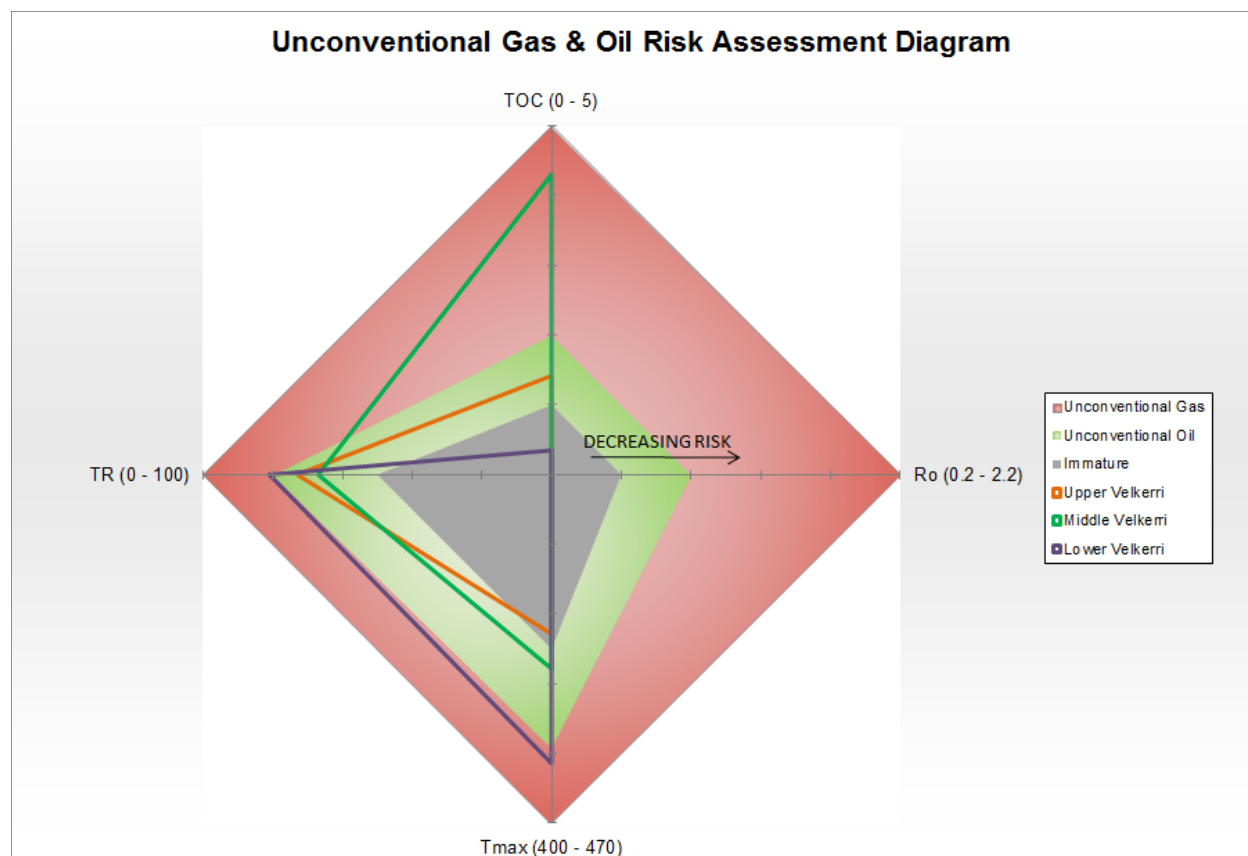


Figure 2. Geochemical Risk Assessment diagram for Mesoproterozoic Velkerri Formation source rocks in the Alexander 1 well.

The other formations examined in the current study are considered to represent low to moderate risk for in-situ shale oil/gas production. This is primarily related to organic richness, although additional factors also need to be considered. The Upper Velkerri samples have an average TOC of 1.42 wt.% and thermal maturity indicators suggest early window maturity. On the risk assessment diagram, average Tmax value of 432°C is below the recommended minimum value of 435°C for shale oil, but the Transformation Ratio of 73% is above the minimum threshold (Fig. 2). For these reasons, the Upper Velkerri interval is considered to be moderate risk for commercial shale oil development and high risk for shale gas. Given its proximity to the underlying Middle Velkerri, it would be logical to conclude that any contribution to the overall resource potential from this horizon would simply be included within the evaluation of the Middle Velkerri, since fracture stimulation would likely connect both horizons, especially when considering the most prospective zone with elevated NOC values is the basal section of the Upper Velkerri.

