Shea 1 Interpretive Summary

Kyalla – Middle Velkerri Interval

As a part of:
Northern Territory Geological Survey - Australia
McArthur Basin Integrated Petroleum Geochemistry, 2016

Submitted to:
Daniel Revie
Northern Territory Geological Survey
Department of Mines and Energy
38 Farrell Crescent
Winnellie, NT 0820 Australia

Prepared By:
Weatherford Laboratories
Study Project No. AB-74329

June 29, 2016

Report Contributors:

Tim Ruble (Petroleum Geochemistry)

Elizabeth Roberts (Compiler)

Brian Hankins & Jennifer Yee (Isologica Data Processing)

Weatherford
LABORATORIES

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

PETROLEUM GEOCHEMISTRY

INTRODUCTORY NOTE

A geochemical investigation has been conducted to assess hydrocarbon prospectivity of the Kyalla, Upper and Middle Velkerri Formations in the Shea 1 well located in the McArthur Basin, Northern Territories, Australia. Seventeen (17) 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 142 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*
Shea 1	Kyalla	**Estimated Original →**		Good (1.81% TOC)	Oil-prone Type I/II	High
Measured Currently →		Minor Oil	Early Oil Window	Good (1.73% TOC)	Oil-prone Type II	
Shea 1	Upper Velkerri	**Estimated Original →**		Good (1.39% TOC)	Oil-prone Type II	High
Measured Currently →		Minor Oil	Peak Oil Window	Fair (0.62% TOC)	Mixed Type II/III	
Shea 1	Middle Velkerri	**Estimated Original →**		Excellent (4.43% TOC)	Oil-prone Type II	Low
Measured Currently →		Oil	Peak Oil Window	Very Good (3.68% 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

KYALLA FORMATION

Four samples (4) from the Kyalla Formation were analyzed for LECO TOC content and programmed pyrolysis, with the remaining data set (48 samples) composed of client supplied public data (Fig. 1). TOC contents ranged from 0.55 to 4.28 wt.% and averaged 1.73 wt.% (good). Forty-six (46) samples have TOC content that is above the minimum requirement of 1 wt.% for *effective* petroleum source rocks, while sixteen (16) samples have TOC content above the minimum requirement of 2 wt.% for *economic* petroleum source rocks. Highest TOC content was found near the middle of the designated Kyalla interval (136.7 m depth) (Fig. 1). The middle interval between 70 to 165 m depth has TOC content > 1.0 wt.% and is considered to have good source potential (Fig. 1).

The S1 values of the Kyalla source rock samples average 0.55 mg HC/g rock (12 bbl oil/acre-ft) and S2 values average 8.83 mg HC/g rock (193 bbl oil/acre-ft). The S1 and S2 values imply fair in-situ hydrocarbon saturation and good remaining generative potential (Fig. 1). The normalized oil content (NOC) in the Kyalla samples, (S1/TOC) x 100, averages 33 (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 is S1 cross over at two depths (180 and 200 m) within the Kyalla Formation (Fig. 1).

