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Petroleum Potential of the Souris Valley Beds of the Lodgepole Formation in Southern Saskatchewan

Sienna R. Johnson, Department of Geology, University of Regina
Stephen L. Bend, Department of Geology, University of Regina

Summary

The overall goal of this study is to determine the petroleum potential of the Madison Group Souris Valley 'B-Member' (Lodgepole Formation) in southern Saskatchewan. To facilitate that goal, this study aims to further our understanding of the petrophysical characteristics of the 'B-Member' such as: the density/ frequency of bedding laminae, petroleum potential using using organic petrography, fracture analysis (density and fracture propagation direction), Rock Eval pyrolysis and bitumen fractional analysis, and carbonate/silicate ratios in conjunction with the high resolution sampling of oriented core. Initial studies indicate that one core from well Silver Hawk Hardy 01/07-9-4-21W2 has significant petroleum potential. Organic petrography of lamination density indicates generally 4 to 12 laminae per centimetre and a cyclic nature to their presence/absence, suggesting their existence is linked to alternations in organic matter content. Fracture frequency and orientation analysis found that micro-fractures are moderately mutually exclusive: either being dominantly parallel-to or cross-cutting the laminae. Stereonet-rose analysis of these cross-cutting fractures trend from 247.5^{o} (WNW) to 22.5^{o} (NNE). The fracture analysis also found that fractures are dominantly bitumen in-filled. A comparison fractional analysis of bitumen within the Souris Valley 'B-Member' and Upper Bakken shale was conducted and found that there was a large difference between aromatic and NSO compounds within the two samples. The Souris Valley 'B-Member' yielded 59.24 wt % aromatics and 32.91 wt % NSOs while the Upper Bakken shale contained 9.16 wt % aromatics and 87.00 wt % NSOs.

Introduction

The Mississippian Souris Valley Beds (Lodgepole Formation) in southern Saskatchewan are mid-ramp to basinal carbonate and consist of alternating laminae of bituminous and bitumen-deficient lime mudstone (Kent, 1997). They represent the basinal unit of the Madison Group and conformably overly the deeper-water classics of the Upper Bakken Shale Member (Sereda, 1990; Kent, 1997; Nickel, 2005).

The Souris Valley Beds vary in thickness from a few meters in the South to West-Central part of Saskatchewan to 224m in the very Southwest corner of Manitoba (Mackie, 2013; TGI Williston Basin Working Group, 2008). Previous studies report that the organic matter within these beds are dominated by Type II kerogen up to 6 wt% TOC and are considered marginal to thermally mature and that they are considered to be the source of most oils (i.e., Family 'C') within the Mississippian Madison Group

(Brooks, et al., 1987; Osadetz, et al., 1992; Jiang et al., 2001). The Souris Valley Beds are also reported to have a high sulphur content up to 3.6 wt% as a characteristic feature (Lillis, 2012).

Using the high resolution sampling of core obtained from the Souris Valley Beds (i.e., 1955m to 1962.5m) from borehole Silver Hawk Hardy 01/07-9-4-21W2 in the Bengough area of southern Saskatchewan, the overall goal of this study is to determine the petroleum potential of the 'B-Member'. Secondary objectives include the determination of lamina density/frequency, geochemical characteristics using organic petrography, Rock Eval pyrolysis and bitumen fractional analysis, fracture analysis (density and fracture propagation direction) and carbonate/silicate ratios.

Methods

The cored interval (1955m to 1962.5m) was slabbed, measured, logged and sampled to give the most detailed analysis and assessment of the Souris Valley 'B-Member' to date. The presence of laminae was analyzed with respect to the density and number of laminae per measured depth interval (every 5 cm), and samples for RockEval VI analysis, bitumen fractional analysis, carbonate/silicate analysis and petrographic analysis were obtained every 5cm from uncontaminated core.

The analysis of laminae density was conducted by adopting the method typically employed by Quaternary geoscientists when seeking to determine lake varve analysis and annual growth events generating an expression of number of laminae per depth interval (Lotter and Lemcke, 1999). Since the core obtained from 01/07-9-4-21W2 is an oriented core, the fracture orientation and density data was recorded either with respect to this datum or within the plane of bedding. Both methods were performed on a per depth interval basis of 5cm. Fractional analysis of extracted bitumen was obtained using a Foss Industries Soxtec extraction method of solvent extraction using an azeotropic mixture of dichloromethane (DCM) and methanol (93:7v/v). Each aliquot of extract was then subsequently fractionated using column liquid chromatography to separate the extractable organic matter into hydrocarbon (saturate and aromatic) and non-hydrocarbon (e.g., nitrogen-, sulphur- and oxygen-bearing compounds) fractions. Light petroleum ether, petroleum ether/dichloromethane (30:70v/v) and dichloromethane/methanol (50:50v/v) respectively as solvent for the elution of each of these fractions. Bulk geochemical analyses were obtained using a Rock Eval VI analyzer according to the method prescribed by (Lafargue *et al*. 1998) and detailed petrographic analysis were conducted in both reflected and transmitted white light, augmented by reflected fluorescent microscopy.