The Lower Velkerri has an average TOC value of only 0.35 wt.%. This is far below the recommended minimum for *effective* source rocks and plot on the risk assessment diagram in an unfavorable location for shale oil. Furthermore, measured in-situ oil saturation in this source rock interval is very low (avg. 3 bbl oil/acre-ft) which suggest that any generated oil has either been cracked to gas or expelled from the source rock. Thermal maturity parameters suggest this interval has a relatively high maturity within the early wet gas/condensate window. On the risk assessment diagram the Tmax value of 458°C and Transformation Ratio of 81% are both above the minimum thresholds for prospective shale gas. However, the low TOC content of this interval preclude any significant hydrocarbon generation and thus this interval is considered a high risk for both unconventional oil and unconventional gas development.

In the Middle Velkerri source interval, measured in-situ oil saturation determined by programmed pyrolysis S1 yields is very good (avg. 71 bbl oil/acre-ft), suggesting low risk for shale oil development (Fig. 3).

Hydrocarbon yield calculations on as-received samples show estimates of average generated oil from the Middle Velkerri at 326 bbl oil/acre-ft, along with 7 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 comparable to the Middle Velkerri and minor differences could be due to differences in retention/expulsion efficiency possibly related to differences in geologic age of these formations.

In the Upper Velkerri source interval measured in-situ oil saturation from S1 yields is generally good (avg. 28 bbl oil/acre-ft), but estimated generated oil yields are only moderate (avg. 128 bbl oil/acre-ft) due to lower organic richness (Fig. 3). The Lower Velkerri has the lowest measured in-situ oil saturation (3 bbl oil/acre-ft), but this could be a partial consequence of elevated thermal maturity and loss of volatile oil saturation. Estimated generated oil yield is low (34 bbl oil/acre-ft) along with some minor amounts of secondary cracked gas (44 Mcf/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 early and peak oil window and hydrocarbon saturation is likely to vary from moderately heavy to light with increasing depth. 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.

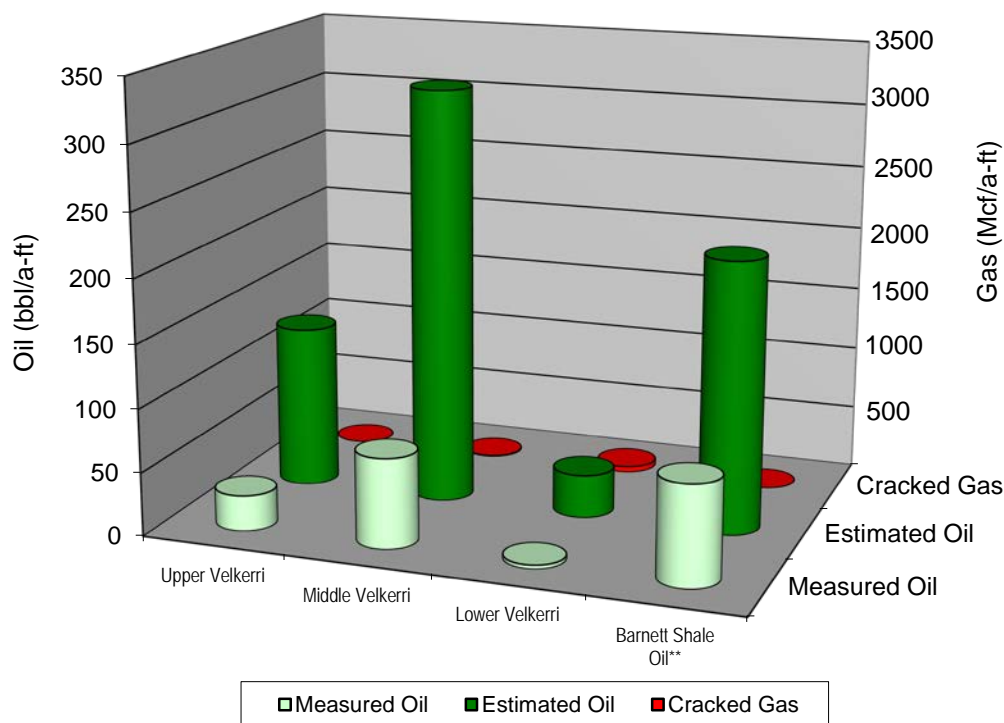


Figure 3. Hydrocarbon yield estimates for the Mesoproterozoic source rocks in the Alexander 1 well compared to Barnett Shale in the oil window.

