Altree 2 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 Altree 2 well located in the Beetaloo Sub-Basin, Northern Territories, Australia. Five (5) 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 241 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
Altree 2	Upper Velkerri	**Estimated Original** →		Very Good (2.27% TOC)	Oil-prone Type II	Moderate
Measured Currently →		Minor Oil	Early Oil Window	↓ Good (1.02% TOC)	↓ Oil-prone Type II	
Altree 2	Middle Velkerri	**Estimated Original** →		Excellent (5.10% TOC)	Oil-prone Type II	Low
Measured Currently →		Oil	Early Oil Window	↓ Very Good (3.75% TOC)	↓ Mixed Type II/III	
Altree 2	Lower Velkerri	**Estimated Original** →		Very Good (2.20% TOC)	Oil-prone Type II	High
Measured Currently →		Light Oil Wet Gas	Wet Gas Window	↓ Fair (0.56% 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

One sample (1) from the Upper Velkerri Formation was analyzed for LECO TOC content and programmed pyrolysis, with the remaining data set (84 samples) composed of client supplied public data (Fig. 1). TOC contents ranged from 0.27 to 5.08 wt.% and averaged 1.02 wt.% (good). Nineteen (19) of these samples have TOC contents above the minimum requirement of 1 wt.% for *effective* petroleum source rocks, while eleven (11) 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 (> 600 m depth) and increases dramatically at the contact with the underlying Middle Velkerri Formation (Fig. 1). Most of the upper section of this interval has TOC content < 1 wt.% and is considered to have only fair to poor source potential (Fig. 1).

The S1 values of the Upper Velkerri source rock samples average 1.54 mg HC/g rock (34 bbl oil/acre-ft) and S2 values average 7.83 mg HC/g rock (171 bbl oil/acre-ft). The S1 and S2 values imply good in-situ hydrocarbon saturation and generative potential, but like TOC this is generally restricted to the basal section of the sampled interval (Fig. 1). The normalized oil content (NOC) in the Upper Velkerri samples, (S1/TOC) x 100, averages 77 (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 601.28 m and the interval between 638.60−661.47 m (Fig. 1) in the Upper Velkerri Formation.

Measured Hydrogen Index (HI) values in the Upper Velkerri average 337 mg HC/g TOC, indicating oil-prone Type II kerogen quality in these source rocks at present day. Depth trends show elevated HI values are restricted to the basal section of this source rock interval where TOC values are also highest (Fig. 1). Original HI_o of these samples are estimated to average 489 mg HC/g rock, which also indicate oil-prone Type II kerogen and suggests that thermal maturity levels are moderate. Transformation Ratios (TR) based upon HI average only 46%, which is consistent with an early oil window thermal maturity. T_{max} values in the Upper Velkerri samples average 435°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 435°C is equivalent to a Calc. $\%R_o$ value of 0.68%. 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 0.17. These moderate PI values are consistent with source rocks in the peak oil window, which typically have PI values between ~0.15 to 0.25. Samples in the late oil window tend to have elevated PI values in the range of 0.25 to 0.35, which is more consistent with higher in-situ hydrocarbon saturations. It is noteworthy that samples in the depth range of 638.60−661.47 m do have elevated PI values between 0.19 and 0.30 that is consistent with their elevated NOC and suggest possible producible in-situ oil saturation within this horizon.

MIDDLE VELKERRI FORMATION

Two samples (2) from the Middle Velkerri Formation were analyzed for LECO TOC content and programmed pyrolysis, with the remaining data set (132 samples) composed of client supplied public data (Fig. 1). The Middle Velkerri Formation in the Altree 2 well exhibits very good generative potential for petroleum source rocks based on TOC content values (Fig. 1). TOC content ranges from 0.30 to 8.63 wt.% and averages 3.75 wt.%. One hundred thirty-two (132) 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 710.15, 814.40 and 922.59 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 2.46 mg HC/g rock (54 bbl oil/acre-ft), indicating very good in-situ hydrocarbon saturation (Fig. 1) and are consistent with a thermal maturity in the early 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 56. Oil cross over (NOC > 100) was observed for many samples in the middle of this unit between the depths of 845.00−918.75 m (Fig. 1), which suggests possible producible hydrocarbons at these depths. The S2 values in this interval average 12.92 mg HC/g rock (283 bbl oil/acre-ft), which indicates very good remaining generative potential.

Measured HI values in these samples average 274 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 456 mg HC/g TOC, which indicate oil-prone Type II kerogen quality. This is

