Source Rock Characterization of the Carboniferous Golata Formation and Devonian Besa River Formation Outcrops, Liard Basin, Northwest Territories

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Summary

The evaluation of regional stratigraphic relationships and geochemical characteristics of Devonian to Carboniferous age shales in the Liard Basin area of the Northwest Territories is necessary for the assessment of shale gas exploration potential for this region. Field studies of the Golata Formation were conducted at Etanda Lakes and Sheaf Creek in 2012 and 2013, respectively. Besa River Formation field studies were conducted at Nahanni River in 2013 (Figure 1). Geochemical studies currently completed on the Golata and Besa River Formations samples include: 1) Rock Eval/TOC, 2) vitrinite reflectance, ICP-ES and ICP-MS (lithogeochemistry).
The Golata Formation at Etanda Lakes and Sheaf Creek is characterized by relatively low uranium abundance, moderate levels of terrigenous input and detrital clays, and relatively high silica content. Combined with outcrop observations, these data support the interpretation that the Golata Formation was deposited in a prodelta environment. Rock-Eval, vitrinite reflectance and TOC data from Etanda Lakes indicates that the Golata Formation is a fair to good source rock. The Besa River Formation at Nahanni River is characterized by enrichment in uranium and vanadium, a relatively low level of terrigenous input, and high silica content. These data indicate that the Besa River shales were deposited in a reducing, anoxic, low energy environment. Full results of this study will be published by the Northwest Territories Geoscience Office (NTGO) as an Open Report. X-ray diffraction (XRD) results for all three sections, TOC and vitrinite reflectance data for Sheaf Creek and Nahanni River will be incorporated into the report once available.

