Thermal Maturity and Organic Petrology of the Upper Ordovician Utica and Lorraine Shales, Southern Quebec, Canada*

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Abstract

This study presents the preliminary results of the organic matter characterization of core samples from the Upper Ordovician Utica and Lorraine shales in southwestern Quebec. Samples have generally fair TOC content of ranging from 0.08 to 2.25%. The current TOC content of samples represents only the remaining 94-98% of the residual carbon in the sample. Samples from one of the study wells at the deeper section of the Utica Shale, are in the dry gas zone while shallower samples of Utica and Lorraine shales are in the oil generation window. The thermal maturity data obtained from the Rock-Eval's T_{max} for the over mature samples is not reliable due to negligible S_2 content.

The major organic matter constituents of samples are matrix and migrated solid bitumen and chitinozoan skeletons. Organic carbon comprises up to 4.7% in volume of total rock. A portion of organic matter in the samples may contribute to porosity enhancement, such as matrix pyrobitumen, which is likely resulting from the formation of gas by secondary cracking of bitumen compounds. Porous matrix solid bitumen appears to form during migration and dissemination of hydrocarbon into the porous clay fraction of the rock. This is often associated with significant bacterial sulfate reduction possibly in the early stages of generation and migration of bitumen. Based on organic petrology and Rock-Eval data it appears that the siltstone facies of the Utica Shale especially for the deeply buried section of the Utica Shale in this area acts as a reservoir rather than source rock.

Random vitrinite reflectance (VRo) measurement is shown to be a robust method for indicating the thermal maturity in these samples. Recent improvements in petrographic analysis allow accurate reflectance measurements on nanoscale spots, providing reliable information on thermal maturity. The reflectance has been measured on matrix and solid bitumen and chitinozoan skeletons. There is a significant agreement between bitumen reflectance and chitinozoan reflectance when they are converted to vitrinite reflectance.

Introduction

In the eastern Canada, significant industry interest has recently focused on the Upper Ordovician black shales in southern Quebec and Anticosti Island, it includes the Utica, Lorraine, and Macasty Shale Formations (Bertrand and Lavoie, 2006; Castonguay et al., 2010; Dietrich et al., 2011; Lavoie et al., 2011; Lavoie and Thériault, 2012; Lavoie et al., 2013). Extensive testing through high pressure hydraulic fracturing has been shown that the calcareous shales of the Utica Shale have the capacity to release a significant volume of natural gas (Lavoie and Thériault, 2012). Previous works on the hydrocarbon potential of the Cambrian-Ordovician St. Lawrence Platform and of the Utica Shale source rock led to the understanding of a regional distribution of thermal domains at the surface and at depth for the area (Bertrand and Lavoie, 2006; Lavoie et al., 2009).

The Upper Ordovician deep-marine, thick clastic succession of Utica and Lorraine shales in southern Quebec overlies the predominantly shallow marine carbonate facies of the Cambrian-Ordovician St. Lawrence Platform (Figure 1). The Upper Ordovician Utica Shale (50 to 300 m thick) and Lorraine Shale (500 to 2000 m thick) are found in southern Quebec between Montreal and Quebec City. The calcareous shales of the Utica Shale started to accumulate in a poorly oxygenated setting due to rapid increase in sea level rise, where the carbonate producing zone was partially shut down leaving siliciclastic muds with subordinate carbonate mud to accumulate. The Lorraine Group overlies the Utica Shale (Figure 1), which is a flysch succession dominated by mudstones and siltstones with local thicker bedded sandstones.

Results and Discussion

The present study focuses on results of the Rock-Eval analysis and organic petrology of cores from four wells in the southern Quebec (Figure 2). The Talisman Saint-Edouard #1 (1997 to 2030 m) and Junex Saint-Augustin #1 (351 to 514 m) samples are from the deeply to shallowly-buried Utica section, respectively. While F1 and F4 samples (7 to 57 m) come from near surface shallow wells drilled by the Geological Survey of Canada (GSC) from the Lotbiniere Formation (a correlative of Lorraine Shale) and from a tectonic sliver of the Utica Shale, respectively.