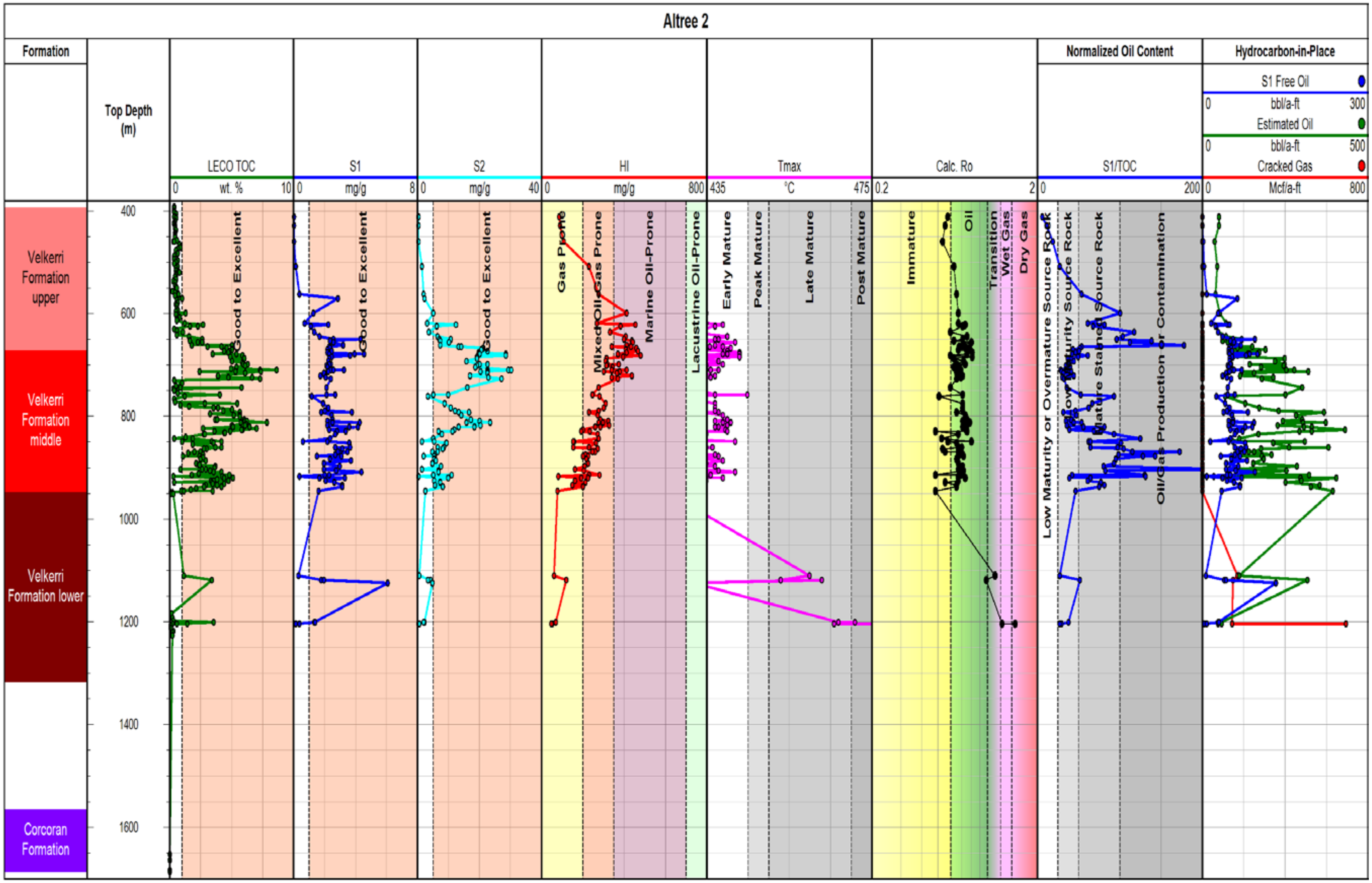

Figure 1. Geochemical depth plots for the Altree 2 well.

consistent with elemental analyses of select kerogen samples from the Middle Velkerri that have average H/C ratios of 1.36, which is typical for Type II kerogen. Transformation Ratios (TR) based upon HI average only 52%, which is consistent with an early oil window thermal maturity.

The organic-matter in the Middle Velkerri interval in the Altree 2 well is thermally mature and is interpreted to be in the early oil window. Programmed pyrolysis T_{max} values average 435°C (Fig. 1). 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 435°C is equivalent to a Calc. %R_o value of 0.67%. 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 0.21. These elevated PI values are consistent with source rocks in the peak 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 (18 samples) composed of client supplied public data (Fig. 1). TOC contents ranged from 0.10 to 3.44 wt.% and averaged 0.56 wt.% (fair). Only three (3) of these samples have TOC contents above the minimum requirement of 1 wt.% for *effective* petroleum source rocks, and only one (1) sample exceeds the minimum requirement of 2 wt.% for *economic* petroleum source rocks. The highest measured TOC content is near the middle of the designated Lower Velkerri interval (1120 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 0.68 mg HC/g rock (15 bbl oil/acre-ft) and S2 values are also low with an average 1.51 mg HC/g rock (33 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 1120 m depth (Fig. 1). The normalized oil content (NOC) in the Lower Velkerri samples average 41 (Fig. 1) and there is no oil "cross-over" observed. This would be interpreted to represent zones with low potential for containing producible hydrocarbon saturation.

Measured Hydrogen Index (HI) values in the Lower Velkerri average only 72 mg HC/g TOC, indicating gas-prone Type III kerogen quality in these source rocks at present day (Fig. 1). 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 89%, which is consistent with a wet gas/condensate window thermal maturity. T_{max} values in the Lower Velkerri samples average 465°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 (Calculated R_o = (0.0180)(T_{max}) – 7.16), the average measured T_{max} value of 465°C is equivalent to a Calc. %R_o value of 1.20%. 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. However, the thermal maturity assessment of this interval is supported by a variety of thermal maturity indices.