GEOCHEMICAL SUMMARY

The Middle Velkerri source interval in the Alexander 1 well is interpreted to represent low geochemical risk for unconventional shale oil development. It clearly has elevated organic richness (avg. 4.31 wt.% TOC) and is considered an excellent source rock with dominantly oil-prone Type II kerogen. Thermal maturity parameters indicate that the source interval is in the peak oil window, 0.74% Calc. R_o , and key risk ratios are above recommended minimum thresholds for shale oil systems. The Middle Velkerri has likely generated significant amounts of oil (avg. 326 bbl oil/acre-ft) and comparison to other systems such as the Barnett Shale show in-situ oil saturations are generally comparable for the Middle Velkerri. Risk criteria like the S1 versus TOC show oil cross-over for many samples in the middle of this unit between the depths of 363-413 m. Further evaluation of in-situ oil characteristics would be required to fully evaluate potential oil mobility and recovery risk.

The other Velkerri source rock intervals evaluated in the Alexander 1 well generally have higher risk in comparison to the Middle Velkerri. Both of these horizons have lower organic richness, with the Upper Velkerri (avg. 1.42 wt.% TOC) being above the minimum threshold for shale oil and the Lower Velkerri (avg. 0.35 wt. % TOC) far below the threshold. The estimated generated oil is higher in the Upper Velkerri and the basal portion of this interval has generally higher TOC and in-situ oil saturation which would be considered a potential unconventional shale oil target.