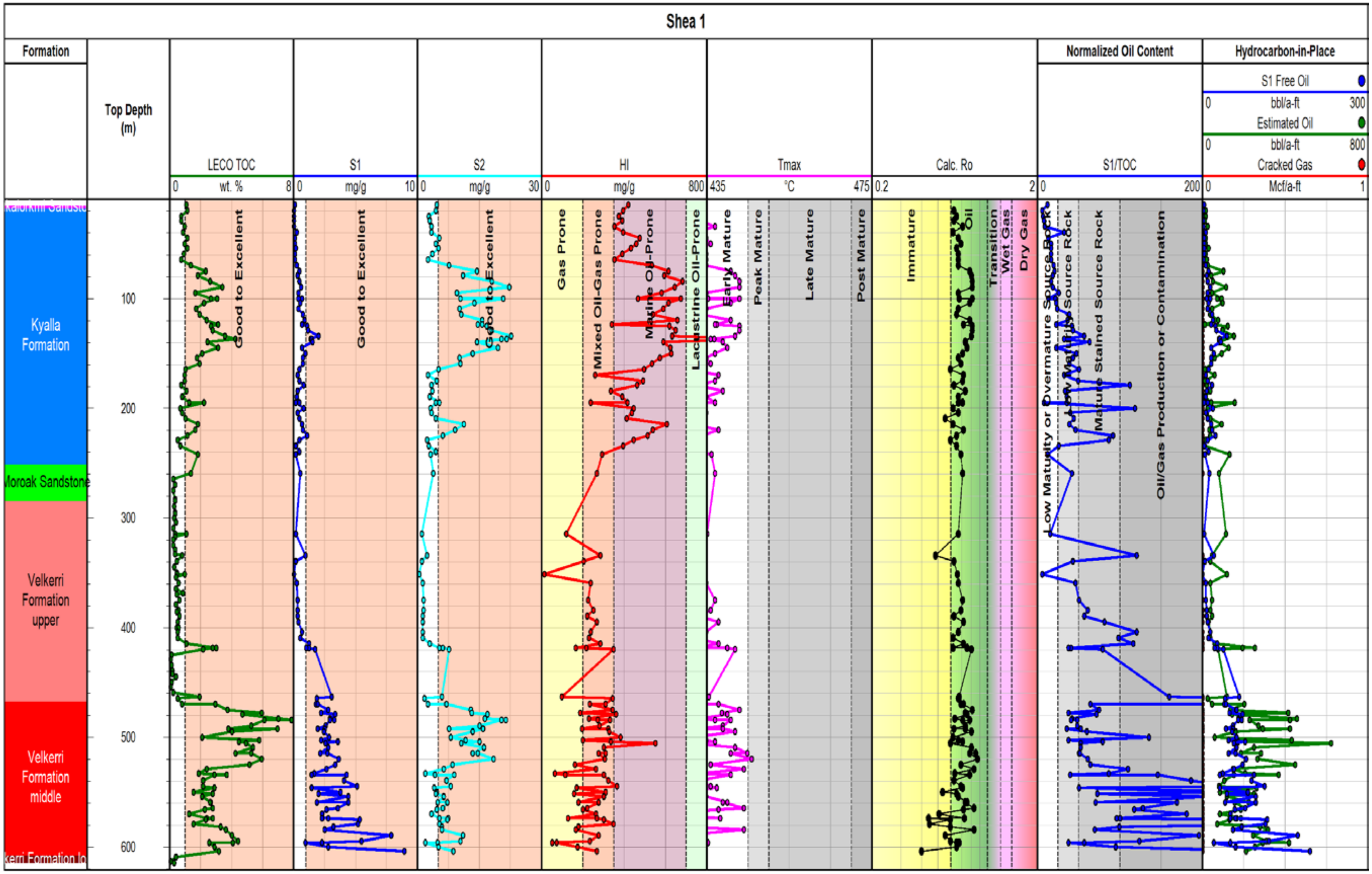

Figure 1. Geochemical depth plots for the Shea 1 well.

Measured Hydrogen Index (HI) values in the Kyalla average 493 mg HC/g TOC, indicating oil-prone Type II kerogen quality in these source rocks at present day (Fig. 1). Original HI_o of these samples are estimated to average 583 mg HC/g rock, which indicate oil-prone Type I/II kerogen. Transformation ratios (TR) based upon HI average only 28%, which is consistent with an early oil window thermal maturity. T_{max} values in the Kyalla samples average 436°C. T_{max} between 425 and 435°C typically indicate early oil window, while values between 435 and 445°C indicate peak oil window (Type II kerogen). On the basis of these guidelines, the average Kyalla 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 436°C is equivalent to a Calc. %R_o value of 0.70%. 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 Kyalla samples average 0.07. These low PI values are consistent with immature source, which typically have PI values < 0.10. Samples in the early oil window tend to have PI values in the range of ~0.10 to 0.15.

The thermal maturity of the Kyalla Formation source rocks was also evaluated 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 (1) sample from the base of the Kyalla at 242.2 m depth (50% clays) has a measured Kübler Index of 0.160, which is equivalent to a measured vitrinite reflectance of >4% (late stage metagenesis). This interpretation is inconsistent with the other geochemical data reported in this study and suggests the Kübler Index should be used with caution to evaluate thermal maturity in Mesoproterozoic aged source rocks.

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 (45 samples) composed of client supplied public data (Fig. 1). The Upper Velkerri Formation in the Shea 1 well exhibits fair generative potential for petroleum source rocks based on TOC content values (Fig. 1). TOC content ranges from 0.11 to 3.03 wt.% and averages 0.62 wt.% (fair). Only three (3) samples analyzed exceed the minimum value of 2.0 wt.% for *economic* petroleum source rocks (Lewan, 1987). High TOC samples occur in a thin bed of approximately 5 m thickness in the lower portion of the sampled interval with the maximum value at a measured depth of 419 m (Fig. 1).

The S1 values in the Upper Velkerri average 0.87 mg HC/g rock (19 bbl oil/acre-ft), indicating fair in-situ hydrocarbon saturation (Fig. 1) and are consistent with the marginal organic richness found in this source interval. 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 Upper Velkarri interval are much higher in comparison to the Kyalla Formation and average 77. Oil cross over (NOC > 100) was observed in in several samples from the lower portion of this interval (Fig. 1), which suggests possible producible hydrocarbons. The S2 values in the Upper Velkerri average 2.66 mg HC/g rock (58 bbl oil/acre-ft), indicating fair remaining hydrocarbon generation potential.

Measured HI values in these samples average 223 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 63%, which is consistent with an early to peak oil window thermal maturity.

The organic-matter in the Upper Velkerri interval in the Shea 1 well is thermally mature and is interpreted to be in the peak 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 Upper Velkerri samples average 0.23. 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 Upper 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.

MIDDLE VELKERRI FORMATION

Eight (8) samples from the Middle Velkerri Formation were analyzed for LECO TOC content and programmed pyrolysis, with the remaining data set (40 samples) composed of client supplied public data (Fig. 1). TOC contents ranged from 0.85 to 7.90 wt.% and averaged 3.68 wt.% (very good). Forth-three (43) of these samples exceed the minimum requirement of 2 wt.% for *economic* petroleum source rocks. There are three distinct cycles of TOC within this interval with maxima occurring at depths of 487, 520 and 595 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 source rock samples average 3.20 mg HC/g rock (70 bbl oil/acre-ft) and S2 values are moderate with an average 9.24 mg HC/g rock (202 bbl oil/acre-ft). The S1 and S2 values imply very good in-situ hydrocarbon saturation and good remaining generative potential (Fig. 1). The normalized oil content (NOC) in the Middle Velkerri samples average 87 (Fig. 1) and there are multiple samples exhibiting oil “cross-over”, notably in the basal section of this source rock interval. This would be interpreted to represent zones with high potential for containing producible hydrocarbon saturation.

Measured Hydrogen Index (HI) values in the Middle Velkerri average 256 mg HC/g TOC, indicating mixed oil/gas-prone Type II/III kerogen quality in these source rocks at present day (Fig. 1). Original HI_o of these samples are estimated to average 455 mg HC/g rock, which indicate oil-prone Type II kerogen. Transformation Ratios (TR) based upon HI average 57%, which is consistent with an early to peak oil window thermal maturity. T_{max} values in the Middle Velkerri samples average 436°C. T_{max} between 425 and 435°C typically indicate early oil window, while values between 435 and 445°C indicate peak oil window (Type II kerogen). On the basis of these guidelines, the average Middle 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 436°C is equivalent to a Calc. $\%R_o$ value of 0.69%. 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. Additional support for this interpreted thermal maturity comes from aromatic biomarker ratios examined using core slice experiments (608 m sample depth), which give a range of calculated reflectance values from 0.68 to 0.91% R_o (Flannery and George, 2014).