It is highly unusual to suggest that the Lower Velkerri interval would have such a relatively high thermal maturity in comparison to the overlying intervals, which appear to be only into the early oil window. One possible explanation is that this may be a consequence of a localized heating event initiated by dolerite sill emplacement within the formation. This has been suggested by Taylor et al. (1994) for well locations in the northwest portion of the Beetaloo Sub-basin and may be applicable to the Lower Velkerri Formation in the Altree 2 well. Further geologic documentation would be necessary to confirm this hypothesis. A dolorite sill has been noted deeper in the Altree 2 well between 1688.23-1699.85 m depths, which is below the Corcoran Formation that underlies the Lower Velkerri. Given the depth separation, it is unlikely that this particular volcanic intrusive would have much effect on thermal maturity within the Lower Velkerri. Regardless, it is clear that there are distinct differences between the geochemical maturity indices in the Lower Velkerri Formation in comparison to overlying units in this well.

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):

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

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	13	87	0	0	489
Middle Velkerri	2	98	0	0	456
Lower Velkerri	0	100	0	0	450

Table 2. Average Kerogen Estimations for Altree 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):

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

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 489 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 0.46 to 0.89 (Table 3), i.e., on average an estimated 46 to 89% 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 2.20 to 5.10 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 Altree 2 well, the average $S2_o$ values vary from 9.9 to 23.3 mg HC/g rock or approximately 216 to 510 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 227 bbl/acre-ft. The generated oil yield from overlying Upper Velkerri was lower with an average value of only 78 bbl/acre-ft. The average generated oil yield from the Lower Velkerri averaged 135 bbl/acre-ft along with 290 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	2.00	337	177	489	0.46	2.27	250	34	78	0
Middle Velkerri	4.41	274	283	456	0.52	5.10	510	54	227	0
Lower Velkerri	1.68	72	33	450	0.89	2.20	216	15	135	290

Table 3. Hydrocarbon Yields average data for Altree 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 57% in the Upper unit, 76% in the Middle and 92% 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 Altree 2 well are interpreted to be in the early oil window and hydrocarbon yield calculations suggest minor to significant amounts of generation have occurred (predominantly oil with some presumed associated gas). From an exploration risk perspective, this is favorable. In the Lower Velkerri, hydrocarbon yield estimates suggest moderate 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 510 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 216 to 250 bbl oil/acre-ft and these two units do not compare favorably with other unconventional US Shale plays.

Sample Database Averages TOC >1%	HI° mg/g TOC	TR	TOC° wt%	S2° 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	489	0.46	2.27	11.41	171	250	0.00	34	78	0
Middle Velkerri	456	0.52	5.10	23.30	283	510	0.00	54	227	0
Lower Velkerri	450	0.89	2.20	9.88	33	216	0.32	15	135	290

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 Middle Velkerri Formation (850 m depth). In this instance the SRP oil saturations are much lower than those determined by SRA methods using the S1 yields. The saturation determined by SRP was 0.31 mg oil/g AR Rock (7 bbl oil/acre-ft), while that determined from S1 yields on the same sample is 0.65 mg oil/g AR Rock (14 bbl oil/acre-ft). This observation is rather unusual, because the S1 usually underestimates the total hydrocarbons extracted using Dean-Stark methods (toluene) due to the inclusion of non-volatile polar and asphaltene components of the extracted in-situ oil/bitumen saturation. 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 Altree 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. 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 HI_o estimates using measured and interpreted fractional composition of kerogen macerals.