Results and Discussion

Figure 1 is a composite, detailed litho-petrophysical log that conveys the frequency and density of bedding laminae, the presence or absence and frequency of indigenous micro-fractures both within the plane of bedding or those micro-fractures that cross-cut the bedding laminae, and the azimuthal orientation of cross-cutting fractures over this cored interval.

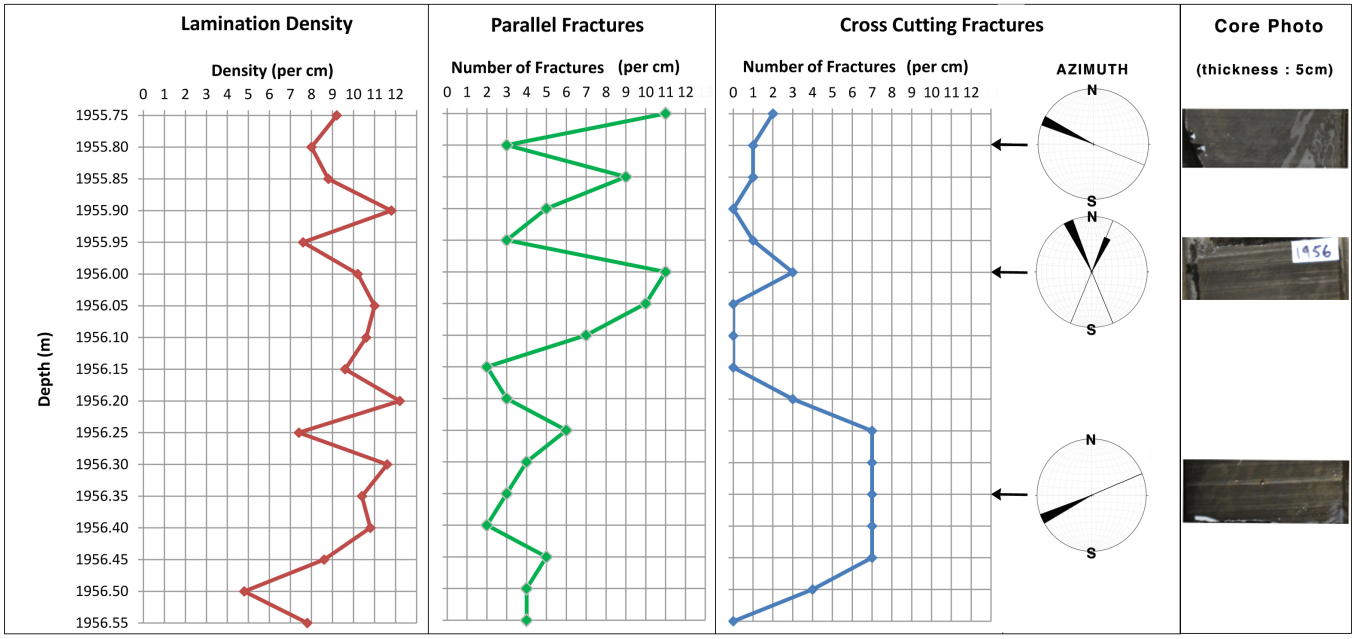

Figure 1. Litho-petrophysical log of density laminae and fracture presence/orientations from a section of Souris Valley 'B-Member' from Well 01/07-9-4-21W2.

The Souris Valley 'B-Member' generally has a highly laminated appearance (Figure 2), in which laminae appear as alternations of dark or light, parallel to slightly sub-parallel, bands that exhibit a gradational boundaries at the microscopic level. Generally occurring with a lamination density of between 4 to 12 laminae per centimetre, initial interpretations suggests the presence of a cyclic nature to the presence/absence and frequency of the laminae. Analysis using UV/autofluorescent light also reveals the distinct appearance of the laminae, suggesting alternations in organic matter content.

Another apparent feature of the Souris Valley 'B-Member' is the existence of micro-fractures, typically in-filled with bitumen (Figure 2). Fracture frequency and orientation analysis was conducted on this oriented core and a distinction made between those micro-fractures that occur within the laminae or are dominantly parallel to them, and those micro-fractures that cross-cut the laminae. Figure 1 shows the depth and number of parallel micro-fractures per centimetre, the depth and number of cross-cutting micro-fractures and the respective azimuthal

