



## **Golden Grove 1 Interpretive Summary**

### **Lower Velkerri – Corcoran Interval**

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*Submitted to:*

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## PETROLEUM GEOCHEMISTRY

### INTRODUCTORY NOTE

A geochemical investigation has been conducted to assess hydrocarbon prospectivity of the Lower Velkerri and Corcoran Formations in the Golden Grove 1 well located in the McArthur Basin, Northern Territories, Australia. Thirty-seven (37) core chip samples from this well were analyzed by a variety of geochemical techniques, including total organic carbon (TOC, LECO®), programmed pyrolysis (SRA) and organic petrology with measured maceral reflectance ( $R_o$ ). 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
Golden Grove 1	Lower Velkerri	Estimated Original →		Good (1.84% TOC)	Oil-prone Type II	Moderate
Measured Currently →		Oil	Peak Oil Window	Good (1.44% TOC)	Gas-prone Type III	
Golden Grove 1	Corcoran	Estimated Original →		Fair (0.96% TOC)	Oil-prone Type II	High
Measured Currently →		Oil	Late Oil Window	Fair (0.69% TOC)	Inert Type IV	

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

**Table 1. Geochemical Summary**

### LOWER VELKERRI FORMATION

Fifteen (15) samples from the Lower Velkerri Formation were analyzed for LECO TOC content and programmed pyrolysis (Fig. 1). The Lower Velkerri Formation in the Golden Grove 1 well exhibits good generative potential for petroleum source rocks based on TOC content values (Fig. 1). TOC contents ranged from 0.45 to 7.01 wt.% and averaged 1.44 wt.% (good). Five (5) samples have TOC content above the minimum requirement of 1 wt.% for *effective* petroleum source rocks, while two (2) of the samples have TOC content above the minimum requirement of 2 wt.% for *economic* petroleum source rocks. The TOC values reach a maximum near the middle of the sampled interval at a depth of 107.9 m and are generally much lower outside of this ~10 m thick zone of elevated organic richness (Fig. 1).

The S1 values of the Lower Velkerri source rock samples average 0.15 mg HC/g rock (3 bbl oil/acre-ft) and the S2 values average 1.45 mg HC/g rock (32 bbl oil/acre-ft). The S1 and S2 values imply poor in-situ hydrocarbon saturation and poor remaining generative potential (Fig. 1). The normalized oil content (NOC) in the Lower Velkerri samples,  $(S1/TOC) \times 100$ , average 11 (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. Very low NOC values  $< 20$  are most likely related to post-mature source rocks that have likely generated and expelled most of their in-situ hydrocarbon saturation. 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 no S1 cross over TOC in any of the samples analyzed (Fig. 1).