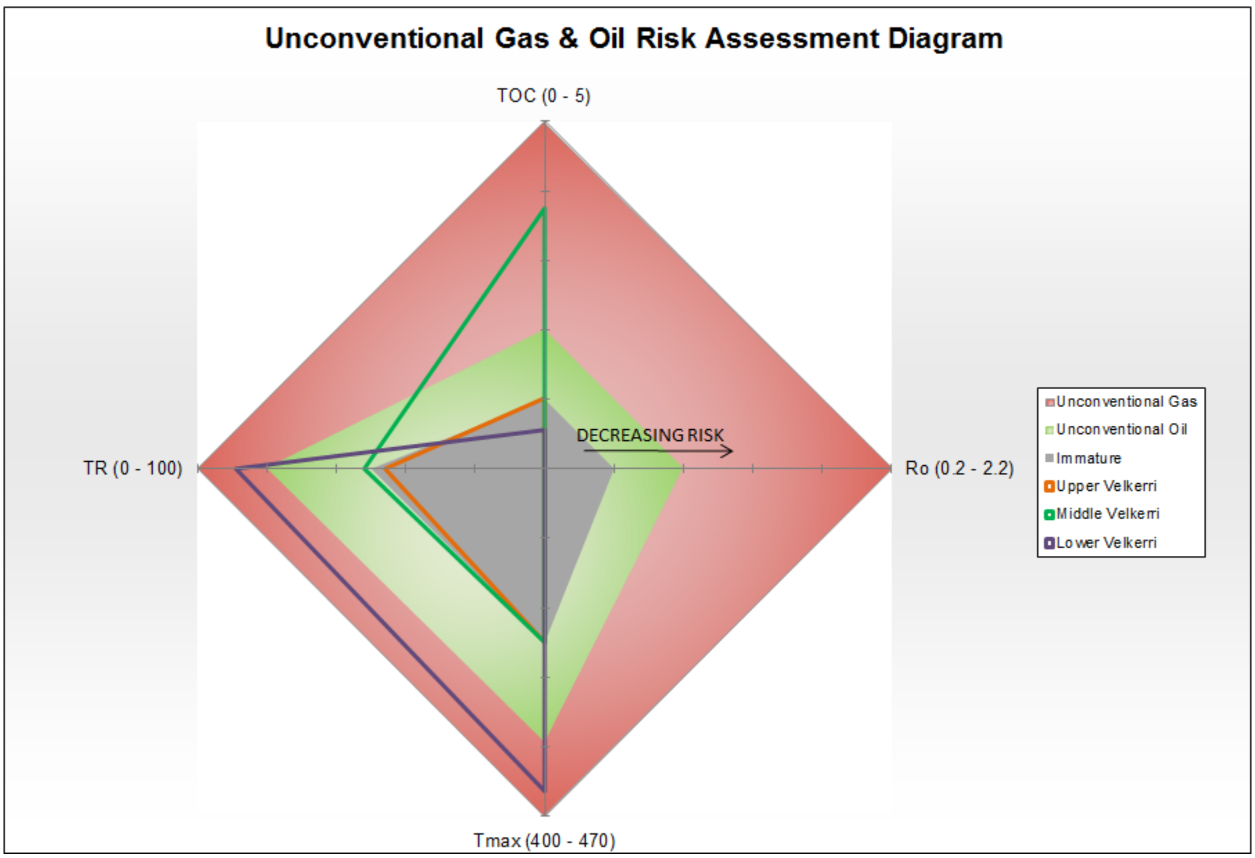

Figure 2. Geochemical Risk Assessment diagram for Mesoproterozoic Velkerri Formation source rocks in the Altree 2 well.

The Middle Velkerri source rock interval in the Altree 2 well is interpreted to represent a low geochemical risk for in-situ shale oil production. The average TOC content of 3.75 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 early oil window. The average Tmax value of 435°C is right at 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 minor to significant amounts of hydrocarbons from this organic-rich, oil prone source facies. Transformation Ratios (TR), the least constrained risk parameter, average 52% and fall just 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).

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 1.02 wt.% and thermal maturity indicators suggest early window maturity. On the risk assessment diagram, average Tmax value of 435°C is right at the recommended minimum value of 435°C for shale oil, but the Transformation Ratio of 46% is slightly below 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 0.56 wt.%. This is far below the recommended minimum for *effective* source rocks and plot on the risk assessment diagram in unfavorable location for shale oil. Furthermore, measured in-situ oil saturation in this source rock interval is low (avg. 15 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 an anomalously high maturity within the early wet gas/condensate window. On the risk assessment diagram the Tmax value of 465°C and Transformation Ratio of 89% are well 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. 54 bbl oil/acre-ft), suggesting low risk for shale oil development (Fig. 3). This is mitigated somewhat by the low in-situ hydrocarbon saturations determined from SRP analysis (7 bbl oil/acre-ft), although this single sample may not be representative of the entire interval. Hydrocarbon yield calculations on as-received samples show estimates of average generated oil from the Middle Velkerri at 227 bbl oil/acre-ft. 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 thermal maturity (Barnett Shale oil example is at a peak oil widow maturity of 0.86% VR_o).

In the Upper Velkerri source interval measured in-situ oil saturation from S1 yields is generally good (avg. 34 bbl oil/acre-ft), but estimated generated oil yields are quite low (avg. 78 bbl oil/acre-ft) due to marginal organic richness (Fig. 3). The Lower Velkerri has the lowest measured in-situ oil saturation (15 bbl oil/acre-ft), but this could be a partial consequence of elevated thermal maturity and loss of volatile oil saturation. Estimated generated oil is fairly elevated (135 bbl oil/acre-ft) along with some minor amounts of secondary cracked gas (290 Mcf/acre-ft). While these average values may seem somewhat attractive, it should be noted that they are skewed by a single high TOC sample at 1120 m depth and thus may not be entirely representative of the overall potential of the unit.

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 oil window and hydrocarbon saturation is likely to be moderately heavy. 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.

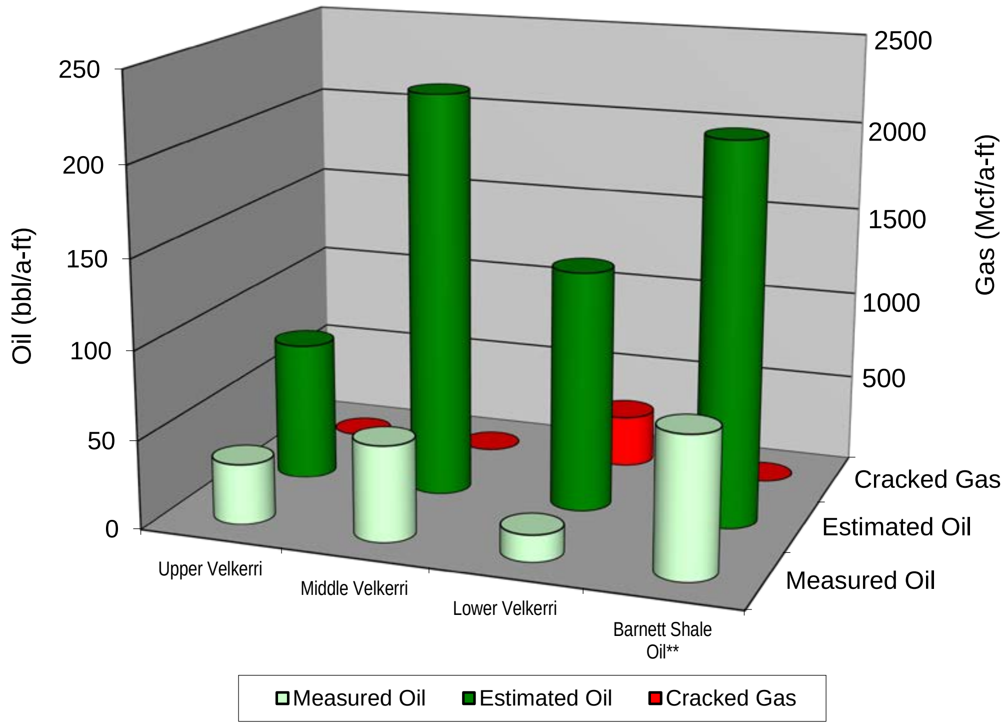

Figure 3. Hydrocarbon yield estimates for the Mesoproterozoic source rocks in the Altree 2 well compared to Barnett Shale in the oil window.