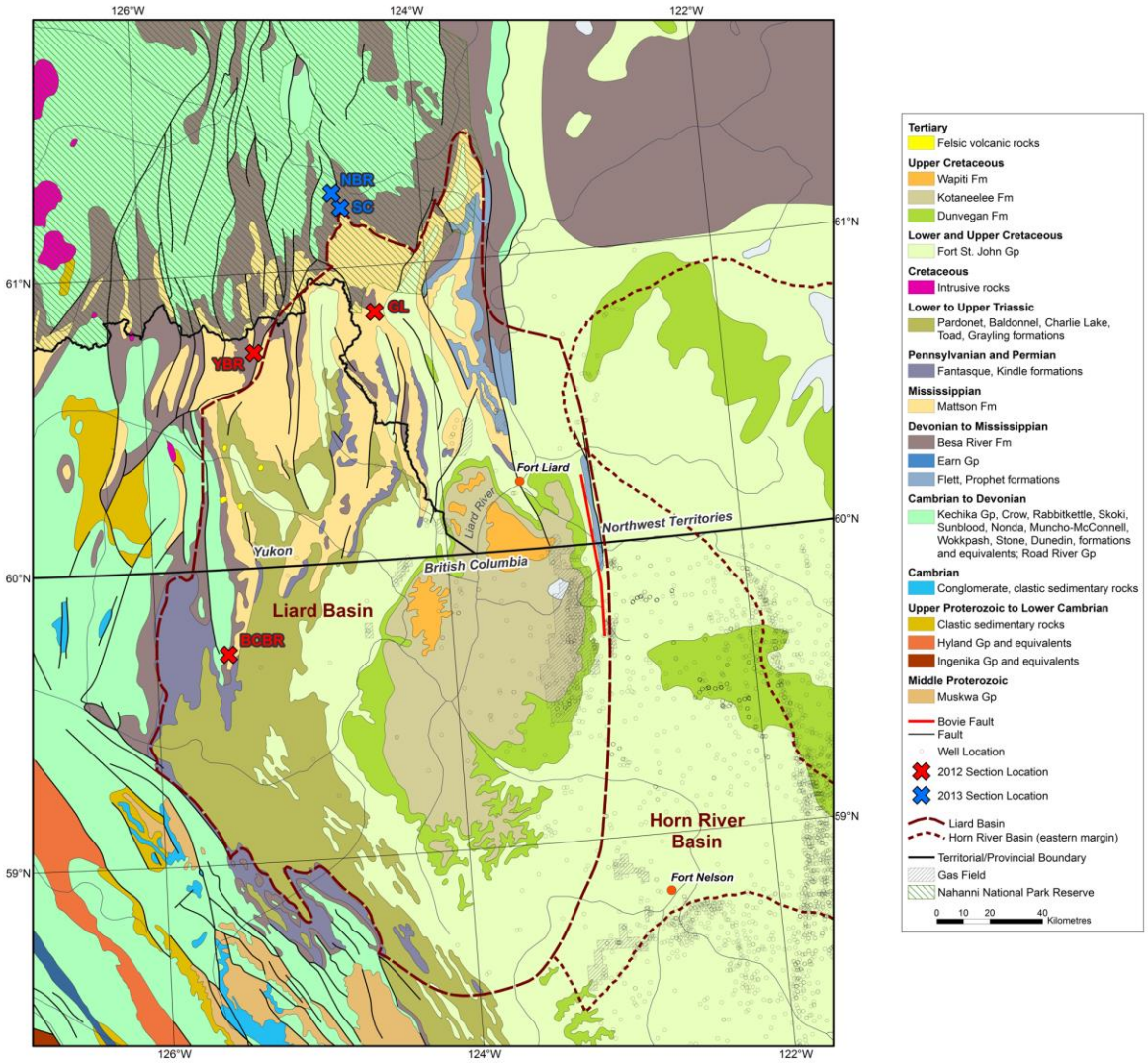

Figure 1: Geology of the Liard Basin region. This map also shows oil and gas wells, territorial and provincial boundaries, Bovie Fault and stratigraphic sections measured in both 2012 and 2013 (geology after Wheeler & McFeely, 1991).

Introduction

The Besa River Formation was first described at the type section near the Muskwa River (Kidd, 1963). At this locality, it is approximately 1000 m thick and occurs as dark grey to black shales, varying from slightly calcareous to non-calcareous, with little fossil content. The shales of the Besa River Formation were interpreted to have been deposited in a moderately deep basin floor environment (Richards, 1989). More recently, Ferri et al. (2011) shows that the Besa River Formation ranges from Devonian to Carboniferous in age and represents basinal equivalents of similar aged carbonate ramps units. The Besa River Formation is a known source rock in Liard Basin and a likely source rock for the Bovie Structural gas play (Hannigan et al., 2011). The Carboniferous Golata Formation was first described by Halbertsma (1959) at the Imperial Belloy 12-14-78-1W6 well near Peace River, AB. At its type location the Golata

Formation is approximately 53 m thick and consists of fossiliferous, argillaceous limestones that grade upwards into green or grey shales with occasional anhydrite and thin coal beds. In the Liard Basin area, the Golata Formation varies in thickness from 0 to over 500 m and is interpreted to have been deposited in a prodelta setting (Richards, 1989).

Field studies in the Liard Basin of the Northwest Territories were conducted as part of the Liard Basin Hydrocarbon Project, a field- and subsurface-based study being conducted by the NTGO in collaboration with the Yukon Geological Survey and the British Columbia Ministry of Energy, Mines, and Natural Gas. One of the main objectives of the study is to extensively characterize Devonian to Carboniferous age shale formations in outcrop to facilitate correlation with subsurface wells in the Northwest Territories and other jurisdictions.

Theory and/or Method

Over the course of two field seasons, three outcrops totalling 359 m of strata were measured and described. Spectral gamma ray measurements were taken every metre in order to create a gamma ray profile for each outcrop. Chips samples were taken at two-metre intervals and were subjected to multiple analyses. Source rock potential and organic content were determined using Rock-Eval, total organic carbon (TOC) and vitrinite reflectance. XRD was used to determine mineralogy and ICP-MS to provide abundances of major oxides and trace elements. Carbonate concretions were sampled and analysed for conodonts in order to determine age and the degree of thermal alteration. Thin sections were made from select coarser-grained intervals to coarsely estimate proportions of major minerals and porosity.

Major oxide and trace element data can be used to estimate relative mineral abundances, select rock properties and depositional conditions. Weight percent SiO_2 can be used to estimate quartz content and assess formation brittleness. Uranium abundance profiles tend to follow TOC trends because the reduction of that element is tied to bacterial activity and the abundance of organic matter (Tribovillard et al., 2006). Due to uranium being a major contributor to spectral gamma ray counts, both profiles tend to correlate well. The SiO_2/Zr trend can highlight intervals of excess silica relative to terrigenous input. The excess silica in these intervals is interpreted as biogenically derived (Wright et al., 2010). A terrigenous input profile is the summation of major oxides most related to land-derived sediment, and is typically mirrored by the Th/U trend, which serves as a proxy for detrital clay input (Hildred and Rice, 2012). Finally, a calculated EFV (enrichment factor of vanadium) serves as a proxy for depositional redox conditions (Tribovillard et al., 2006).