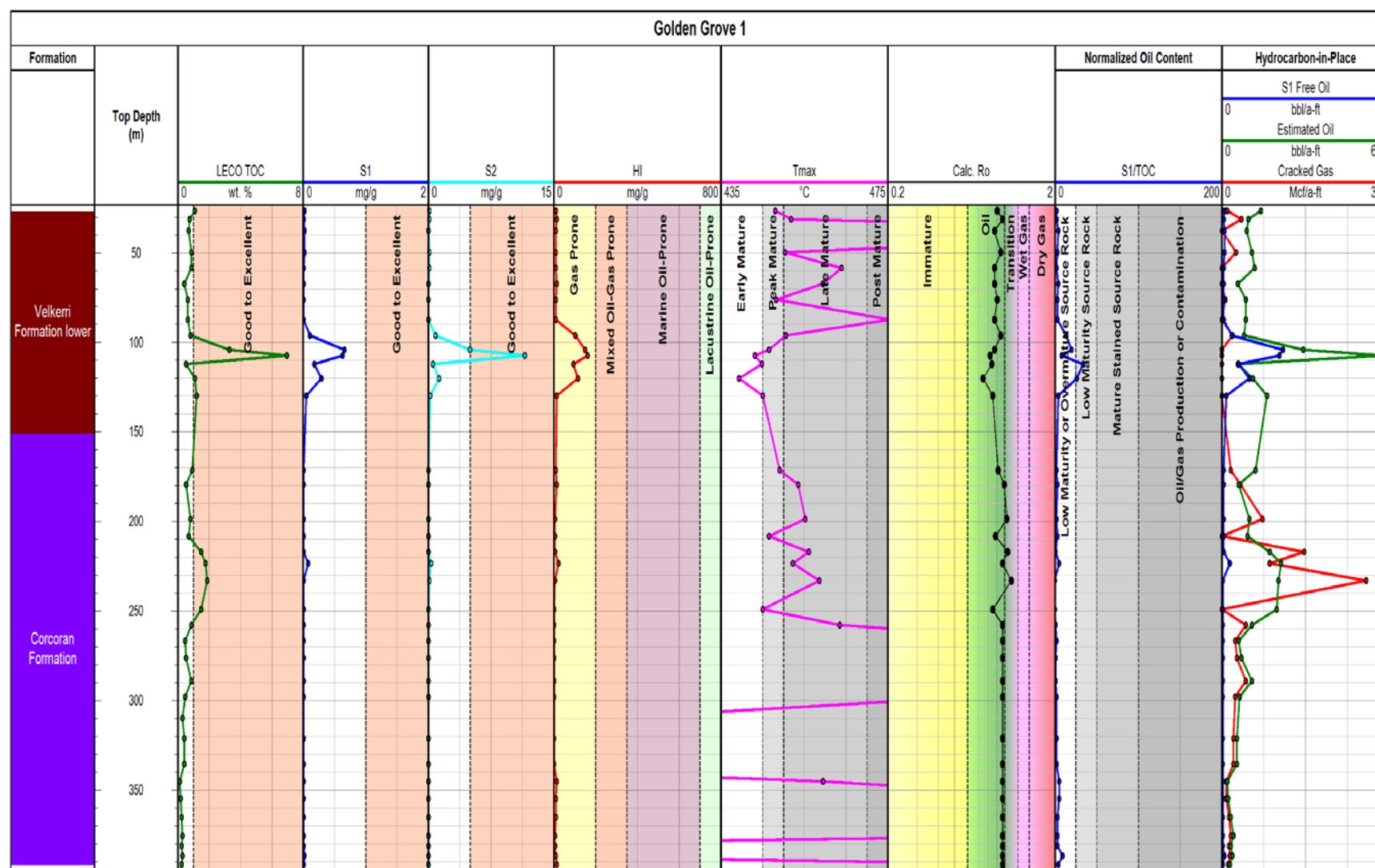


Figure 1. Geochemical depth plots for the Golden Grove 1 well. Note Tmax values plot off scale on depth plot beyond post-mature field.

The measured Hydrogen Index (HI) values in the Lower Velkerri average 54 mg HC/g TOC, indicating gas-prone Type III kerogen quality in these source rocks at present day. Original  $HI_o$  of these samples are estimated to average 450 mg HC/g rock, which indicate oil-prone Type II kerogen. Transformation Ratios (TR) based upon HI are 92%, which is more consistent with a post-mature dry gas window thermal maturity. The organic-matter in the Lower Velkerri within the Golden Grove 1 well is thermally mature and is interpreted to be in the peak oil window. Programmed pyrolysis  $T_{max}$  values average 447°C (Fig. 1), on the basis of select samples considered reliable for this maturity assessment. 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 447°C is equivalent to a Calc. % $R_o$  value of 0.88%. 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, especially post-mature samples where S2 yields are very low.

Production Index (PI) values in these Lower Velkerri samples average 0.18. These moderate PI values consistent with source rocks in the peak oil window, which typically have PI values in the range of 0.15 to 0.25.

### CORCORAN FORMATION

Twenty-two (22) samples from the Corcoran Formation were analyzed for LECO TOC content and programmed pyrolysis (Fig. 1). The Corcoran Formation in the Golden Grove 1 well exhibits fair generative potential for petroleum source rocks based on TOC content values (Fig. 1). TOC content ranges from 0.18 to 1.88 wt.% and averages 0.69 wt.% (fair). Only four (4) samples analyzed exceed the minimum value of 1.0 wt.% for *effective* petroleum source rocks, and no samples exceed the 2.0 wt.% threshold for *economic* petroleum source rocks (Lewan, 1987). Maximum TOC content occurs in the upper portion of the sampled interval at a depth of 233.1 m (Fig. 1).

The S1 values in the Corcoran average 0.02 mg HC/g rock (0 bbl oil/acre-ft), which indicates very poor in-situ hydrocarbon saturation (Fig. 1). NOC values in the Corcoran interval are lower in comparison to the overlying strata and average just 2. Oil cross over (NOC > 100) was not observed in this unit. The S2 values in this interval average only 0.06 mg HC/g rock (1 bbl oil/acre-ft), which indicates very poor remaining generative potential.

Measured HI values in the Corcoran samples average 8 mg HC/g TOC, which indicate inert Type IV 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 99%, which is more consistent with post-mature dry gas window thermal maturity.