Geochemical Summary

The Middle Velkerri source interval in the Altree 2 well is interpreted to represent low geochemical risk for unconventional shale oil development. It clearly has elevated organic richness (avg. 3.75 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 early oil window, 0.67% Calc. R_o, and key risk ratios are at or above recommended minimum thresholds for shale oil systems. While the Middle Velkerri has likely generated significant amounts of oil (avg. 227 bbl oil/acre-ft), comparison to other systems such as the Barnett Shale show in-situ oil saturations are generally lower 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 845.00−918.75 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 Altree 2 well generally have higher risk in comparison to the Middle Velkerri. Both of these horizons have marginal organic richness, with the Upper

Velkerri (avg. 1.02 wt% TOC) being just above the minimum threshold for shale oil and the Lower Velkerri (avg. 0.56 wt. % TOC) far below the threshold. The estimated generated oil is higher in the Lower Velkerri but this may be skewed by sampling bias and measured in-situ oil saturation is low. The basal portion of the Upper Velkerri has generally higher TOC and in-situ oil saturation and would be considered a potential unconventional shale oil target.

REFERENCES CITED

Bohacs, K., J. Macquaker, G. Grabowski, R. Lazar, and T. Demko, 2013, Local expression of regional and global factors in mudstone-reservoir occurrence, character, and distribution in Toarcian Platform/Ramp source-rock settings, NW Europe, Houston Geological Society – Applied Geoscience Conference, February 18-19.

Crick I. H., Boreham, C. J., Cook, A. C. and Powell, T.G., 1988,Petroleum geology and geochemistry of Middle Proterozoic McArthur Basin, Northern Territory II: Assessment of source rock potential. American Association of Petroleum Geologists, Bulletin 72(12), 1495–1514.

Jarvie, D. M., 2012, Shale resource systems for oil and gas: Part 2 – shale-oil resource systems, *in* Breyer, J.A., ed., Shale reservoirs—giant resources for the 21st century: AAPG Memoir 97, CD-ROM Material, p. 89-119.

Jarvie, D. M., Hill, R.J., Ruble, T.E., and Pollastro, R.M., 2007, Unconventional shale gas systems: the Mississippian Barnett Shale of north-central Texas as one model for thermogenic shale-gas assessment, American Association of Petroleum Geologists Bulletin, v. 91, p. 475-499.

Jarvie, D. M. and Tobey, M H., 1999, TOC, Rock-Eval, or SR Analyzer Interpretive Guidelines: Application Note 99-4: Weatherford Laboratories, 16 p.

Lanigan, K., Hibbird, S., Menpes, S. and Torkington, J., 1994. Petroleum exploration in the Proterozoic Beetaloo Sub‐basin, Northern Territory. APEA Journal 34, 674 –691.

Law, B. E., Ahlbrandt, T. and Hoyer, D., 2010, Source and reservoir rock attributes of Mesoproterozoic shale, Beetaloo Basin, Northern Territory, Australia. Search and Discovery Article #110130 (14 June 2010). Adapted from oral presentation at session: Genesis of shale gas – physicochemical and geochemical constraints affecting methane adsorption and desorption, at AAPG Annual Convention, New Orleans, Louisiana, April 11–14, 2010.
http://www.searchanddiscovery.com/documents/2010/110130law/ndx_law.pdf

Lewan, M. D.,1987, Petrographic study of primary petroleum migration in the Woodford Shale and related rock units, *in* B. Doligez, ed., Migration of hydrocarbons in sedimentary basins, 2nd Edition, IFP Exploration Research Conference, Carcans, France, June 15-19, 1987, p. 113-130.

Peters, K. E., 1986, Guidelines for evaluating petroleum source rocks using programmed pyrolysis, AAPG Bulletin, v 70, p. 318-329.

Peters, K. E., C. C. Walters, and M. Moldowan, 2005, The biomarker guide, 2nd Edition, Volumes 1 and 2, Cambridge University Press, 1155 p.

Taylor, D. P., Kontorovich, A. E., Larichev, A. I. and Glikson, M., 1994. Petroleum source rocks in the Roper Group of the McArthur Basin: Source characterisation and maturity determinations using physical and chemical methods. APEA Journal 34, 279 –296.