Etanda Lakes & Sheaf Creek – Golata Formation

The Golata Formation at the Etanda Lakes section comprises mainly mudstone and shale, with minor beds of siltstone, dolomitic lime mudstone or dolostone, and sandstone which increases up section toward the base of the Mattson Formation. At Sheaf Creek, the Golata Formation consists mostly of shale and silty shale, grading upwards into siltstone and very fine sandstone. It also contains minor limestone, lime mudstone, and dolostone. The thickness of the Golata Formation in the study area varies substantially between the two sections, from approximately 500m at Etanda Lakes (only lower 232m measured) to 78m at Sheaf Creek.

Samples from the Golata Formation at Etanda Lakes yielded TOC values that ranged from 0.37 to 24.32 weight %, with approximately 83% of samples between 0.5 and 2.0 weight %. These results indicate that the Golata Formation at Etanda Lakes is comprised of fair to good source rocks. Vitrinite reflectance analyses from the base and top of this section yielded values greater than 1.5 % Ro (gas-generating), in agreement with a conodont color alteration index of 3 (110ºC-200ºC) from the middle of the measured section. Whole rock lithogeochemistry analyses indicate total silica values ranging from 33.93% to 71.13%. Uranium abundance values range from 1.4 to 4.1 ppm, with an average of approximately 2.4 ppm. The uranium abundance trend generally follows the TOC profile for the section (Figure 2). Terrigenous input values in the Golata Formation at Etanda Lakes range from approximately 11.19 to 29.55 weight %, with an average of approximately 23 weight %. The terrigenous input profile is closely followed by the Th/U trend. The Si/Zr trend is the inverse of the terrigenous input proxies, which indicates the lack of biogenic silica in the formation. Finally, the EFV trend generally follows the TOC profile, which is typical of rocks with average TOC values equal to or less than 2 weight % and relatively low uranium abundances (Tribovillard et al., 2006). Relatively high terrigenous input values, lack of excess silica and uranium seem to indicate a proximal depositional environment. Lithological observations in outcrop combined with a generally upwards-coarsening trend support a prodelta environment interpretation by Richards (1989).

Samples from the Golata Formation at Sheaf Creek have yielded total silica values ranging from 22.39% to 82.09%, with over 50% of the samples containing above 70 weight % SiO_2. Since TOC results are not yet available, the uranium abundance profile is used as a proxy for the TOC profile for comparison with other trends. Uranium abundance values range from 2 to 3.6 ppm, with an average of approximately 2.6 ppm. The Th/U trend generally follows the terrigenous input profile with the exclusion of samples from a bed anomalously enriched in Fe_2O_3, possibly due to diagenetic changes. The terrigenous input values range from 10.74 to 30.67 weight %, with an average of approximately 20 weight %. The Si/Zr values are relatively low and the trend does not correlate well to the inverse of the terrigenous input profile, which indicates a relative enrichment of Zr. This matches observations in outcrop, which shows an increase in coarser-grained sediment vertically through the section. The EFV trend generally follows the uranium abundance profile, which is typical since the uranium abundance in the Golata Formation at Sheaf Creek is not significantly different from the uranium abundance at Etanda Lakes (Figure 2). Analysis of a thin section of Golata Formation siltstone revealed that they are composed mostly of quartz (approximately 80%), clay minerals (approximately 15%), with trace altered feldspar grains and muscovite. Clay minerals were present within discrete laminations at macroscopic scale and along grain boundaries. Porosity was visually estimated at approximately 5%. Comparison of geochemical trends may be of limited use at the Sheaf Creek site due to an increased detrital influence compared to Etanda Lakes. The 54 to 78 m portion of the section is increasingly dominated by silt to sand-sized quartz grains, highlighting an increase in detrital sediment not captured by the terrigenous input profile. Similarity of uranium abundance values to the Etanda Lakes section may indicate similar TOC values, which can only be confirmed once that analysis is complete. In general, geochemical trends and outcrop observations indicate a similar depositional setting to that at Etanda Lakes. The much thinner Golata Formation at Sheaf Creek and the greater abundance of silt and sand confirm that it was deposited nearer to the delta front at that location.