Production Index (PI) values in the Middle Velkerri samples average 0.28. These elevated PI values are consistent with source rocks in the late oil window, which typically have PI values between ~0.25 and 0.35.

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 Kyalla and 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**
Kyalla	44	56	0	0	583
Upper Velkerri	0	100	0	0	450
Middle Velkerri	2	98	0	0	455

Table 2. Average Kerogen Estimations for Shea 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):

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

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 average HI_o values of 450 to 583 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 0.28 to 0.63 (Table 3), i.e., on average an estimated 28 to 63% 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):

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

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 1.39 to 4.43 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 Kyalla and Velkerri source rocks examined in the Shea 1 well, the average $S2_o$ values vary from 6.3 to 20.2 mg HC/g rock or approximately 137 to 442 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 Upper Velkerri samples analyzed in the current study, the generated oil yields average 79 bbl/acre-ft. The generated oil yield from overlying Kyalla was lower with an average value of only 54 bbl/acre-ft. The average generated oil yield from the Middle Velkerri averaged 240 bbl/acre-ft and would be considered the most prospective interval within the Shea 1 well (Table 3).

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
Kyalla	1.67	493	193	583	0.28	1.81	248	12	54	0
Upper Velkerri	1.13	223	58	450	0.63	1.39	137	19	79	0
Middle Velkerri	3.68	256	202	455	0.57	4.43	442	70	240	0

Table 3. Hydrocarbon Yields average data for Shea 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 intervals varies from 78% in the Kyalla, 76% in the Upper Velkerri and 71% in the Lower Velkerri. The higher expulsion efficiency of the Kyalla and Upper Velkerri intervals is likely due to these units having adjacent porous reservoir lithologies in which expelled oil could more easily migrate.

The Kyalla and Upper Velkerri source rock intervals in the Shea 1 well are interpreted to be in the early to peak oil window and hydrocarbon yield calculations suggest minor amounts of generation have occurred (predominantly oil with some presumed associated gas). The Middle Velkerri source interval in this well is interpreted to be in the peak oil window and has likely generated significant amounts of oil and associated 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 ($S2_o$) 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 442 bbl oil/acre-ft, this compares favorably to the list of unconventional US Shale plays shown below. For the Kyalla and Upper Velkerri, original generation potential is much lower from 137 to 248 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
Kyalla	583	0.28	1.81	11.32	193	248	0.00	12	54	0
Upper Velkerri	450	0.63	1.39	6.28	58	137	0.00	19	79	0
Middle Velkerri	455	0.57	4.43	20.21	202	442	0.00	70	240	0

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 (483.12 m depth). In this instance the measured SRP oil saturations are slightly lower than those determined by SRA methods using the S1 yields. The saturation determined by SRP was 2.29 mg oil/g AR Rock (50 bbl oil/acre-ft), while that determined from S1 yields on a split of the same sample is 2.97 mg oil/g AR Rock (65 bbl oil/acre-ft). This suggests that the S1 is slightly overestimating the total hydrocarbons extracted using Dean-Stark methods (toluene). This could potentially be caused by a loss of volatile oil saturation during the Dean-Stark process and is somewhat unusual to observe in samples interpreted to be in the early to peak oil window. Low maturity oils generally contain relatively high abundances of non-volatile polar and asphaltene components associated with the in-situ oil/bitumen saturation that are normally better quantified via solvent extraction. 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 Kyalla and Velkerri Formation source rocks in the Shea 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 lie 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.