Appendix I

Hydrocarbon Yield Calculation
Beetaloo Sub-Basin Group
Altree 2

McArthur Basin Integrated Petroleum Geochemistry, 2016

Northern Territory Geological Survey - Australia

Weatherford LABORATORIES

Altree-2

Hydrocarbon Yield Calculation

																S2 (meas)	S2 (orig)				
Sample	Top Depth	TOC*	HI*	S1*	S2*	Calc.Ro	PI*	%Type IV 50 HI°	% Type III 125 HI°	%Type II 450 HI°	%Type I 750 HI°	HI°	TR	TOC°	S2°	Remaining Potential	Original Potential	Oil Cracked	S1 Free Oil	Estimated Oil	Cracked Gas
Altree-2	(m)	wt%	mg/g TOC	mg/g Rock	mg/g Rock	%						mg/g TOC		wt%	mg/g Rock	bbl/a-ft	bbl/a-ft	%	bbl/a-ft	bbl/a-ft	Mcf/a-ft
	412	0.46	88	0.03	0.40	***0.58***	0.07	0	0	100	0	450	0.87	0.59	2.67	9	58	0.00	1	50	0
	430	0.47	92	0.06	0.43	***0.56***	0.12	0	0	100	0	450	0.86	0.61	2.74	9	60	0.00	1	51	0
	460	0.36	107	0.07	0.39	***0.54***	0.15	0	0	100	0	450	0.84	0.47	2.12	9	46	0.00	1	38	0
1394454	509	0.69	233	0.19	1.61	***0.63***	0.11	0	0	100	0	450	0.60	0.82	3.71	35	81	0.00	4	46	0
1394469	563	0.72	279	0.39	2.01	***0.65***	0.16	0	0	100	0	450	0.51	0.85	3.82	44	84	0.00	9	40	0
1394479	601	1.29	413	1.30	5.33	***0.67***	0.20	0	0	75	25	525	0.38	1.49	7.84	117	172	0.00	28	55	0
1394484	620	1.23	269	0.76	3.31	***0.67***	0.19	0	0	100	0	450	0.54	1.47	6.59	72	144	0.00	17	72	0
1394485	623	2.76	455	2.25	12.57	***0.74***	0.15	0	0	75	25	525	0.27	3.06	16.07	275	352	0.00	49	77	0
1394486	627	1.67	383	1.14	6.40	***0.71***	0.15	0	0	100	0	450	0.26	1.85	8.31	140	182	0.00	25	42	0
1394489	639	1.14	334	1.34	3.81	***0.60***	0.26	0	0	100	0	450	0.41	1.34	6.05	83	132	0.00	29	49	0
1394491	646	1.63	409	1.70	6.67	***0.76***	0.20	0	0	75	25	525	0.39	1.89	9.94	146	218	0.00	37	72	0
1394492	650	2.68	402	2.58	10.78	***0.71***	0.19	0	0	75	25	525	0.40	3.10	16.28	236	356	0.00	57	120	0
1394493	654	1.70	441	2.36	7.50	***0.63***	0.24	0	0	75	25	525	0.33	1.98	10.38	164	227	0.00	52	63	0
1394494	658	2.33	445	2.61	10.37	***0.80***	0.20	0	0	75	25	525	0.31	2.66	13.95	227	305	0.00	57	78	0
1394495	661	1.82	414	3.24	7.53	***0.71***	0.30	0	0	75	25	525	0.41	2.19	11.50	165	252	0.00	71	87	0
1394496	665	3.06	434	2.36	13.27	***0.74***	0.15	0	0	75	25	525	0.32	3.43	17.99	291	394	0.00	52	103	0
HD14DJR085	666	4.20	341	2.29	14.32	***0.68***	0.14	0	0	100	0	450	0.37	4.71	21.19	314	464	0.00	50	151	0
1394497	669	4.62	461	2.40	21.31	***0.78***	0.10	0	0	75	25	525	0.23	4.98	26.13	467	572	0.00	53	106	0
243724V	671	5.08	408	2.20	20.73	***0.67***	0.10	0	0	75	25	525	0.36	5.61	29.44	454	645	0.00	48	191	0
Upper Velkerri (Avg)		**2.00**	**337**	**1.54**	**7.83**	**0.68**	**0.17**	**0**	**0**	**87**	**13**	**489**	**0.46**	**2.27**	**11.41**	**171**	**250**	**0.00**	**34**	**78**	**0**
1394498	673	4.82	468	2.47	22.56	**0.76**	0.10	0	0	75	25	525	0.21	5.17	27.13	494	594	0.00	54	100	0
1394499	677	4.80	414	2.23	19.89	**0.81**	0.10	0	0	75	25	525	0.35	5.30	27.80	436	609	0.00	49	173	0
1394500	681	5.43	372	2.29	20.20	**0.76**	0.10	0	0	100	0	450	0.28	5.90	26.54	442	581	0.00	50	139	0
	682	5.93	481	3.65	28.51	**0.60**	0.11	0	0	75	25	525	0.19	6.35	33.36	624	730	0.00	80	106	0
1394501	684	4.90	397	2.47	19.45	**0.81**	0.11	0	0	100	0	450	0.21	5.27	23.72	426	519	0.00	54	93	0
1394502	688	6.07	316	2.29	19.18	**0.63**	0.11	0	0	100	0	450	0.42	6.81	30.63	420	671	0.00	50	251	0