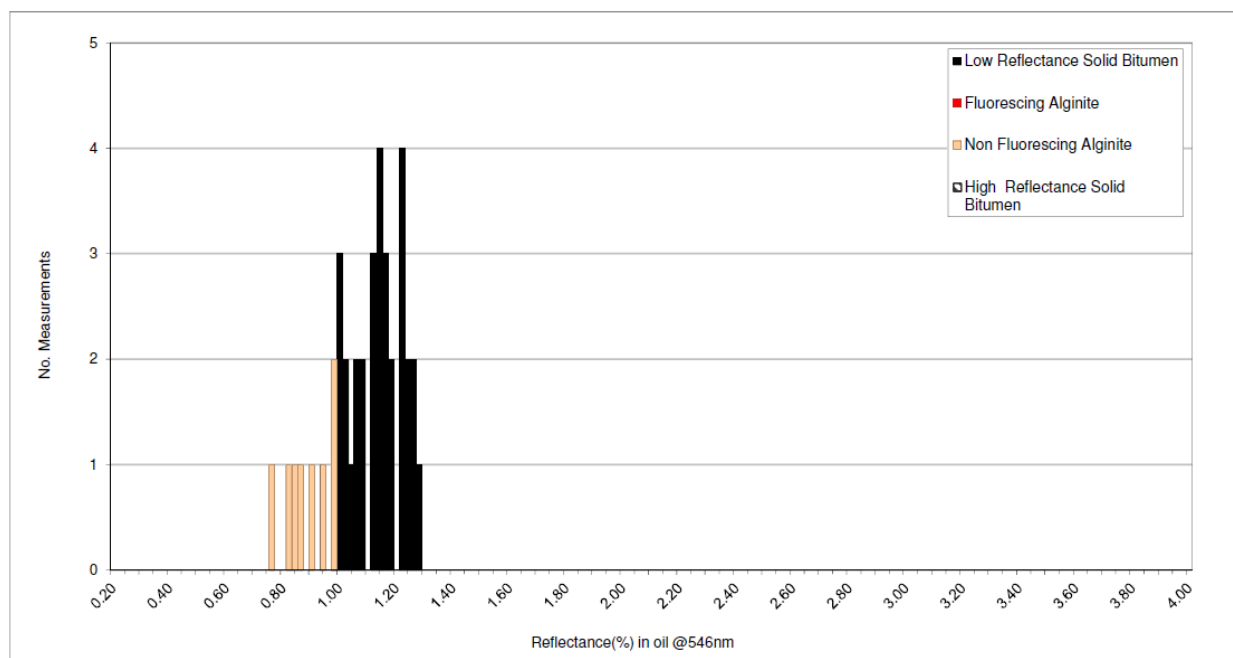
The organic-matter in the Corcoran interval in the Golden Grove 1 well is thermally mature and is interpreted to be in the late oil window. Programmed pyrolysis  $T_{max}$  values average 452°C (Fig. 1), on the basis of select samples considered reliable for this maturity assessment. Using the formula 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 452°C is equivalent to a Calc. % $R_o$  value of 0.98%. 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, especially post-mature samples where S2 yields are very low.

Production Index (PI) values in these Corcoran samples average 0.29. These elevated PI values are consistent with source rocks in the late oil window, which typically have PI values in the range of 0.25 to 0.35.

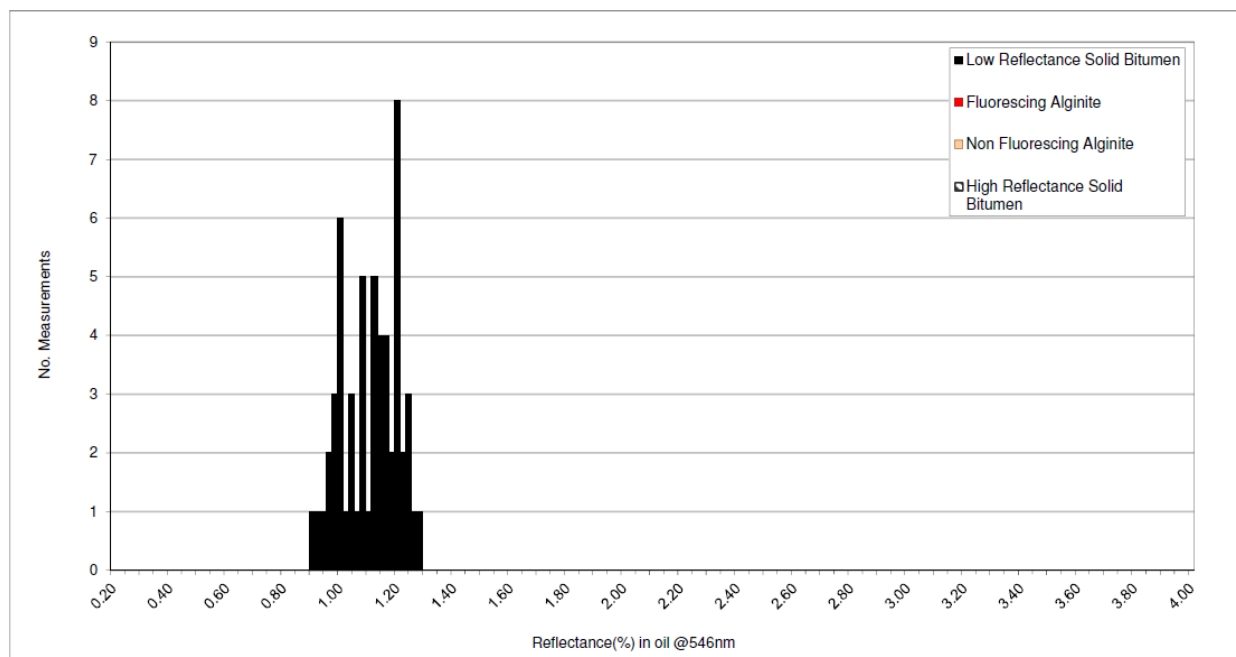
Organic petrology was performed on three (3) samples from the Corcoran interval (217.40, 224.10 and 233.1 m) in the Golden Grove 1 well (Figs. 2-4). The results from these analyses show distributions that consist of macerals identified as either non-fluorescing Alginite, low reflecting solid bitumen or high reflectance solid bitumen. The low reflecting solid bitumen population has reflectance values that average between 1.10 and 1.13%  $R_o$  and are considered the most representative indigenous kerogen population for thermal maturity assessment. This group of organic macerals is thought to possibly represent fine