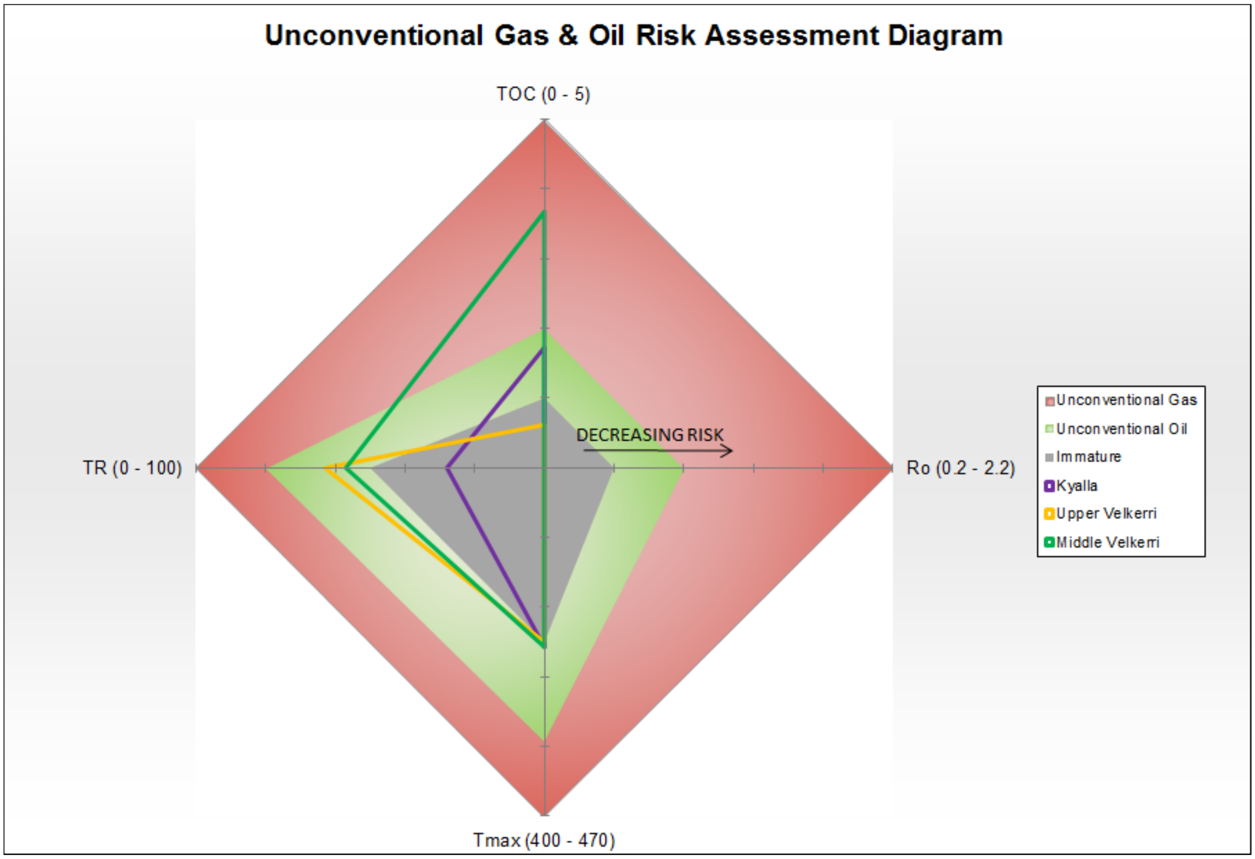

Figure 2. Geochemical Risk Assessment diagram for Mesoproterozoic source rocks in the Shea 1 well.

The Middle Velkerri source rock interval in the Shea 1 well is interpreted to represent a low geochemical risk for in-situ shale oil production. The average TOC content of 3.68 wt.% is well 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 436°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 57% and fall above the recommended minimum of 50% for shale oil systems but well below the 80% threshold for shale gas (Fig. 2). Aromatic biomarker thermal maturity parameters reported for this interval (Flannery and George, 2014) in the McManus well provide an independent confirmation of peak oil thermal maturity conclusions from programmed pyrolysis. 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 since all of the risk parameters fall above recommended minimum thresholds (Fig. 2).

The other formations examined in the current study are considered to represent high risk for in-situ shale oil/gas production. This is primarily related to organic richness and thermal maturity. The Kyalla samples have an average TOC of 1.73 wt.% and thermal maturity indicators suggest early window maturity. On the risk assessment diagram, average Tmax value of 436°C is just above the recommended minimum value of 435°C for shale oil, but Transformation Ratio of 28% is well below the minimum threshold (Fig. 2). For these reasons, the Kyalla interval is considered to be a high risk for commercial shale oil and shale gas development.

The Upper Velkerri samples have an average TOC of only 0.62 wt. %, which is well below the minimum threshold for shale oil (Fig. 2). Thermal maturity indicators suggest an early oil window maturity but higher than the overlying Kyalla. On the risk assessment diagram, average Tmax value of 435°C is right at the recommended minimum value of 435°C for shale oil and the Transformation Ratio of 63% is above at the minimum threshold (Fig. 2). 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.

In the Upper Velkerri source interval, measured in-situ oil saturation determined by programmed pyrolysis S1 yields is only fair (avg. 19 bbl oil/acre-ft), suggesting high risk for shale oil development (Fig. 3). Hydrocarbon yield calculations on as-received samples show estimates of average generated oil from the Upper Velkerri at 79 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 much higher in comparison to the Upper Velkerri and are primarily due to differences organic richness and in thermal maturity (Barnett Shale oil example averages 5.47 wt.% TOC and is at a peak oil widow maturity of 0.86% VR_o).

In the Kyalla source interval measured in-situ oil saturation from S1 yields is generally lower (avg. 12 bbl oil/acre-ft) and estimated generated oil yields are also quite low (avg. 54 bbl oil/acre-ft) due primarily to marginal thermal maturity (Fig. 3). As noted previously, this source rock is considered a high risk for shale oil development.

The Middle Velkerri has the highest measured in-situ oil saturation (70 bbl oil/acre-ft), which is a consequence of higher organic richness and elevated thermal maturity. Estimated generated oil is high (240 bbl oil/acre-ft). This is also supported by the high in-situ hydrocarbon saturations determined from SRP analysis (50 bbl oil/acre-ft), although this single sample may not be representative of the entire interval. These values are comparable to those of samples from the core area of Barnett Shale oil production in the Fort Worth Basin (Fig. 3) and suggest a low risk for commercial shale oil development.

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 Kyalla and Upper 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). In contrast, the interpreted thermal maturity of the Middle Velkerri is peak oil window and in-situ oil saturation is likely to be more mobile with a higher gas/oil ratio in comparison to the overlying units. Source rock extract fingerprints and bulk fractional compositional analyses from select Velkerri samples would 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.