1394503	695	5.07	312	2.27	15.80	**0.72**	0.13	0	0	100	0	450	0.43	5.74	25.85	346	566	0.00	50	220	0
1394504	699	6.30	321	2.45	20.23	**0.65**	0.11	0	0	100	0	450	0.41	7.04	31.70	443	694	0.00	54	251	0
243724O	701	6.00	377	2.33	22.59	**0.74**	0.09	0	0	100	0	450	0.26	6.47	29.13	495	638	0.00	51	143	0
1394505	703	6.12	318	2.15	19.45	**0.67**	0.10	0	0	100	0	450	0.41	6.84	30.79	426	674	0.00	47	248	0
1394506	706	5.38	346	2.19	18.63	**0.63**	0.11	0	0	100	0	450	0.34	5.94	26.72	408	585	0.00	48	177	0
1394507	710	8.63	343	2.44	29.60	**0.69**	0.08	0	0	100	0	450	0.34	9.40	42.28	648	926	0.00	53	278	0
243724M	711	7.34	413	2.61	30.31	**0.67**	0.08	0	0	75	25	525	0.34	7.99	41.95	664	919	0.00	57	255	0
1394508	713	5.34	382	2.20	20.39	**0.65**	0.10	0	0	100	0	450	0.25	5.76	25.91	447	567	0.00	48	121	0
	715	7.42	306	2.24	22.70	**0.65**	0.09	0	0	100	0	450	0.44	8.30	37.36	497	818	0.00	49	321	0
1394509	718	6.15	368	1.98	22.65	**0.65**	0.08	0	0	100	0	450	0.28	6.64	29.86	496	654	0.00	43	158	0
1394510	722	3.91	438	1.73	17.13	**0.71**	0.09	0	0	75	25	525	0.29	4.25	22.32	375	489	0.00	38	114	0
1394511	725	6.66	344	2.07	22.92	**0.69**	0.08	0	0	100	0	450	0.34	7.29	32.80	502	718	0.00	45	216	0
243724J	727	7.35	372	2.45	27.32	**0.65**	0.08	0	0	100	0	450	0.27	7.91	35.57	598	779	0.00	54	181	0
	747	5.83	280	2.14	16.31	**0.60**	0.12	0	0	100	0	450	0.50	6.69	30.09	357	659	0.00	47	302	0
	760	4.04	249	2.14	10.06	**0.71**	0.18	0	0	100	0	450	0.58	4.81	21.63	220	474	0.00	47	253	0
	764	1.24	282	1.16	3.50	**0.51**	0.25	0	0	100	0	450	0.52	1.49	6.71	77	147	0.00	25	70	0
	777	2.85	312	1.91	8.90	**0.71**	0.18	0	0	100	0	450	0.44	3.30	14.83	195	325	0.00	42	130	0
	784	3.60	302	2.27	10.87	**0.71**	0.17	0	0	100	0	450	0.46	4.17	18.77	238	411	0.00	50	173	0
	792	4.35	280	2.04	12.18	**0.71**	0.14	0	0	100	0	450	0.51	5.05	22.72	267	498	0.00	45	231	0
243724C	793	5.67	234	1.79	13.25	**0.65**	0.12	0	0	100	0	450	0.60	6.68	30.06	290	658	0.00	39	368	0
	800	5.20	274	2.48	14.26	**0.74**	0.15	0	0	100	0	450	0.52	6.05	27.20	312	596	0.00	54	283	0
	807	6.05	288	2.54	17.41	**0.76**	0.13	0	0	100	0	450	0.49	6.93	31.18	381	683	0.00	56	302	0
243723Y	812	6.27	323	2.22	20.26	**0.71**	0.10	0	0	100	0	450	0.40	6.98	31.43	444	688	0.00	49	245	0
	814	7.90	298	4.29	23.56	**0.74**	0.15	0	0	100	0	450	0.47	9.02	40.58	516	889	0.00	94	373	0
	815	5.75	277	2.54	15.93	**0.78**	0.14	0	0	100	0	450	0.51	6.65	29.91	349	655	0.00	56	306	0
243723W	820	6.15	330	2.20	20.31	**0.76**	0.10	0	0	100	0	450	0.38	6.82	30.70	445	672	0.00	48	228	0
	821	6.44	285	3.61	18.35	**0.71**	0.16	0	0	100	0	450	0.50	7.45	33.52	402	734	0.00	79	332	0
	822	5.10	263	4.19	13.41	**0.72**	0.24	0	0	100	0	450	0.56	6.09	27.41	294	600	0.00	92	307	0
HD14DJR086	828	5.82	204	2.32	11.86	**0.75**	0.16	0	0	100	0	450	0.67	7.02	31.58	260	692	0.00	51	432	0
	830	4.90	235	3.37	11.50	**0.76**	0.23	0	0	100	0	450	0.61	5.91	26.61	252	583	0.00	74	331	0
	832	3.63	192	2.82	6.98	**0.49**	0.29	0	0	100	0	450	0.70	4.54	20.41	153	447	0.00	62	294	0
1394518	837	2.90	273	2.70	7.92	**0.67**	0.25	0	0	100	0	450	0.54	3.49	15.69	173	344	0.00	59	170	0
1394520	845	1.90	280	2.37	5.32	**0.53**	0.31	0	0	100	0	450	0.53	2.32	10.43	117	228	0.00	52	112	0
	850	3.44	157	2.22	5.41	**0.58**	0.29	0	0	100	0	450	0.76	4.37	19.65	118	430	0.00	49	312	0