grained migrabitumen, although they could also represent preserved original cyanobacterial kerogen that has subsequently undergone thermal conversion to form a dispersed solid bitumen network within these Velkerri Formation source rocks. The maturity assessment from this maceral group would be consistent with the late oil window, which is also supported by the presence of dark brown algal fluorescence colors.

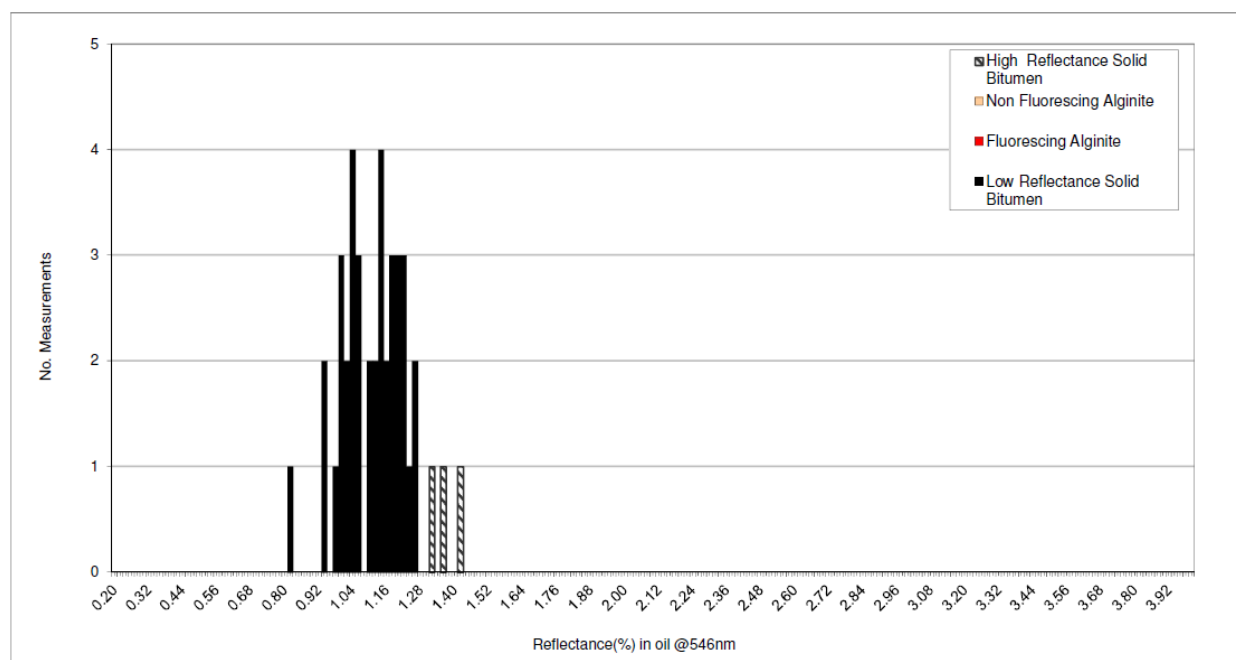
The non-fluorescing Alginite maceral group from the 217.4 m sample had an average reflectance value of 0.88%  $R_o$ , which would suggest a peak oil window thermal maturity. The high reflecting solid bitumens tended to have slightly higher reflectance readings in comparison to the other maceral groups. The mean measured reflectance value for these solid organic macerals in the 233.1 m sample is 1.36%  $R_o$ . Published solid bitumen conversions were applied to both populations of solid bitumen reflectance values. The conversion formula published by Landis and Castaño (1995) for bitumen in lenses/layers (Eq.  $R_o = (\text{Bitumen } R_o + 0.41)/1.09$ ) resulted in values of 1.38 to 1.41% Eq.  $R_o$  when applied to these low reflecting solid bitumens. The conversion formula published by Jacob (1985) equation (Eq.  $R_o = (\text{Bitumen } R_o \times 0.618) + 0.4$ ) for 'angular-like' pyrobitumen trapped in mineral pore spaces resulted in a value of 1.24% Eq.  $R_o$  when applied to the high reflecting solid bitumens. The Landis and Castaño (1995) conversion does not appear to be applicable for these solid bitumen reflectance readings since it would suggest a early dry gas window thermal maturity. However, the Jacob (1985) conversion does appear to provide a possible correction back to a more suitable thermal maturity that is in general agreement with the average value from the population of low reflectance solid bitumens. Comparison with other samples examined in the current study suggest that the high reflectance solid bitumen reflectance readings can be corrected using the Jacob (1985) formula and often these "corrected" values compare favorably to "uncorrected" readings from the population of low reflectance solid bitumen within the same sample. Thus, the calculated 1.24% Eq.  $R_o$  value and the measured 1.11%  $R_o$  values would both suggest the Corcoran samples in this well are within the late oil to early wet gas/condensate window.