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Appendix I

Hydrocarbon Yield Calculation

Shelf Group

Alexander 1

McArthur Basin Integrated Petroleum Geochemistry, 2016

Northern Territory Geological Survey - Australia



Alexander-1
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
Alexander-1	(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
1329950	102	0.78	141	0.33	1.10	0.69	0.23	0	0	100	0	450	0.78	1.00	4.50	24	99	0.00	7	74	0
1329880	112	1.44	97	1.56	1.40	0.54	0.53	0	0	100	0	450	0.86	1.92	8.66	31	190	0.00	34	159	0
HD14DJR031	120	1.49	26	0.10	0.38	0.70	0.21	0	0	100	0	450	0.96	2.01	9.03	8	198	0.00	2	189	0
1329879	142	0.78	436	0.42	3.40	0.67	0.11	0	0	75	25	525	0.30	0.86	4.52	74	99	0.00	9	25	0
1329951	152	0.72	185	0.53	1.33	0.60	0.28	0	0	100	0	450	0.71	0.91	4.11	29	90	0.00	12	61	0
1329878	162	0.70	190	0.48	1.33	0.69	0.27	0	0	100	0	450	0.70	0.88	3.97	29	87	0.00	11	58	0
1329952	173	0.99	218	0.61	2.16	0.58	0.22	0	0	100	0	450	0.64	1.22	5.49	47	120	0.00	13	73	0
HD14DJR033	178	2.46	11	0.07	0.26	0.64	0.21	0	0	100	0	450	0.99	3.32	14.92	6	327	0.00	2	321	0
1329954	183	1.50	216	1.01	3.24	0.74	0.24	0	0	100	0	450	0.65	1.85	8.34	71	183	0.00	22	112	0
	183	0.58	55	0.19	0.32	0.62	0.37	0	0	100	0	450	0.92	0.78	3.51	7	77	0.00	4	70	0
1329953	193	2.10	274	2.16	5.76	0.65	0.27	0	0	100	0	450	0.54	2.54	11.44	126	251	0.00	47	124	0
1329877	203	0.68	143	0.58	0.97	0.63	0.37	0	0	100	0	450	0.78	0.89	3.99	21	87	0.00	13	66	0
1329962	213	2.15	280	2.48	6.03	0.62	0.29	0	0	100	0	450	0.53	2.61	11.74	132	257	0.00	54	125	0
HD14DJR035	217	2.25	123	0.92	2.76	0.54	0.25	0	0	100	0	450	0.81	2.90	13.03	60	285	0.00	20	225	0
1329961	223	1.39	263	3.43	3.65	0.62	0.48	0	0	100	0	450	0.58	1.78	8.02	80	176	0.00	75	96	0
	223	1.52	121	1.19	1.84	0.60	0.39	0	0	100	0	450	0.82	1.99	8.97	40	196	0.00	26	156	0
1329960	253	1.54	193	2.65	2.97	0.42	0.47	0	0	100	0	450	0.70	2.00	9.00	65	197	0.00	58	132	0
1329959	263	0.61	161	1.33	0.98	0.62	0.58	0	0	100	0	450	0.76	0.81	3.66	21	80	0.00	29	59	0
1329958	273	1.69	179	2.87	3.03	0.63	0.49	0	0	100	0	450	0.73	2.21	9.93	66	217	0.00	63	151	0
HD14DJR036	278	3.03	143	2.87	4.34	0.57	0.40	0	0	100	0	450	0.78	3.92	17.64	95	386	0.00	63	291	0
Upper Velkerri (Avg)		1.42	173	1.29	2.36	0.62	0.33	0	0	99	1	454	0.73	1.82	8.22	52	180	0.00	28	128	0
1329957	283	4.35	277	3.96	12.07	0.65	0.25	0	0	100	0	450	0.53	5.19	23.34	264	511	0.00	87	247	0
HD14DJR037	288	4.63	179	2.29	8.30	0.57	0.22	0	0	100	0	450	0.71	5.72	25.76	182	564	0.00	50	382	0
1329956	293	5.75	241	2.87	13.84	0.67	0.17	0	0	100	0	450	0.59	6.82	30.70	303	672	0.00	63	369	0
	293	6.37	223	3.28	14.23	0.58	0.19	0	0	100	0	450	0.63	7.63	34.32	312	752	0.00	72	440	0
	296	5.74	174	1.62	9.98	0.56	0.14	0	0	100	0	450	0.72	7.00	31.51	219	690	0.00	35	471	0
1329955	303	6.90	239	2.78	16.50	0.67	0.14	0	0	100	0	450	0.59	8.12	36.52	361	800	0.00	61	438	0
1329843	313	5.45	221	4.37	12.04	0.76	0.27	0	0	100	0	450	0.64	6.65	29.94	264	656	0.00	96	392	0
1329842	323	3.25	230	2.75	7.46	0.71	0.27	0	0	100	0	450	0.62	3.99	17.96	163	393	0.00	60	230	0
1329841	333	4.90	234	4.35	11.45	0.74	0.28	0	0	100	0	450	0.62	5.97	26.89	251	589	0.00	95	338	0
1329840	333	4.25	411	4.17	17.48	0.89	0.19	0	0	75	25	525	0.38	4.87	25.59	383	560	0.00	91	178	0
1329839	343	5.10	251	3.77	12.82	0.87	0.23	0	0	100	0	450	0.58	6.11	27.50	281	602	0.00	83	322	0
	343	4.35	252	2.29	10.96	0.74	0.17	0	0	100	0	450	0.57	5.16	23.21	240	508	0.00	50	268	0
HD14DJR038	348	7.78	216	3.33	16.79	0.72	0.17	0	0	100	0	450	0.64	9.26	41.69	368	913	0.00	73	545	0
1329838	353	4.65	247	3.92	11.48	0.87	0.25	0	0	100	0	450	0.59	5.62	25.29	251	554	0.00	86	302	0
1329837	363	3.10	204	4.30	6.32	0.98	0.40	0	0	100	0	450	0.68	3.94	17.74	138	388	0.06	94	235	88
1329893	373	3.85	191	5.34	7.34	0.81	0.42	0	0	100	0	450	0.70	4.91	22.09	161	484	0.00	117	323	0
1329866	383	4.90	219	6.42	10.72	0.85	0.37	0	0	100	0	450	0.65	6.12	27.54	235	603	0.00	141	368	0
	383	3.90	197	3.59	7.70	0.76	0.32	0	0	100	0	450	0.69	4.88	21.95	169	481	0.00	79	312	0
1329865	393	1.66	191	2.63	3.17	0.71	0.45	0	0	100	0	450	0.71	2.15	9.67	69	212	0.00	58	142	0
HD14DJR040	400	2.64	174	2.34	4.60	0.81	0.34	0	0	100	0	450	0.73	3.36	15.12	101	331	0.00	51	230	0
1329864	403	2.35	169	3.22	3.98	0.98	0.45	0	0	100	0	450	0.74	3.05	13.71	87	300	0.06	71	201	75
1329863	413	1.03	183	1.57	1.88	0.74	0.46	0	0	100	0	450	0.72	1.34	6.04	41	132	0.00	34	91	0
1329862	423	4.35	172	3.40	7.49	0.71	0.31	0	0	100	0	450	0.73	5.48	24.64	164	540	0.00	74	376	0
	423	4.25	98	1.47	4.15	0.47	0.26	0	0	100	0	450	0.85	5.48	24.65	91	540	0.00	32	449	0
	426	4.37	132	2.46	5.78	0.65	0.30	0	0	100	0	450	0.80	5.57	25.08	127	549	0.00	54	423	0
1329861	433	3.60	170	3.18	6.12	0.87	0.34	0	0	100	0	450	0.74	4.57	20.57	134	450	0.00	70	316	0
HD14DJR041	438	4.79	91	1.79	4.38	0.41	0.29	0	0	100	0	450	0.86	6.19	27.83	96	610	0.00	39	514	0
1329860	443	2.50	147	3.12	3.67	0.94	0.46	0	0	100	0	450	0.78	3.26	14.68	80	322	0.03	68	233	47
Middle Velkerri (Avg)		4.31	205	3.24	9.03	0.74	0.29	0	0	99	1	453	0.67	5.30	23.98	198	525	0.01	71	326	7
1329859	453	0.16	200	0.25	0.32	1.08	0.44	0	0	100	0	450	0.69	0.21	0.93	7	20	0.16	5	11	13
1329851	463	0.24	117	0.12	0.28	1.08	0.30	0	0	100	0	450	0.82	0.31	1.41	6	31	0.16	3	21	23
	463	0.26	31	0.07	0.08	1.08	0.47	0	0	100	0	450	0.96	0.35	1.59	2	35	0.16	2	28	31
1329850	473	0.13	131	0.05	0.17	1.08	0.23	0	0	100	0	450	0.80	0.17	0.76	4	17	0.16	1	11	12
1329849	483	0.13	192	0.05	0.25	1.08	0.17	0	0	100	0	450	0.69	0.16	0.73	5	16	0.16	1	9	10
1395384	493	0.13	162	0.04	0.21	1.08	0.16	0	0	100	0	450	0.74	0.16	0.74	5	16	0.16	1	10	11
	502	0.16	13	0.05	0.02	1.08	0.71	0	0	100	0	450	0.98	0.22	0.99	0	22	0.16	1	18	20
1329848	503	0.10	110	0.03	0.11	1.08	0.21	0	0	100	0	450	0.83	0.13	0.59	2	13	0.16	1	9	10
1329847	513	0.08	263	0.05	0.21	1.08	0.19	0	0	100	0	450	0.55	0.10	0.43	5	9	0.16	1	4	5