Altree-2

Hydrocarbon Yield Calculation

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	S2 (meas) Remaining Potential	S2 (orig) Original Potential	Oil Cracked	S1 Free Oil	Estimated Oil	Cracked Gas
Altree-2	(m)	wt%	mg/g TOC	mg/g Rock	mg/g Rock	%						mg/g TOC		wt%	mg/g Rock	bbl/a-ft	bbl/a-ft	%	bbl/a-ft	bbl/a-ft	Mcf/a-ft
	850	1.03	159	0.65	1.64	**0.80**	0.28	0	0	100	0	450	0.75	1.32	5.93	36	130	0.00	14	94	0
1394522	853	3.55	267	3.60	9.48	**0.65**	0.28	0	0	100	0	450	0.55	4.29	19.31	208	423	0.00	79	215	0
1394524	860	3.75	232	3.67	8.71	**0.67**	0.30	0	0	100	0	450	0.62	4.61	20.77	191	455	0.00	80	264	0
HD14DJR087	863	4.21	155	2.74	6.52	**0.70**	0.30	0	0	100	0	450	0.76	5.33	23.97	143	525	0.00	60	382	0
	864	3.03	274	3.19	8.31	**0.54**	0.28	0	0	100	0	450	0.54	3.66	16.48	182	361	0.00	70	179	0
1394526	869	2.50	263	2.90	6.57	**0.56**	0.31	0	0	100	0	450	0.56	3.06	13.78	144	302	0.00	64	158	0
	871	2.02	250	3.49	5.04	0.67	0.41	0	0	100	0	450	0.60	2.55	11.47	110	251	0.00	76	141	0
1394528	876	2.75	214	2.71	5.89	**0.71**	0.32	0	0	100	0	450	0.66	3.43	15.45	129	338	0.00	59	209	0
	880	2.42	227	3.12	5.49	**0.72**	0.36	0	0	100	0	450	0.64	3.04	13.70	120	300	0.00	68	180	0
	880	1.08	203	1.55	2.19	0.67	0.41	0	0	100	0	450	0.68	1.39	6.25	48	137	0.00	34	89	0
1394530	884	2.50	220	2.40	5.50	**0.65**	0.30	0	0	100	0	450	0.65	3.11	14.00	120	307	0.00	53	186	0
1394532	892	2.15	229	2.00	4.92	**0.67**	0.29	0	0	100	0	450	0.63	2.66	11.98	108	262	0.00	44	155	0
1394534	899	3.75	209	3.02	7.84	**0.71**	0.28	0	0	100	0	450	0.66	4.64	20.89	172	457	0.00	66	286	0
	905	0.86	164	1.99	1.41	0.67	0.59	0	0	100	0	450	0.76	1.14	5.15	31	113	0.00	44	82	0
1394536	907	3.30	206	2.75	6.80	**0.72**	0.29	0	0	100	0	450	0.67	4.10	18.47	149	404	0.00	60	256	0
1394538	915	1.80	283	2.34	5.09	**0.49**	0.31	0	0	100	0	450	0.53	2.20	9.89	111	217	0.00	51	105	0
243723L	916	4.85	231	2.05	11.20	**0.69**	0.15	0	0	100	0	450	0.61	5.78	26.01	245	570	0.00	45	324	0
	919	0.30	83	0.40	0.25	0.67	0.61	0	0	100	0	450	0.88	0.41	1.84	5	40	0.00	9	35	0
243723K	920	4.40	229	1.72	10.06	**0.74**	0.15	0	0	100	0	450	0.62	5.25	23.62	220	517	0.00	38	297	0
1394550	923	5.15	195	3.32	10.03	**0.67**	0.25	0	0	100	0	450	0.69	6.34	28.54	220	625	0.00	73	405	0
	927	3.38	162	2.07	5.48	**0.67**	0.27	0	0	100	0	450	0.75	4.27	19.19	120	420	0.00	45	300	0
1394552	930	3.43	217	2.65	7.44	**0.56**	0.26	0	0	100	0	450	0.65	4.22	19.01	163	416	0.00	58	253	0
	936	3.84	152	3.14	5.85	**0.65**	0.35	0	0	100	0	450	0.77	4.90	22.05	128	483	0.00	69	355	0
1394554	938	4.20	201	3.15	8.43	**0.65**	0.27	0	0	100	0	450	0.68	5.20	23.40	185	513	0.00	69	328	0
	946	3.52	78	1.65	2.73	**0.49**	0.38	0	0	100	0	450	0.89	4.62	20.81	60	456	0.00	36	396	0
Middle Velkerri (Avg)		**4.41**	**274**	**2.46**	**12.92**	**0.67**	**0.21**	**0**	**0**	**98**	**2**	**456**	**0.52**	**5.10**	**23.30**	**283**	**510**	**0.00**	**54**	**227**	**0**
HD14DJR089	1110	1.21	64	0.34	0.78	**1.12**	0.30	0	0	100	0	450	0.91	1.61	7.25	17	159	0.20	7	113	170
1394559	1120	3.44	123	1.81	4.24	**0.99**	0.30	0	0	100	0	450	0.81	4.42	19.90	93	436	0.07	40	318	150
1394564	1204	0.60	53	0.18	0.32	**1.23**	0.36	0	0	100	0	450	0.92	0.81	3.63	7	80	0.33	4	48	144
HD14DJR090	1206	1.45	48	0.40	0.70	**1.47**	0.36	0	0	100	0	450	0.93	1.94	8.75	15	192	0.66	9	60	697
Lower Velkerri (Avg)		**1.68**	**72**	**0.68**	**1.51**	**1.20**	**0.33**	**0**	**0**	**100**	**0**	**450**	**0.89**	**2.20**	**9.88**	**33**	**216**	**0.32**	**15**	**135**	**290**
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 intrepreted 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)