**Figure 2. Organic petrology of the Corcoran Formation (217.4 m) in the Golden Grove 1 well. Mean maceral reflectance of non-fluorescing Alginite is 0.88%  $R_o$  and mean maceral reflectance of low reflecting solid bitumen is 1.13%  $R_o$ .**



**Figure 3. Organic petrology of the Corcoran Formation (224.1 m) in the Golden Grove 1 well. Mean maceral reflectance of low reflecting solid bitumen is 1.10% R<sub>o</sub>.**



**Figure 4. Organic petrology of the Corcoran Formation (233.1 m) in the Golden Grove 1 well. Mean maceral reflectance of low reflecting solid bitumen is 1.10% R<sub>o</sub>. The high reflecting solid bitumen has mean reflectance of 1.36% R<sub>o</sub>, which equates to Eq. R<sub>o</sub> of 1.24% R<sub>o</sub> using the conversion of Jacob (1985).**



## ORIGINAL GENERATIVE POTENTIAL AND HYDROCARBON YIELD CALCULATIONS

Petroleum generative capacity depends on the original quantity of organic matter (TOC<sub>o</sub>) and the original type of organic matter (HI<sub>o</sub>) (Peters et al., 2005, p. 97). The petroleum generation process has likely decreased the remaining generative potential as measured by TOC<sub>pd</sub> and HI<sub>pd</sub> 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<sub>o</sub> values can be computed from visual kerogen assessments and assigned kerogen-type HI<sub>o</sub> 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. For the Golden Grove 1 well, the measured kerogen maceral distributions show 100% Type II kerogen for all three samples examined (dominantly inert AOM and lens/layer AOM with minor diffuse AOM). 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<sub>o</sub> 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 <sub>o</sub>	%Type II 450 HI <sub>o</sub>	%Type III 125 HI <sub>o</sub>	%Type IV 50 HI <sub>o</sub>	HI <sub>o</sub>
Lower Velkerri	0	100	0	0	450
Corcoran	0	100	0	0	450

**Table 2. Average Kerogen Estimations for Golden Grove 1 well.**

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

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

HI<sub>pd</sub> and PI<sub>pd</sub> are the measured HI and PI values for the various source rock samples in this well. The average HI<sub>pd</sub> and PI<sub>pd</sub> for the formations evaluated in the current study are shown in Table 3. HI<sub>o</sub> and PI<sub>o</sub> 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<sub>o</sub> values of 450 mg HC/g TOC (Table 2). We assume a PI<sub>o</sub> of 0.02 (see Peters et al., 2005). Using these values in equation 2, the extent of fractional conversion of HI<sub>o</sub> to petroleum varies from 0.92 to 0.99 (Table 3), i.e., on average an estimated 92 to 99% of the petroleum generation process has been completed.