Alexander-1
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
Alexander-1	(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
1329846	523	0.07	229	0.05	0.16	1.08	0.24	0	0	100	0	450	0.62	0.09	0.39	4	9	0.16	1	4	5
1329845	533	0.28	375	0.34	1.05	1.08	0.24	0	0	100	0	450	0.31	0.32	1.45	23	32	0.16	7	7	8
1329844	543	0.08	213	0.04	0.17	1.08	0.19	0	0	100	0	450	0.65	0.10	0.44	4	10	0.16	1	5	6
1329858	553	0.20	30	0.04	0.06	1.08	0.40	0	0	100	0	450	0.96	0.27	1.22	1	27	0.16	1	22	24
HD14DJR043	558	0.89	29	0.10	0.26	1.08	0.28	0	0	100	0	450	0.96	1.21	5.44	6	119	0.16	2	96	105
1329857	563	0.22	77	0.13	0.17	1.08	0.43	0	0	100	0	450	0.89	0.30	1.33	4	29	0.16	3	21	24
1329856	573	0.60	50	0.26	0.30	1.08	0.46	0	0	100	0	450	0.93	0.81	3.65	7	80	0.16	6	62	68
1329855	593	0.89	62	0.32	0.55	0.96	0.37	0	0	100	0	450	0.91	1.19	5.36	12	117	0.04	7	101	28
1329854	603	1.79	54	0.54	0.97	1.19	0.36	0	0	100	0	450	0.92	2.39	10.76	21	236	0.29	12	153	367
HD14DJR045	609	0.40	10	0.02	0.04	1.08	0.33	0	0	100	0	450	0.99	0.55	2.48	1	54	0.16	0	45	50
1329853	613	0.46	24	0.11	0.11	1.08	0.50	0	0	100	0	450	0.97	0.63	2.82	2	62	0.16	2	50	55
Lower Velkerri (Avg)		0.36	118	0.13	0.27	1.08	0.33	0	0	100	0	450	0.81	0.48	2.18	6	48	0.16	3	34	44
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)