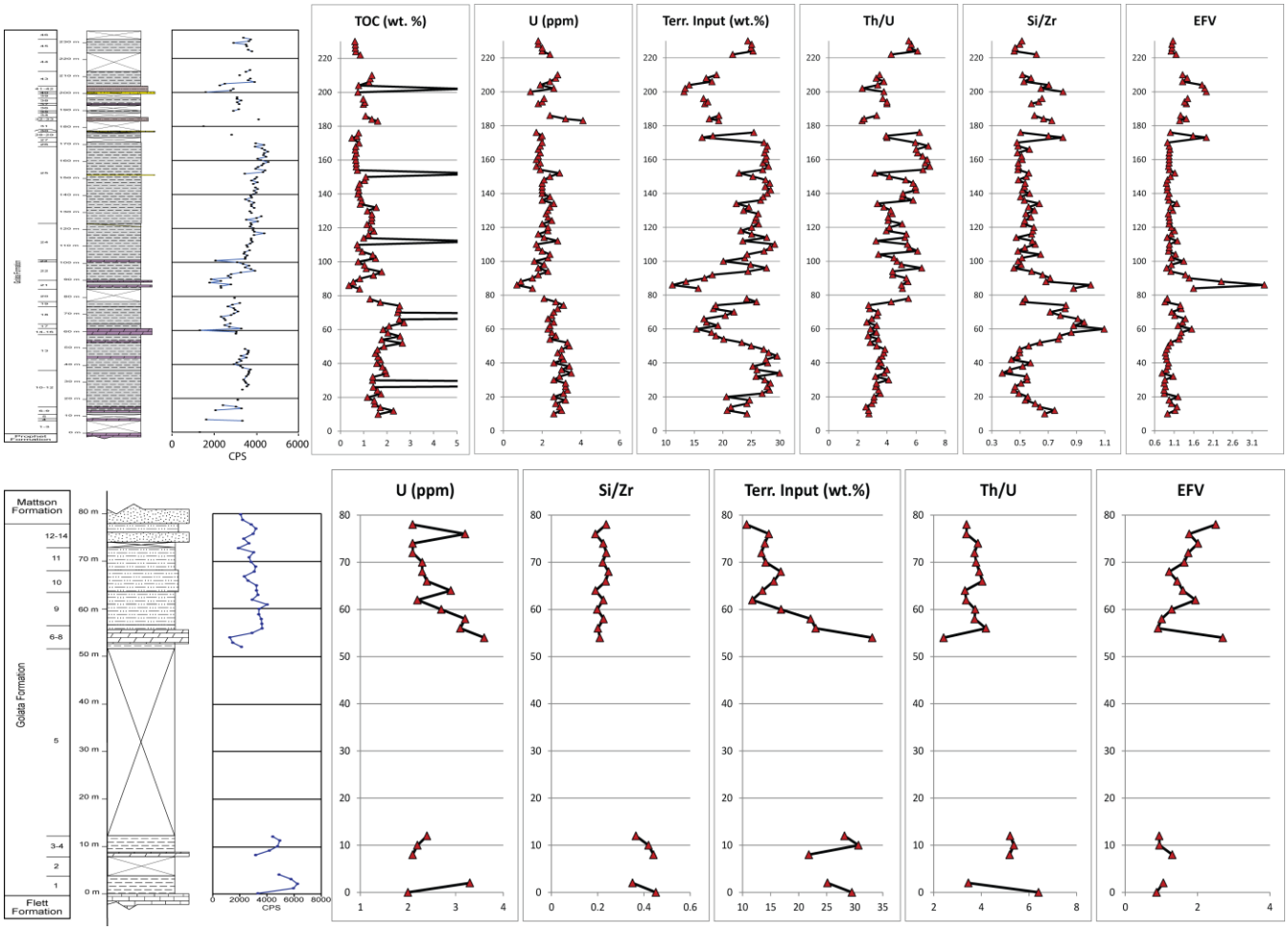

Figure 2: Select geochemical data and ratios from the Golata Formation at Etanda Lakes (top) and Sheaf Creek (bottom).

Nahanni River – Besa River Formation

The section near the Nahanni River measured during the 2013 field season is an exposure of 49m of Besa River Formation stratigraphy. The section is composed mostly of medium to dark grey shale and calcareous shale, with minor mudstone and lime mud concretions. No fossils were observed in outcrop.

Whole rock lithogeochemistry analyses from the Nahanni River section indicate total silica values ranging from 51.39% to 87.58%, with over 75% of the samples containing greater than 80 weight % SiO_2. Uranium abundances range from 3.6 to 10.3 ppm, with an average of approximately 6.6 ppm. The uranium abundance curve is used as a proxy for TOC since those results are not yet available. Terrigenous input values range from 6.53 to 14.43 weight %, with an average of approximately 8.5 weight %. The terrigenous input profile and the Si/Zr trend are generally the inverse of each other, indicating the lack of excess silica in the section. The Th/U trend weakly correlates with the terrigenous input profile, which may be related to the uranium enrichment in the section. Finally, the EFV trend appears to be completely decoupled from the uranium abundance, which can be due to several factors (see Figure 3). In rocks enriched with vanadium or with relatively high average TOC values (>2.0 weight %), the EFV trend may no longer correlate with either TOC or U abundance (Tribovillard et al, 2006). Therefore, this lack