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

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

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

Using equation 3, the average estimated original  $TOC_o$  for the source rock samples in this well before petroleum generation varies from 0.96 to 1.84 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 Golden Grove 1 well, the average  $S2_o$  values vary from 4.3 to 8.3 mg HC/g rock or approximately 95 to 181 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 Lower Velkerri samples analyzed in the current study, the estimated generated oil yields average 148 bbl/acre-ft, along with 7 Mcf/acre-ft of secondary cracked gas (Table 3). The estimated generated oil yield from underlying Corcoran was lower at 87 bbl/acre-ft along with 41 bbl/acre-ft of cracked gas (based on an estimated 7% oil cracking).

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
Lower Velkerri	1.44	54	32	450	0.92	1.84	181	3	148	7
Corcoran	0.71	8	1	450	0.99	0.96	95	0	87	41

**Table 3. Hydrocarbon Yields average data for Golden Grove 1 well.**

For shale oil systems, 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 these source rock intervals ranges from 98 to 100%, which is generally more consistent with samples in the main gas window where all in-situ oil has either been expelled and/or converted to secondary gas.

The Lower Velkerri and Corcoran source rock intervals in the Golden Grove 1 well are interpreted to be in the peak to late window and hydrocarbon yield calculations suggest only moderate amounts of generation have occurred (predominantly oil with minor associated and cracked gas). From an exploration risk perspective, this is generally unfavorable. 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 Lower Velkerri original generation potential ( $S2_o$ ) averages 181 bbl oil/acre-ft, this is below all of the other formations on the list of unconventional US Shale plays shown below. For the Corcoran, original generation potential is much lower at only 95 bbl oil/acre-ft and this unit also does not compare favorably with other unconventional US Shale plays.

Sample Database Averages TOC >1%	HI <sup>o</sup> mg/g TOC	TR	TOC <sup>o</sup> wt%	S2 <sup>o</sup> 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
Lower Velkerri	450	0.92	1.84	8.29	32	181	0.01	3	148	7
Corcoran	450	0.99	0.96	4.34	1	95	0.07	0	87	41

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

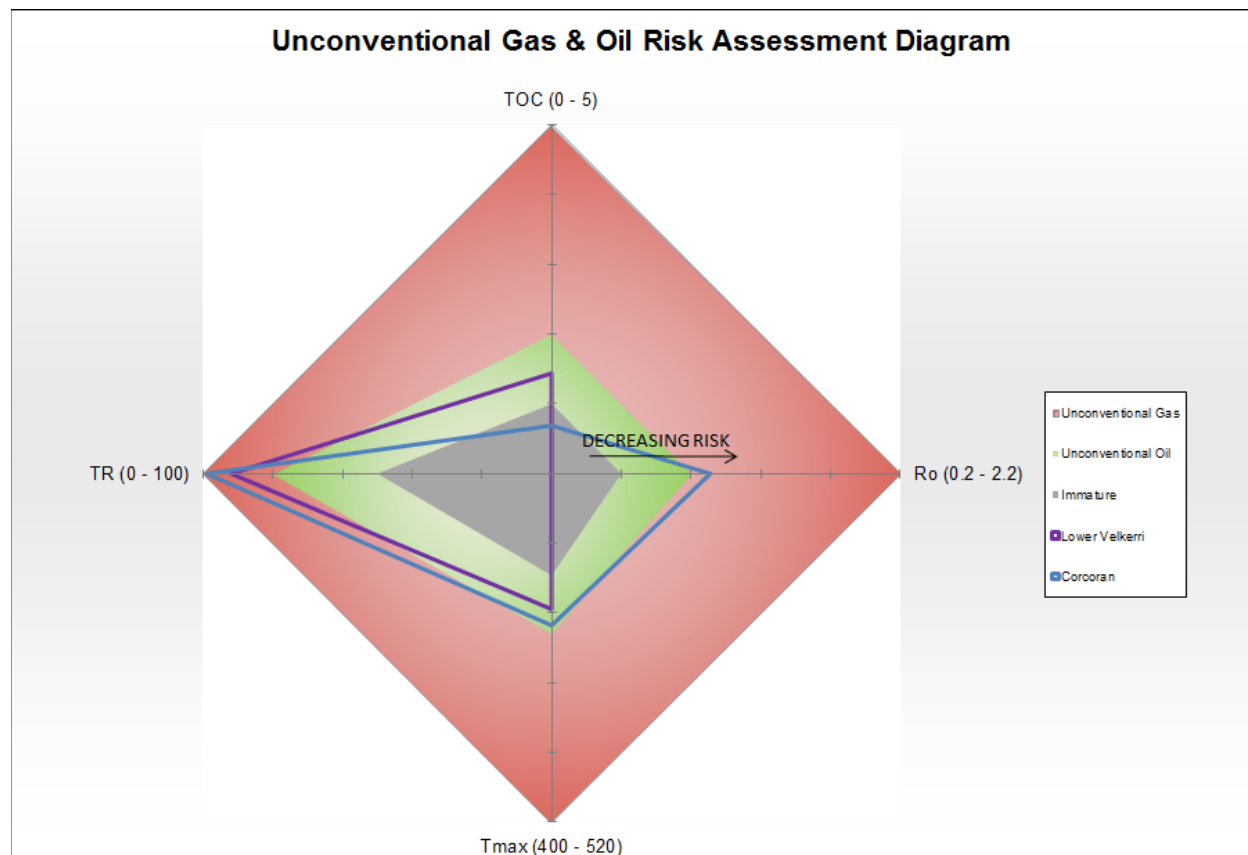
## UNCONVENTIONAL OIL & GAS RISK ASSESSMENT