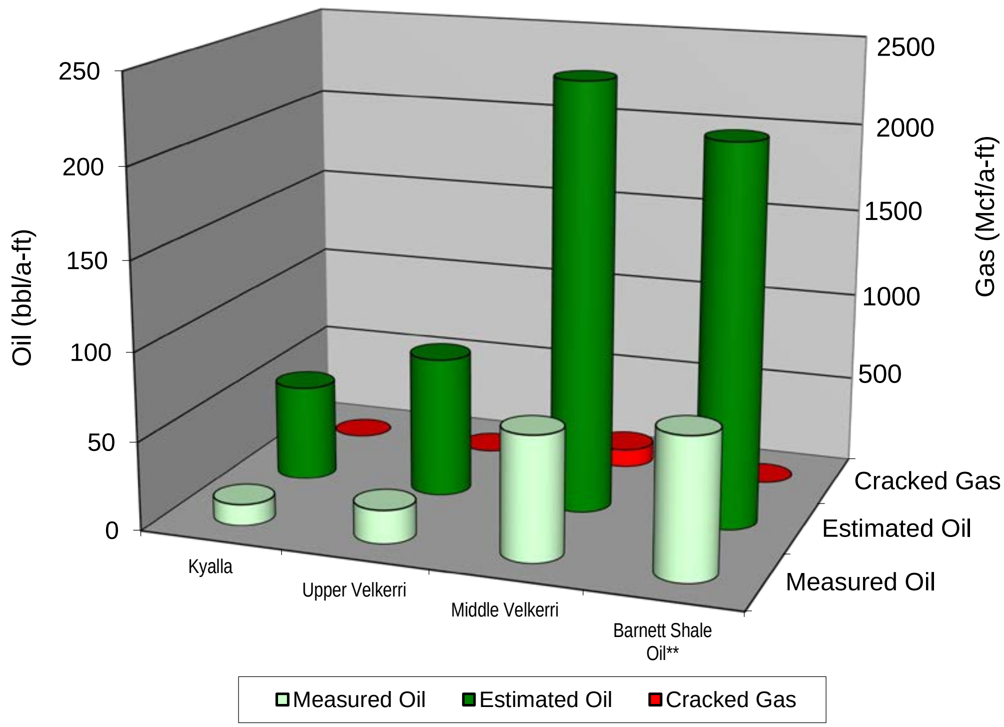

Figure 3. Hydrocarbon yield estimates for the Mesoproterozoic source rocks in the Shea 1 well compared to Barnett Shale in the oil window.

GEOCHEMICAL SUMMARY

The Middle Velkerri source interval in the Shea 1 well is interpreted to represent low geochemical risk for unconventional shale oil development. It clearly has elevated organic richness (avg. 3.68 wt.% TOC) and is considered an 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, 0.69% Calc. R_o and key risk ratios are at or above recommended minimum thresholds for shale oil systems. The Middle Velkerri has likely generated significant amounts of oil (avg. 240 bbl oil/acre-ft) and comparison to other systems such as the Barnett Shale show in-situ oil saturations are generally comparable. Risk criteria like the S1 versus TOC show oil cross-over for several samples in this unit, notably in the basal section. Further evaluation of in-situ oil characteristics would be required to fully evaluate potential oil mobility and recovery risk.

The other source rock intervals evaluated in the Shea 1 well generally have higher risk in comparison to the Middle Velkerri. The Upper Velkerri Formation has marginal organic richness (avg. 0.62 wt% TOC), although it is just above the thermal maturity thresholds for shale oil it is still considered to be in the early oil window. The Kyalla (avg. 1.73 wt. % TOC) exceeds the minimum threshold for TOC, but calculated transformation ratios are generally below the minimum threshold for shale oil and suggest an even lower early oil window thermal maturity. For these reasons, both of these source intervals are considered high risk for shale oil development.

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.

Flannery, E. M. and George, S. C., 2014, Assessing the syngeneity and indigeneity of hydrocarbons in the ~1.4 Ga Velkerri Formation, McArthur Basin, using slice experiments, Organic Geochemistry, v. 77, p. 115-125.

Jacob, H., 1985, Disperse solid bitumens as an indicator for migration and maturity in prospecting for oil and gas, Erdöl und Kohle-Erdgas-Petrochemie, v. 38, no. 8, p. 365.

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.

Landis C.R. and Castaño J.R., 1995, Maturation and bulk chemical properties of a suite of solid hydrocarbons, Organic Geochemistry, V. 22, p. 137-150.

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
Shelf Group
Shea 1

McArthur Basin Integrated Petroleum Geochemistry, 2016
Northern Territory Geological Survey - Australia

