Petroleum Systems and Quantitative Oil Chemometric Models for Heavy Oils in Alberta and Saskatchewan to Characterize Oil-Source Correlations

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GeoConvention 2012:Vision

Produced oils from western Canada in the Kindersley, Lloydminster and Cold Lake heavy oil belt are commonly believed to be genetically sourced from the Type IIS Exshaw shales (south central Alberta) based on the quantitative molecular geochemistry of >100 produced oils from previous work (Obermajer et al., 2004), plus hundreds of produced oil samples from the surrounding basin (Deroo et al., 1977; Brooks et al., 1988; Allan and Creaney, 1991; Creaney and Allan, 1992; Riediger et al., 1993; Osadetz et al., 1994; Li et al., 1996, 1997; Karavas et al., 1998; Stevenson, 1998; Riediger et al., 1999; Manzano-Kareah et al., 2004). However, seven potential source rocks that are thermally mature exist in south central Alberta through the Lower Cretaceous and Paleozoic section, and this study shows that multiple oil families do in fact exist in the heavy oil belt. Oils sourced from rocks other than the Exshaw shale surrounding the heavy oil belt based on biomarker and molecular composition include Ostracode and Duvernay (Q and D) oils observed in the Provost region (Riediger et al., 1999). Also, the Banff/Madison (M) and Exshaw oils are observed in the Medicine Hat region (Manyberries) (Manzano-Kareah et al., 2004).

The potential for oil charge from other source rocks in the region, may in part, explain some of the minor but outstanding differences in biomarker compositions, molecular concentrations (e.g. diamondoids; Fay, 2010) and isotope evidence (Marcano et al., 2011) that are observed in produced oils from the heavy oil belt (Obermajer et al., 2004). Currently, these differences are attributed to source facies and thermal maturity variations. Of particular interest, most reservoirs sampled from the Lloydminster and Cold Lake districts, often in close stratigraphic and regional juxtaposition, appear to contain more carbonate versus clastic sourced oils based on higher C_{24} tetracyclic versus C_{26} tricyclic terpanes and C_{35} homohopane prominence, compared to produced oils from the Kindersley district to the south (Fay, 2010). Plus, Q-compound biomarkers that definitively indicate that Ostracode sourced oils (e.g. Li et al., 1996a, b) exist east of Lloydminster (section 48 to 49-24W3) in Saskatchewan (Fay, 2010), whereas previously these oils were only traced into the Provost district, Alberta (Riediger et al., 1999). Evidence for multiple, active oil-source petroleum systems in southern Alberta and Saskatchewan are important in light of the recent industrial activity in tight oil and shale liquids that primarily target dominantly in situ sourced hydrocarbons, as well as targeting sweet spots for cold heavy oil production. For example, the Bakken-Lodgepole(!) petroleum systems in the Williston Basin are prolific, but the contemporaneous Exshaw-Lodgepole(!) rocks in the Alberta Basin show that the Exshaw Formation has higher TOC and greater overpressure (Osadetz et al., 2011). Overpressure is interpreted to result from additional kerogen to oil, and oil to gas cracking (Jarvie and Benoit, 2011). The question remains, are the differences in produced oils from the Lloydminster and Cold Lake regions related to more carbonate rich rocks in the Exshaw petroleum system south central Alberta, or do Banff source rocks (contemporaneous with Lodgepole source rocks in the Williston Basin) contribute to generated oils in Alberta?

Oil Family	Source Rock	Type	Reference
F2	Cret. Colorado	Type II	Allan and Creany, 1991; Osadetz et al., 1998
Q	Cret. Ostracod	Type I/II	Riediger et al., 1997; Ardic, 1998; Wheeler et al., 2008
F1	Jur. Rierdon	Type II	Karavas et al., 1998
M	Miss. Banff/Madison	Type II	Stevenson, 1998; Manzano-Kareah et al., 2004
C	Miss. Lodgepole	Type II	Osadetz et al., 2004
E	Dev.-Miss. Exshaw	Type II/IIS	Karavas et al., 1998; Riediger et al., 1999; Obermajer et al., 2004
D	L.Dev. Duvernay	Type II/I, low S	Riediger et al., 1999; Fowler et al., 2001

Table 1 – Source rock formations and oil families in southern Alberta and Saskatchewan provinces defined by previous studies.

Previous work has proposed secondary charge into the heavy oil belt to explain the abundance low molecular weight compounds such as light to medium ($C_{5\text{-}8}$ to $C_{12\text{-}30}$) molecular weight alkane and isoprenoid hydrocarbons, when heavier homolog compounds are absent. The interplay of petroleum biodegradation and input of fresh oil charge into severely biodegraded heavy oil reservoirs has resulted in variable fluid properties in the region with dead oil viscosities ranging from 130 to 98,300 cP viscosity (at 20 °C) and API gravities ranging from 8.2° to 21.8° API (at 60 °F) (Fay et al., 2010). The variation in biomarker and molecular compositions of reservoired oils, and the apparent late stage light oil and condensate charge into the heavy belt, suggests either that multiple oil charge pulses occurred from different organofacies and different thermal source kitchens within the Exshaw shale, or that multiple source rocks contribute oils to the region (Fay, 2010).

This study shows good evidence for oils sourced from the Ostracode Shale, and arguably from the Banff shale in south-central Alberta, and the Duvernay Shale in central Alberta. The implications of multiple oil-source petroleum systems in the heavy oil belt may suggest additional targets for shale gas and liquids exploration, and targetable production sweet-spots in heavy oil production using molecular geochemistry.

In this study, alternating least squares (ALS) quantitative oil compositional models are used to calculate theoretical oil-source rock mixing ratios in the region based on the utility of molecular biomarkers. The molecular biomarkers used include the absolute concentrations of C_{27} + C_{29} steranes, Tm, C_{29}H, C_{30}H, C_{34}H and C_{35}H terpanes and C_{32}–C_{35} benzohopanes because these compounds are diagnostic biomarkers to distinguish between the clastic Bakken source rocks and the carbonate Lodgepole source rocks reported by Jiang et al. (2001) for the Williston basin. Additional source rock extract molecular geochemistry analyses are needed for the Ostracode, Banff, Exshaw and Duvernay shales in the Rocky Mountain foreland basin in Alberta and SW Saskatchewan to better trace their generation and expulsion, and to better understand the organofacies distributions of each formation. The ALS oil de-mixing models indicate that reservoired oils in the Kindersley district have 88.3–97.0 wt% of Exshaw oil with minor 3.0–11.7 wt% Banff oil source contributions based on the source rock extract absolute concentration data measured by Jiang et al. (2001) for the Bakken-Lodgepole petroleum system. In comparison, the Lloydminster and Cold Lake districts have 62.5–78.1 wt% of Bakken oil versus 37.5–21.9 wt% Banff oil source contributions.

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