of correlation may indicate that TOC values in the Besa River Formation may be relatively high compared to those in the Golata Formation. Significantly lower terrigenous input values indicate a more distal depositional environment than the Golata Formation, possibly a low-energy basin floor setting similar to Richards' (1989) interpretation. High EFV values and uranium abundances along with low Fe_2O_3 concentrations indicate a reducing environment. Lack of biogenic silica is supported by the lack of visible fossils in outcrop and the absence of spiculite or cherty beds at Nahanni River that have been identified in other sections of the Besa River Formation (Richards, 1989; Ferri et al., 2011).

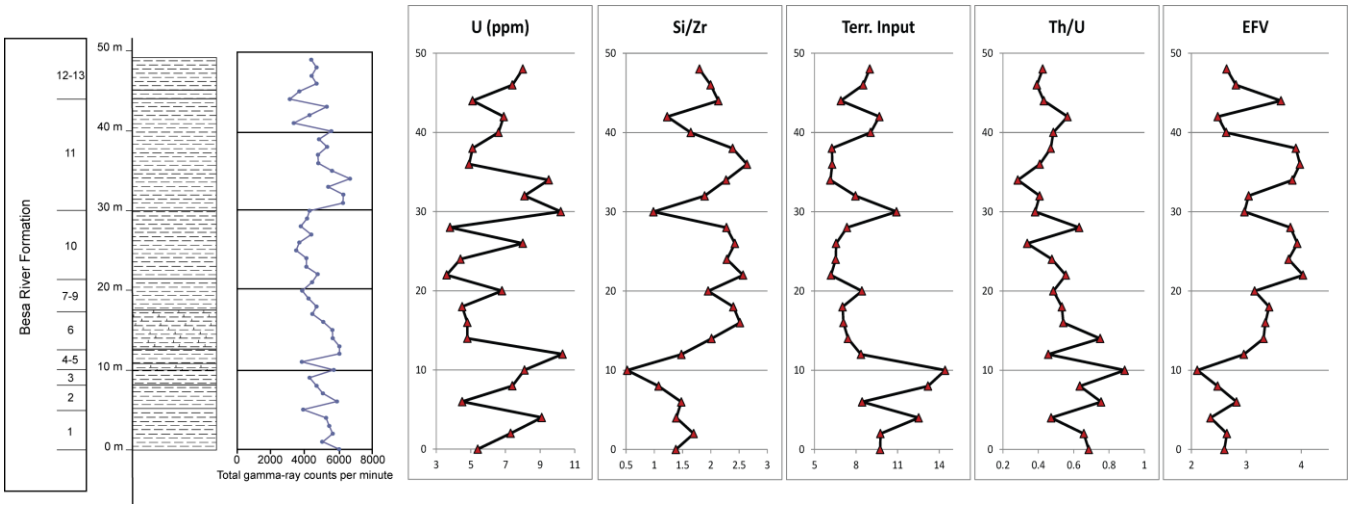

Figure 3: Select geochemical data and ratios from the Besa River Formation at Nahanni River.

Conclusions

The Golata Formation at Etanda Lakes is comprised of organic rich shales that are thermally mature for gas. These shales are also characterized by high silica content with an average value of approximately 58 weight % and display a high degree of brittleness. Lithogeochemical profiles of U, Si/Zr, terrigenous input, Th/U, and EFV show a range of values that favor a prodelta environment of deposition.

At Sheaf Creek the Golata Formation shales are characterized by high silica content with an average value of approximately 66 weight % and display a high degree of brittleness. Lithogeochemical profiles of U, Si/Zr, terrigenous input, Th/U, and EFV show a range of values that favor a prodelta environment of deposition. A rapid upward-coarsening trend, laminated siltstone/fine sandstone, and relative thinness of the Golata Formation favour a more proximal depositional setting than at the Etanda Lakes site. XRD, TOC, Rock-Eval and vitrinite reflectance data for this section will be released as soon as available.

The Besa River Formation at Nahanni River is characterized by very high silica content with and average value of approximately 80 weight % and display a high degree of brittleness. Lithogeochemical profiles of U, Si/Zr, terrigenous input, Th/U, and EFV show a range of values that favour an anoxic basin floor depositional setting. XRD, TOC, Rock-Eval and vitrinite reflectance data for this section will be released as soon as available.

Acknowledgements

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