Weatherford
LABORATORIES

Shea 1

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
Shea 1	(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
1410008	20	1.14	396	0.08	4.51	**0.63**	0.02	0	0	100	0	450	0.18	1.19	5.34	99	117	0.00	2	18	0
1410009	25	0.77	374	0.06	2.88	**0.65**	0.02	0	0	100	0	450	0.24	0.82	3.67	63	80	0.00	1	17	0
1410010	30	0.78	394	0.07	3.07	**0.63**	0.02	0	0	100	0	450	0.19	0.81	3.67	67	80	0.00	2	13	0
1410011	35	1.00	353	0.10	3.53	**0.71**	0.03	0	0	100	0	450	0.31	1.08	4.85	77	106	0.00	2	29	0
1410012	40	0.87	397	0.29	3.45	**0.62**	0.08	0	0	100	0	450	0.20	0.93	4.17	76	91	0.00	6	16	0
1410013	45	1.15	477	0.16	5.48	**0.67**	0.03	0	0	75	25	525	0.16	1.19	6.25	120	137	0.00	4	17	0
1410014	50	1.00	462	0.17	4.62	**0.69**	0.04	0	0	75	25	525	0.20	1.05	5.51	101	121	0.00	4	19	0
1410015	55	1.19	434	0.20	5.16	**0.65**	0.04	0	0	75	25	525	0.28	1.27	6.68	113	146	0.00	4	33	0
1410016	60	0.96	393	0.16	3.77	**0.67**	0.04	0	0	100	0	450	0.20	1.01	4.55	83	100	0.00	4	17	0
1410017	65	0.75	355	0.13	2.66	**0.67**	0.05	0	0	100	0	450	0.31	0.81	3.66	58	80	0.00	3	22	0
1410018	70	1.42	535	0.29	7.60	**0.67**	0.04	0	0	50	50	600	0.20	1.49	8.92	166	195	0.00	6	29	0
1410019	76	2.36	616	0.51	14.54	**0.78**	0.03	0	0	0	100	750	0.37	2.57	19.30	318	423	0.00	11	104	0
1410020	79	1.87	598	0.36	11.18	**0.80**	0.03	0	0	25	75	675	0.23	1.96	13.24	245	290	0.00	8	45	0
1410021	85	2.62	686	0.46	17.98	**0.81**	0.02	0	0	0	100	750	0.20	2.71	20.33	394	445	0.00	10	51	0
1410022	90	3.45	646	0.67	22.29	**0.81**	0.03	0	0	0	100	750	0.30	3.66	27.48	488	602	0.00	15	114	0
1410023	95	1.65	585	0.44	9.65	**0.67**	0.04	0	0	25	75	675	0.27	1.76	11.87	211	260	0.00	10	49	0
HD14DJR068	100	2.69	470	0.39	10.49	**0.68**	0.04	0	0	75	25	525	0.18	2.80	14.72	230	322	0.00	9	93	0
1410024	100	3.08	676	0.69	20.83	**0.81**	0.03	0	0	0	100	750	0.23	3.22	24.15	456	529	0.00	15	73	0
1410025	105	2.25	619	0.54	13.93	**0.78**	0.04	0	0	0	100	750	0.36	2.46	18.41	305	403	0.00	12	98	0
1410026	110	1.72	591	0.43	10.16	**0.67**	0.04	0	0	25	75	675	0.26	1.82	12.31	223	270	0.00	9	47	0
1410027	115	1.98	542	0.79	10.73	**0.65**	0.07	0	0	50	50	600	0.20	2.10	12.61	235	276	0.00	17	41	0
1410028	120	2.39	658	0.90	15.73	**0.78**	0.05	0	0	0	100	750	0.29	2.57	19.30	344	423	0.00	20	78	0
HD14DJR074	124	3.13	343	0.72	14.69	**0.72**	0.05	0	0	100	0	450	0.34	3.41	15.34	322	336	0.00	16	14	0
1410029	125	2.70	622	1.14	16.79	**0.81**	0.06	0	0	0	100	750	0.38	2.99	22.44	368	492	0.00	25	124	0
1410030	130	2.78	652	1.22	18.13	**0.81**	0.06	0	0	0	100	750	0.31	3.02	22.66	397	496	0.00	27	99	0
1410031	135	3.57	635	2.06	22.68	**0.80**	0.08	0	0	0	100	750	0.36	3.97	29.75	497	652	0.00	45	155	0
1410032	140	2.46	591	1.57	14.53	**0.74**	0.10	0	0	25	75	675	0.29	2.70	18.23	318	399	0.00	34	81	0
1410033	145	3.13	626	0.74	19.59	**0.76**	0.04	0	0	0	100	750	0.35	3.39	25.42	429	557	0.00	16	128	0
1410034	150	2.11	631	1.00	13.32	**0.71**	0.07	0	0	0	100	750	0.36	2.34	17.54	292	384	0.00	22	93	0
1410035	155	1.78	576	0.78	10.25	**0.67**	0.07	0	0	25	75	675	0.31	1.94	13.10	224	287	0.00	17	62	0