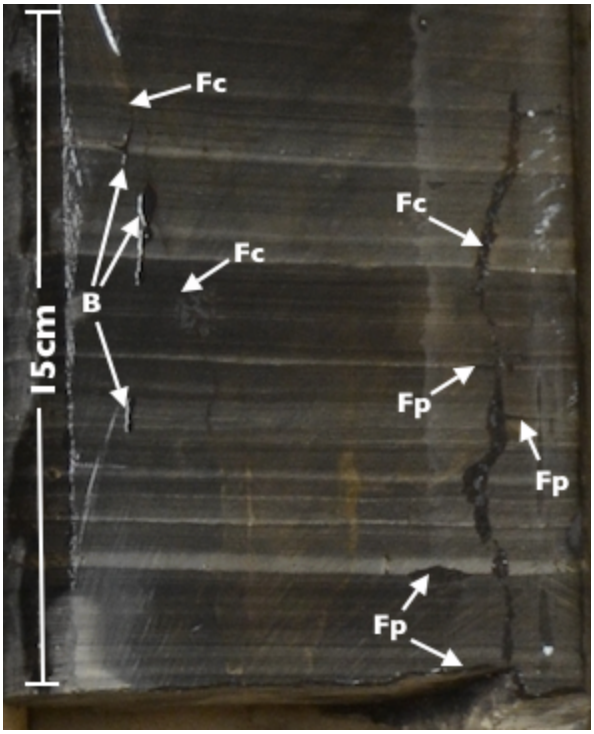

Figure 2. Fracture analysis parameters outlining nomenclature for fractures parallel (Fp) or cross-cutting (Fc) laminations. Bitumen (B) is also a common fracture fill as seen in the core. Core interval is from 1956.4-1956.55m from Well 01/07-9-4-21W2.

orientation of those fractures. Stereonet-rose analysis of fracture orientation indicates dominant fracture orientations that run either parallel to bedding or cross-cut with an orientation trending from 247.5° (WNW) to 22.5° (NNE). The overall dominant trend is 337° (NNW). Furthermore, initial analysis suggests that micro-fractures appear as either being predominantly parallel *or* as cross-cutting, rarely both. Fractures are dominantly bitumen in-filled (Figure 2).

The fractional analysis of bitumen within the Souris Valley 'B-Member' was conducted and directly compared to the Upper Bakken Member shale (Figure 3). The most striking difference is the relative proportion of aromatic compounds within the Souris Valley 'B-Member', which is considerably higher than that of the Upper Bakken. Similarly, the relative proportion of heterocompounds (N, S, O-bearing compounds) is significantly less than that of the Upper Bakken.

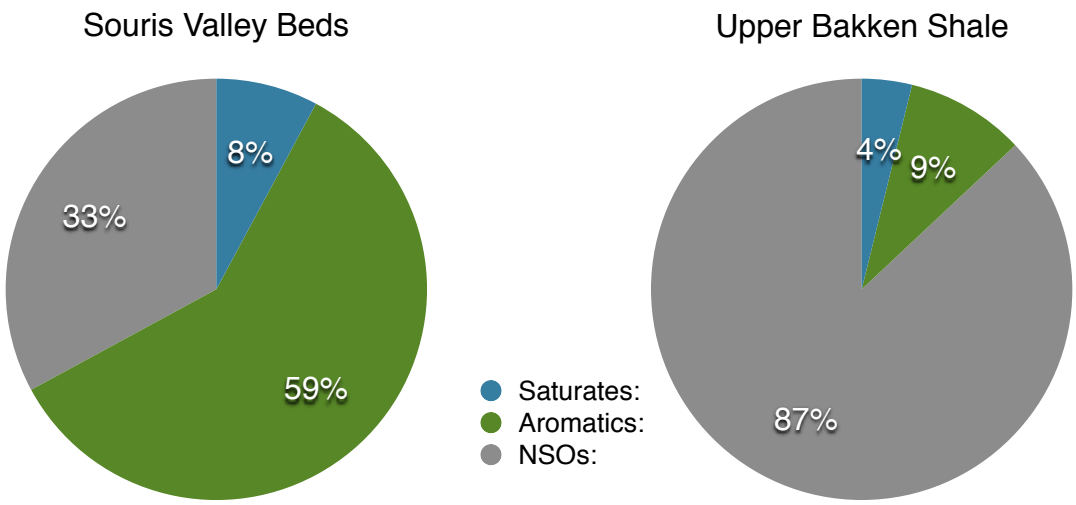

Figure 3**:** Results of fractional analysis on extracted bitumen from sampled core for SV-L and Upper Bakken Shale from Well 01/07-9-4-21W2.

Conclusions

Preliminary analysis suggests that the Souris Valley Beds of the Lodgepole Formation have excellent petroleum potential within southern Saskatchewan, the existence and orientation of pervasive micro-fractures strongly indicate the brittle nature of the Souris Valley 'B-Member' with two fracture orientations predominating between 247.5° (WNW) to 22.5° (NNE). On-going assessment of petroleum generation potential indicates the presence of dominantly aromatic fraction. More detailed analysis will follow.

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