The Mesoproterozoic Lower Velkerri and Corcoran Formation source rocks in the Golden Grove 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. 5) based upon published results from the Barnett Shale in the Fort Worth Basin. The data illustrated in the star plot represents average values for all four diagnostic ratios. 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<sub>o</sub> estimates using measured and interpreted fractional composition of kerogen macerals.

The Lower Velkerri source rock interval in the Golden Grove 1 well is interpreted to represent a moderate geochemical risk for in-situ shale oil production. The average measured TOC content of 1.44 wt.% is above the generally accepted minimum value of 1% TOC to be considered an *effective* source rock for hydrocarbon generation/expulsion (Fig. 5). However, it is below the minimum requirements of 2 wt.% for *economic* petroleum source rocks, which is also the minimum threshold for prospective shale gas. Also, the TOC depth trend within this interval show that the majority of the formation has TOC values that are near or below 1 wt.% (Fig. 1). Original organic matter type is interpreted to be predominantly oil-prone Type II marine algal kerogen. Thermal maturity parameters from programmed pyrolysis place the Lower Velkerri source interval in peak oil window. The average Tmax value of 447°C is above recommended minimum value of 435°C for shale oil, but below the minimum of 455°C for shale gas (Fig. 5). This amount of conversion would likely be sufficient to generate/expel moderate amounts of hydrocarbons from this oil prone source facies. Transformation Ratios (TR), the least constrained risk parameter,

average 92% and fall above the recommended minimum of 50% for shale oil and 80% for shale gas systems (Fig. 5).

The underlying Corcoran Formation interval examined in the current study is considered to represent high risk for in-situ shale oil production. The Corcoran samples have an average TOC of only 0.69 wt.%, which is below the generally accepted minimum value of 1% TOC to be considered an *effective* source rock for hydrocarbon generation/expulsion (Fig. 5), although a few samples in the upper portion of this interval do exceed this threshold. Original organic matter type is interpreted to be predominantly oil-prone Type II marine algal kerogen based upon select measured visual kerogen analyses. Thermal maturity indicators suggest late oil to early condensate/wet gas window maturity. The average Tmax value of 452°C is between recommended minimum values of 435°C for shale oil and 455°C for shale gas (Fig. 5).

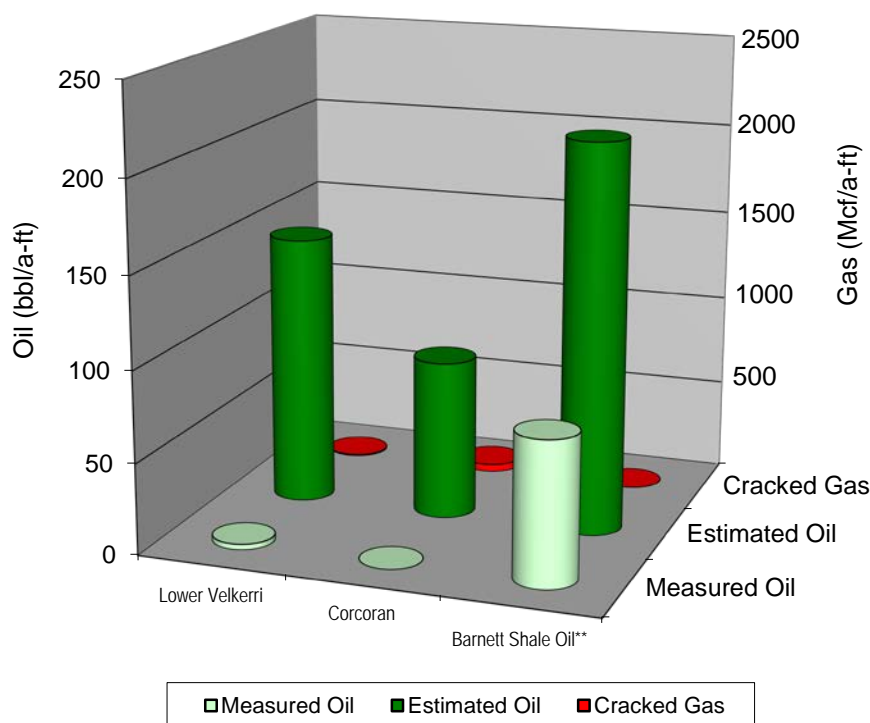


**Figure 5. Geochemical Risk Assessment diagram for Mesoproterozoic Velkerri and Corcoran source rocks in the Golden Grove 1 well.**