1410036	160	1.94	535	0.77	10.38	**0.69**	0.07	0	0	50	50	600	0.22	2.07	12.41	227	272	0.00	17	44	0
1410037	165	1.04	498	0.53	5.18	**0.60**	0.09	0	0	75	25	525	0.13	1.10	5.77	113	126	0.00	12	13	0
1410038	170	1.00	261	0.33	2.61	**0.72**	0.11	0	0	100	0	450	0.55	1.18	5.29	57	116	0.00	7	59	0
1410039	175	0.97	494	0.48	4.79	**0.71**	0.09	0	0	75	25	525	0.14	1.03	5.39	105	118	0.00	11	13	0
1410040	180	0.75	465	0.84	3.49	**0.63**	0.19	0	0	75	25	525	0.26	0.85	4.45	76	97	0.00	18	21	0
1410041	185	1.12	338	0.38	3.78	**0.74**	0.09	0	0	100	0	450	0.36	1.25	5.61	83	123	0.00	8	40	0
1410042	190	0.80	391	0.29	3.13	**0.67**	0.08	0	0	100	0	450	0.22	0.86	3.86	69	85	0.00	6	16	0
1410043	195	1.27	417	0.46	5.30	**0.71**	0.08	0	0	75	25	525	0.33	1.40	7.34	116	161	0.00	10	45	0
HD14DJR069	195	2.23	241	0.19	4.43	**0.67**	0.04	0	0	100	0	450	0.58	2.60	11.71	97	256	0.00	4	159	0
1410044	200	0.74	450	0.88	3.33	**0.62**	0.21	0	0	75	25	525	0.30	0.85	4.45	73	98	0.00	19	25	0
1412943	205	0.80	439	0.32	3.51	**0.67**	0.08	0	0	75	25	525	0.28	0.87	4.58	77	100	0.00	7	23	0
1412944	210	1.08	414	0.48	4.47	**0.56**	0.10	0	0	75	25	525	0.35	1.20	6.30	98	138	0.00	11	40	0
1412945	215	1.86	608	0.74	11.30	**0.62**	0.06	0	0	0	100	750	0.40	2.08	15.63	247	342	0.00	16	95	0
1412946	220	1.68	541	0.79	9.09	**0.72**	0.08	0	0	50	50	600	0.21	1.80	10.78	199	236	0.00	17	37	0
1412947	225	1.19	518	1.10	6.16	**0.65**	0.15	0	0	50	50	600	0.31	1.34	8.05	135	176	0.00	24	41	0
1412948	230	0.55	447	0.48	2.46	**0.60**	0.16	0	0	75	25	525	0.29	0.62	3.25	54	71	0.00	11	17	0
1412949	235	0.74	396	0.20	2.93	**0.65**	0.06	0	0	100	0	450	0.19	0.79	3.53	64	77	0.00	4	13	0
HD14DJR070	242	1.84	296	0.24	3.35	**0.69**	0.07	0	0	100	0	450	0.46	2.09	9.38	73	205	0.00	5	132	0
Kyalla (Avg)		**1.67**	**493**	**0.55**	**8.83**	**0.70**	**0.07**	**0**	**0**	**56**	**44**	**583**	**0.28**	**1.81**	**11.32**	**193**	**248**	**0.00**	**12**	**54**	**0**
1412951	260	1.42	272	0.60	3.86	**0.71**	0.13	0	0	100	0	450	0.52	1.67	7.50	85	164	0.00	13	80	0
Moroak Sandstone (Avg)		**1.42**	**272**	**0.60**	**3.86**	**0.71**	**0.13**	**0**	**0**	**100**	**0**	**450**	**0.52**	**1.67**	**7.50**	**85**	**164**	**0.00**	**13**	**80**	**0**
HD14DJR071	315	1.13	123	0.18	1.20	***0.67***	0.13	0	0	100	0	450	0.81	1.44	6.50	26	142	0.00	4	116	0
1413652	335	0.81	286	0.98	2.32	***0.49***	0.30	0	0	100	0	450	0.52	0.99	4.44	51	97	0.00	21	46	0
1413653	340	0.51	206	0.22	1.05	***0.63***	0.17	0	0	100	0	450	0.66	0.63	2.83	23	62	0.00	5	39	0
HD14DJR072	352	0.98	14	0.06	0.42	***0.66***	0.13	0	0	100	0	450	0.98	1.33	5.98	9	131	0.00	1	122	0
1413657	360	0.60	240	0.28	1.44	***0.67***	0.16	0	0	100	0	450	0.59	0.72	3.26	32	71	0.00	6	40	0
1413660	375	0.65	228	0.33	1.48	***0.71***	0.18	0	0	100	0	450	0.62	0.79	3.57	32	78	0.00	7	46	0
1413662	385	0.62	253	0.38	1.57	***0.69***	0.19	0	0	100	0	450	0.57	0.75	3.37	34	74	0.00	8	39	0
1413663	390	0.63	222	0.36	1.40	***0.63***	0.20	0	0	100	0	450	0.63	0.77	3.48	31	76	0.00	8	46	0

