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A stratigraphic framework for the Ford Lake Shale Formation of north Yukon and its unconventional liquids potential

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Introduction

The Famennian-Tournaisian Ford Lake Shale extends across northern Yukon from Kandik Basin in the west to Peel Plateau in the east. Previous studies on its probable correlative, unit 'Cf' (Allen *et al.* 2015) in the east Richardson Mountains and Peel Plateau, concluded that the shale was a previously overlooked unconventional petroleum target which shows potential as a good to very good source rock with good to very good oil generation potential. The aims of this study are to correlate all measured field outcrop sections of the Ford Lake Shale to date from the Ogilvie Mountains and southeastern margin of Eagle Plain Basin and evaluate its potential for unconventional gas and liquids. The main objectives of this study are to: 1) correlate sections using $\delta^{13}C_{org}$ stable isotopes and lithogeochemical data acquired from ICP and ICP/MS; 2) define oil and gas windows using vitrinite reflectance (%Ro) as a thermal maturity indicator; 3) evaluate kerogen quantity and quality using total organic carbon (TOC) content and RockEval data; and 4) interpret the paleogeography using lithological logs and chemostratigraphic trends. Analytical work for this study was carried out on homogenised 2m-interval rock chip samples collected from outcrop sections during the summers of 2014 and 2015.

Results

Correlations & chemostratigraphy

Field sections for this study from southwest to northeast include: Ogilvie North, Engineer Creek, Dempster Highway, Canyon Creek and Driving Range. Data from the east Richardson Mountains (where available from Allen *et al.* 2015, and referenced herein as unit 'Cf') are also included to extend this section line further east into Peel Plateau. The Ogilvie North, Dempster Highway and Driving Range sections were correlated using similarities in $\delta^{13}C_{org}$ stable isotope trends. The Engineer Creek section was then correlated to Ogilvie North using a maximum flooding surface bounded by retrogradational and progradational parasequences interpreted in gamma ray (Hutchison & Fraser 2014). Finally, Canyon Creek was correlated to Dempster Highway using lithogeochemistry by matching comparable spikes in Ca/Al ratios and a trend of decreasing Zr concentration relative to SiO_2 that suggests an increase in biogenic silica content (e.g. Blood *et al.* 2013). Overall, however, the sections are dominated by detrital silica indicated by covarying Zr and SiO_2 trends. High brittleness indices ranging from 0.83-0.89 indicate the shale will respond well to artificial stimulation by hydraulic fracturing, although a high proportion of dolomite-cemented silt and sandstone beds in the Ogilvie River and Engineer Creek sections will result in reduced net pay thicknesses in this area. High Ni/Co and low Mo/TOC ratios, together with high TOC in part of the Dempster Highway section indicates anoxic bottom waters and a possible restricted basin (Algeo & Lyons 2006), but in general sections are dominated by high terrestrial input profiles and elevated Th concentrations.

Maturity & petroleum potential

Vitrinite reflectance and T_{max} values were compared to current maturity definitions (Jarvie 2015) to define the oil and gas windows and their distribution across the study area. Ogilvie North, Engineer Creek and Dempster Highway fall within the dry gas window (%Ro>1.60) in the southwest, while the remaining sections in the northeast fall within the oil window (%Ro<0.95). Sample T_{max} and production index histograms from Canyon Creek and unit 'Cf' also show early (435-445^{o}C) to peak (445-450^{o}C) oil maturity and oil generation potential.

RockEval data, specifically oxygen index, hydrogen index, S2 and TOC were used to determine kerogen quantity and quality. A general trend of increasing TOC to the northeast is present which ranges from 1.2wt% at Ogilvie North to 4.4wt% at Driving Range. Canyon Creek and unit 'Cf' have mixtures of kerogen types II and III, inferring that organic matter was derived from both marine and terrestrial sources. A general trend of a more marine source is evident towards the southeast. The Driving Range section is predominantly terrestrial type III kerogen. Based on a plot of TOC versus total generation potential (S1+S2) modified from Harris (2015), Canyon Creek, Driving Range and unit 'Cf' plot within an ideal source rock window (high TOC, high generation potential). The Dempster Highway section has a sweet spot interval for gas between 36-48m measured stratigraphic depth defined by high TOC, the presence of biogenic silica and low terrestrial influx. Canyon Creek has a low proportion of non-net pay lithologies (silt/sandstone) and a sweet spot interval focused between 55-56m measured stratigraphic depth. Ogilvie North and Engineer Creek are not considered viable unconventional reservoirs due to low TOC (<2%, c.f. Zou 2013) and a high proportion of non pay lithologies.

Basin redox & paleogeography

In the southwest, low Ni/Co ratios and TOC values suggest open, oxic water conditions during shale deposition at Ogilvie River and Engineer Creek. An erratic, fluctuating $\delta^{13}C_{org}$ isotope signature at the base of the section suggests fluvial influence and close proximity to shoreline. This is supported by the incorporation of bioclastic detritus, possibly shed from a nearby reef during storm reworking or lowstand erosion, and an increase in diagenetic carbonate in the base of the Ogilvie North section. Low terrestrial input profiles and low Mo/TOC ratios in the bottom half of the Dempster Highway section suggest a bathymetric high separated it from Ogilvie North, Engineer Creek and Canyon Creek. The upper half of Dempster Highway and Canyon Creek sections show similarities in lithogeochemical parameters, suggesting these previously restricted areas achieved connectivity due to sea level rise or basin floor subsidence. Much higher TOC values suggest that the Dempster Highway section did not experience the same controls on organic matter preservation as Ogilvie North and Engineer Creek despite their geographic proximity and position in the gas window. The Dempster Highway section more closely correlates to sections within the oil window based on similar chemostratigraphic trends. Ripple laminations and woody debris in Driving Range suggest proximity to the shore compared to Dempster Highway and Canyon Creek. Basin bathymetric relief (sills) may have been formed by fault block rotation in response to back-arc extension off the west coast of Laurentia during Devonian to early Mississippian rifting (e.g. Nelson, 1993; Murphy *et al.* 2006).

Conclusions & implications for petroleum exploration

Sections of Ford Lake Shale can be correlated across the north of Yukon Territory using stable carbon isotopes ($\delta^{13}C_{org}$), chemostratigraphy and parasequences interpreted from gamma ray. With low TOC and low net pay, the Ford Lake Shale at Ogilvie River and Engineer Creek would not represent prospective unconventional targets. The Dempster Highway section, which falls within the gas window, shows high potential as an unconventional reservoir with an interval of high TOC and biogenic silica at 36-48m measured stratigraphic depth. Canyon Creek and unit 'Cf' sections are in the oil window and have high potential for liquids, with kerogen type II/III, and good generation potential. From northeast to southwest, the Ford Lake Shale is expected to transition from the oil window into the gas window. Although immature with respect to oil at surface, results from the Driving Range section suggest the potential for unconventional liquids recovery from this formation in the subsurface of southeastern Eagle Plain Basin – an area currently under active exploration for conventional hydrocarbons in north Yukon.

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