Transformation Ratios (TR), the least constrained risk parameter, average 99% and fall above the recommended minimum of 50% for shale oil and above the 80% threshold for shale gas systems (Fig. 5). Measured maceral reflectance values in the Corcoran Formation give a mean for low reflectance solid bitumen of 1.11%  $R_o$ , which is above the recommended minimum threshold of 0.5%  $R_o$  for shale oil and also above the minimum of 1.0%  $R_o$  for shale gas (Fig. 5).

In both of the source intervals examined in the Golden Grove 1 well, measured in-situ oil saturation determined by programmed pyrolysis S1 yields is poor (avg. 0 to 3 bbl oil/acre-ft), which is a significant concern regarding risk assessment for unconventional oil (Fig. 6). Hydrocarbon yield calculations on as-received samples show estimates of average generated oil from the Lower Velkerri 148 bbl oil/acre-ft, along with minor amounts of secondary cracked gas (7 Mcf/acre-ft). In the Corcoran Formation hydrocarbon yields show 87 bbl oil/acre-ft along with 41 Mcf/acre-ft of secondary cracked gas (Fig. 6). 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 (Fig. 6). These values are much higher compared to the formations examined from this well primarily due to differences in organic richness (Barnett Shale oil example has average of 4.70 wt.% TOC). While the generated oil yields of the Lower Velkerri are about 70% as much as the Barnett Shale, the in-situ oil saturations are significantly lower. This is the reason the Lower Velkerri is considered a moderate risk for commercial shale oil development, despite having all relevant parameters of the risk assessment diagram (Fig. 5) within the low risk area. Further investigation is needed to assess the reasons why measured in-situ hydrocarbon saturation is so low within the Lower Velkerri and Corcoran intervals. It is likely that any in-situ oil saturation has migrated out of these source facies (est. 98 to 100% expulsion) as a consequence of uplift/erosion within the basin, since the depth of these sampled intervals in the Golden Grove 1 well is only ~27–392 m deep.



**Figure 6. Hydrocarbon yield estimates for the Mesoproterozoic source rocks in the Golden Grove 1 well compared to Barnett Shale in the oil window.**

## GEOCHEMICAL SUMMARY

The Lower Velkerri source interval in the Golden Grove 1 well is interpreted to represent moderate geochemical risk for unconventional shale oil development. It clearly has elevated organic richness (avg. 1.44 wt.% TOC) and is considered a good source rock with dominantly oil-prone Type II kerogen. Thermal maturity parameters indicate that this source interval is in the peak oil window, 0.88% Calc.  $R_o$  with a Transformation Ratio of 92%. Although all key risk ratios are above recommended minimum thresholds for shale oil systems, the measured in-situ oil saturations are low (avg. 3 bbl oil/acre-ft). The Lower Velkerri has likely generated moderate amounts of oil (avg. 148 bbl oil /acre-ft), but it appears likely that most of this oil has been expelled from the source rock interval. Risk criteria like the S1 versus TOC show no oil cross-over for any of the samples in this interval confirming the elevated risk assessment. Further evaluation of in-situ oil characteristics would be required to fully evaluate potential oil mobility and recovery risk.

The Corcoran Formation interval in the Golden Grove 1 well is considered a high geochemical risk for shale oil due primarily to its low organic richness (avg. 0.69 wt. % TOC). This interval has oil-prone Type II kerogen and is within the late oil to early condensate/wet gas window, 0.98% Calc.  $R_o$  and 1.11% measured  $R_o$  with a Transformation Ratio of 99%. The Corcoran has likely generated moderate amounts of oil and gas (avg. 87 bbl oil/acre-ft; 41 Mcf gas/acre-ft), but in-situ oil saturations are nil (0 bbl oil/acre-ft) and most of the generated hydrocarbons have likely been expelled.

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# Appendix I

*Hydrocarbon Yield Calculation*

*Shelf Group*

*Golden Grove 1*

McArthur Basin Integrated Petroleum Geochemistry, 2016

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## Hydrocarbon Yield Calculation

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