Shea 1

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
Shea 1	(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
1413664	395	0.54	269	0.44	1.45	*0.72*	0.23	0	0	100	0	450	0.54	0.65	2.94	32	64	0.00	10	33	0
1413666	405	0.57	242	0.69	1.38	*0.67*	0.33	0	0	100	0	450	0.61	0.71	3.21	30	70	0.00	15	40	0
1415955	410	0.57	232	0.56	1.32	*0.62*	0.30	0	0	100	0	450	0.62	0.71	3.20	29	70	0.00	12	41	0
1413668	415	1.09	288	1.27	3.14	*0.72*	0.29	0	0	100	0	450	0.51	1.32	5.95	69	130	0.00	28	62	0
HD14DJR073	419	3.03	168	1.26	5.27	*0.62*	0.19	0	0	100	0	450	0.73	3.78	17.00	115	372	0.00	28	257	0
	420	2.80	221	1.07	6.18	*0.76*	0.15	0	0	100	0	450	0.63	3.38	15.19	135	333	0.00	23	197	0
1416121	420	2.21	351	1.76	7.75	*0.80*	0.19	0	0	100	0	450	0.35	2.52	11.32	170	248	0.00	39	78	0
HD14DJR076	464	1.93	101	3.10	5.99	*0.68*	0.34	0	0	100	0	450	0.85	2.53	11.39	131	249	0.00	68	118	0
1416130	465	0.54	346	1.89	1.87	0.67	0.50	0	0	100	0	450	0.43	0.69	3.08	41	68	0.00	41	27	0
Upper Velkerri (Avg)		**1.13**	**223**	**0.87**	**2.66**	**0.67**	**0.23**	**0**	**0**	**100**	**0**	**450**	**0.63**	**1.39**	**6.28**	**58**	**137**	**0.00**	**19**	**79**	**0**
1416131	470	0.85	313	1.81	2.66	0.69	0.40	0	0	100	0	450	0.48	1.06	4.75	58	104	0.00	40	46	0
	470	3.00	234	1.96	7.03	**0.72**	0.22	0	0	100	0	450	0.61	3.64	16.38	154	359	0.00	43	205	0
1416132	475	3.79	346	2.84	13.10	**0.81**	0.18	0	0	100	0	450	0.36	4.30	19.34	287	424	0.00	62	137	0
HD14DJR077	478	5.94	189	2.26	13.31	**0.74**	0.15	0	0	100	0	450	0.69	7.19	32.36	291	709	0.00	49	417	0
1416133	480	4.70	362	3.37	17.03	**0.76**	0.17	0	0	100	0	450	0.32	5.25	23.64	373	518	0.00	74	145	0
HD14DJR078	483	7.04	233	2.97	16.36	**0.64**	0.15	0	0	100	0	450	0.61	8.32	37.42	358	819	0.00	65	461	0
	485	7.90	272	3.30	21.51	**0.71**	0.13	0	0	100	0	450	0.52	9.09	40.89	471	896	0.00	72	424	0
1416134	485	6.13	332	2.98	20.37	**0.78**	0.13	0	0	100	0	450	0.38	6.86	30.85	446	676	0.00	65	229	0
1416135	490	5.28	284	2.60	15.02	**0.74**	0.15	0	0	100	0	450	0.50	6.10	27.46	329	601	0.00	57	273	0
	493	3.80	200	2.01	7.60	**0.63**	0.21	0	0	100	0	450	0.68	4.66	20.99	166	460	0.00	44	293	0
HD14DJR079	493	7.01	325	2.54	16.04	**0.74**	0.14	0	0	100	0	450	0.40	7.87	35.43	351	776	0.00	56	425	0
1416136	495	4.07	328	2.46	13.35	**0.80**	0.16	0	0	100	0	450	0.40	4.62	20.80	292	456	0.00	54	163	0
1416137	500	2.11	385	2.87	8.12	**0.62**	0.26	0	0	100	0	450	0.29	2.43	10.92	178	239	0.00	63	61	0
	503	5.80	202	2.23	11.73	**0.67**	0.16	0	0	100	0	450	0.67	7.00	31.48	257	689	0.00	49	433	0
1416138	505	4.51	337	3.60	15.22	**0.71**	0.19	0	0	100	0	450	0.39	5.15	23.17	333	507	0.00	79	174	0
HD14DJR080	505	4.93	552	2.62	10.60	**0.60**	0.20	0	0	25	75	675	0.42	5.79	39.11	232	857	0.00	57	624	0
1416139	510	5.38	302	2.84	16.25	**0.80**	0.15	0	0	100	0	450	0.46	6.16	27.73	356	607	0.00	62	251	0
1416140	515	4.26	313	2.19	13.35	**0.85**	0.14	0	0	100	0	450	0.43	4.85	21.84	292	478	0.00	48	186	0
	516	5.30	278	2.75	14.73	**0.78**	0.16	0	0	100	0	450	0.51	6.16	27.73	323	607	0.00	60	285	0
1416141	520	5.97	309	3.66	18.42	**0.87**	0.17	0	0	100	0	450	0.45	6.84	30.76	403	674	0.00	80	270	0
1416142	525	5.15	165	3.36	8.50	**0.69**	0.28	0	0	100	0	450	0.74	6.45	29.03	186	636	0.00	74	450	0
1416143	530	2.40	264	2.66	6.34	**0.83**	0.30	0	0	100	0	450	0.56	2.93	13.19	139	289	0.00	58	150	0
HD14DJR081	533	1.92	67	1.67	1.94	**0.64**	0.46	0	0	100	0	450	0.90	2.57	11.54	42	253	0.00	37	210	0
1416144	535	2.94	302	4.29	8.89	**0.78**	0.33	0	0	100	0	450	0.49	3.56	16.01	195	351	0.00	94	156	0
	535	3.70	118	1.48	4.37	**0.78**	0.25	0	0	100	0	450	0.82	4.74	21.32	96	467	0.00	32	371	0
1416145	540	2.18	326	4.07	7.10	**0.63**	0.36	0	0	100	0	450	0.45	2.65	11.94	155	261	0.00	89	106	0
1416146	545	2.18	369	5.15	8.05	**0.69**	0.39	0	0	100	0	450	0.36	2.64	11.87	176	260	0.00	113	84	0
HD14DJR082	547	2.89	173	1.48	4.19	**0.71**	0.26	0	0	100	0	450	0.73	3.63	16.35	92	358	0.00	32	266	0
1416147	550	1.54	311	3.80	4.79	**0.54**	0.44	0	0	100	0	450	0.49	1.93	8.68	105	190	0.00	83	85	0
	552	2.80	161	2.06	4.52	**0.65**	0.31	0	0	100	0	450	0.75	3.56	16.04	99	351	0.00	45	252	0
1416148	555	2.13	302	4.46	6.43	**0.67**	0.41	0	0	100	0	450	0.50	2.64	11.90	141	261	0.00	98	120	0
	559	2.70	182	1.91	4.92	**0.76**	0.28	0	0	100	0	450	0.71	3.39	15.27	108	335	0.00	42	227	0
1416149	560	2.61	280	4.43	7.32	**0.74**	0.38	0	0	100	0	450	0.54	3.23	14.53	160	318	0.00	97	158	0
1416150	565	2.80	223	3.60	6.24	**0.83**	0.37	0	0	100	0	450	0.64	3.52	15.83	137	347	0.00	79	210	0
	567	2.30	202	2.71	4.64	**0.72**	0.37	0	0	100	0	450	0.68	2.92	13.13	102	288	0.00	59	186	0
1416151	570	1.30	264	2.36	3.43	**0.51**	0.41	0	0	100	0	450	0.57	1.64	7.37	75	161	0.00	52	86	0
HD14DJR083	574	2.42	132	2.33	5.42	**0.73**	0.30	0	0	100	0	450	0.80	3.12	14.02	119	307	0.00	51	188	0
	574	2.80	271	2.81	7.58	**0.44**	0.27	0	0	100	0	450	0.54	3.39	15.23	166	334	0.00	62	168	0
1416152	575	2.36	305	5.38	7.19	**0.60**	0.43	0	0	100	0	450	0.50	2.94	13.23	157	290	0.00	118	132	0
1416153	580	1.54	350	5.22	5.39	**0.45**	0.49	0	0	100	0	450	0.42	1.94	8.72	118	191	0.00	114	73	0
	583	3.30	180	3.28	5.95	**0.60**	0.36	0	0	100	0	450	0.72	4.19	18.85	130	413	0.00	72	283	0
1416154	585	3.63	167	2.53	6.07	**0.83**	0.29	0	0	100	0	450	0.74	4.58	20.62	133	452	0.00	55	319	0
1416155	590	4.03	277	7.92	11.18	**0.56**	0.41	0	0	100	0	450	0.55	5.01	22.54	245	494	0.00	173	249	0
1416185	595	4.43	238	5.52	10.54	**0.60**	0.34	0	0	100	0	450	0.62	5.48	24.65	231	540	0.00	121	309	0
HD14DJR084	596	4.10	52	2.34	5.05	**0.68**	0.32	0	0	100	0	450	0.92	5.40	24.30	111	532	0.00	51	421	0
	597	2.60	77	0.99	2.00	**0.65**	0.33	0	0	100	0	450	0.89	3.42	15.41	44	337	0.00	22	294	0
1416186	600	2.93	176	2.79	5.17	**0.65**	0.35	0	0	100	0	450	0.73	3.73	16.78	113	367	0.00	61	254	0
1416187	605	3.21	270	8.97	8.66	**0.40**	0.51	0	0	100	0	450	0.57	4.10	18.44	190	404	0.00	196	214	0
Middle Velkerri (Avg)		**3.68**	**256**	**3.20**	**9.24**	**0.69**	**0.28**	**0**	**0**	**98**	**2**	**455**	**0.57**	**4.43**	**20.21**	**202**	**442**	**0.00**	**70**	**240**	**0**

Shea 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
Shea 1	(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
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)