For all samples, the lithology varies from shale to fine to medium grained siltstone and are organic fair (TOC up to 2%). The Utica samples have a significantly higher mineral carbon content (MINC up to 12%) than Lorraine Shale samples (MINC < 1%). The Rock-Eval analysis results show that Talisman Saint-Edouard #1 sample are in the dry gas zone, while the Junex Saint-Augustin #1, GSC F1 and F4 samples are in the oil generation zone. Almost all of the organic matter (94 to 98%) in the Talisman Saint-Edouard #1 samples is inert with no further capacity to generate hydrocarbon. The result shows that over 90% of hydrocarbon is already generated due to a high degree of thermal maturity, suggesting that high levels of gaseous hydrocarbon is already generated and potentially contained within the strata. Due to almost complete conversion of S_2, the Talisman Saint-Edouard #1 samples have very sporadic and unreliable T_{max} values (291 to 609°C). In the other three wells, up to 30% of the remaining organic carbon has potential for a further thermal cracking. This observation is in agreement with the thermal maturity and transformation ratio for type III kerogen.

The main organic constituents of these samples are bitumen and chitinozoan skeletons. New spot measurements of random reflectance on nanoscale particles provide reliable information on thermal maturity. The thermal maturity is determined based on the measured reflectance on bitumen ($VR_{Bitumen}$) and chitinozoan ($VR_{Chitinozoan}$). The measured reflectance is converted to vitrinite reflectance equivalent ($VR_{equiv.}$) using equations of Bertrand and Malo, 2001. There is a very good correlation between converted bitumen reflectance and chitinozoan reflectance to $VR_{equiv.}$. The Talisman Saint-Edouard #1 samples have the highest $VR_{equiv.}$ Values ranging from 1.95 to 2.33% $Ro_{equiv.}$.

The variations in $VR_{equiv.}$ within the Talisman Saint-Edouard #1 are caused by the nature of bitumen accumulation, matrix bitumen often shows lower maturity than the solid accumulated bitumen mostly due to surface quality of the measured area. The $VR_{equiv.}$ values of Junex Saint-Augustin #1, GSC F1, and F4 is significantly lower than those of Talisman Saint-Edouard #1 and varies in a narrow range of 1.06 to 1.3% $Ro_{equiv.}$, which is in accordance with the Rock-Eval's T_{max} values. In the Talisman Saint-Edouard #1 well, samples with higher maturity organic matter have lost the fluorescence properties with no observed light hydrocarbon condensations within the pore spaces. The other samples from three shallower wells are within the oil generation window, the lower maturity levels result in a weak fluorescence capacity and on some occasions there is presence of minor volume of light oil.

The Talisman Saint-Edouard #1 comprises of 0.5 to 4.7% organic carbon in volume. A portion of the organic matter in the samples may generate porosity, such as matrix pyrobitumen, which is likely resulting from the formation of gas by secondary cracking of bitumen compounds. There is also a significant portion of organic matter derived from remnants of zooclasts (chitinozoan) and nonporous solid bitumen often associated with overgrown diagenetic carbonates. Porous matrix solid bitumen appears to be formed during hydrocarbon migration and dissemination of bitumen into the porous clay fraction of the rock. This is often associated with significant bacterial sulfate reduction, possibly in the early stage of oil generation and migration.

Conclusions

The Rock-Eval results show that for the most part the deeply buried samples from the Talisman Saint-Edouard #1 are in the dry gas window while the samples from the less buried samples from the same units in the other wells are in the oil generation window. The organic matter in the Talisman Saint-Edouard #1 samples is composed of inert organic matter with no further potential of hydrocarbon generation while the samples from the other three wells still have some potential for hydrocarbon generation. Vitrinite reflectance equivalent from measurements of bitumen and chitinozoan reflectance strongly correlates. There is a potential for some of organic matter to generate porosity. Based on organic petrology and Rock-Eval data it appears that Utica Shale especially the deeply buried sequence is a hybrid play and organic-lean calcareous siltstone facies may serve as reservoir rather than source rock.

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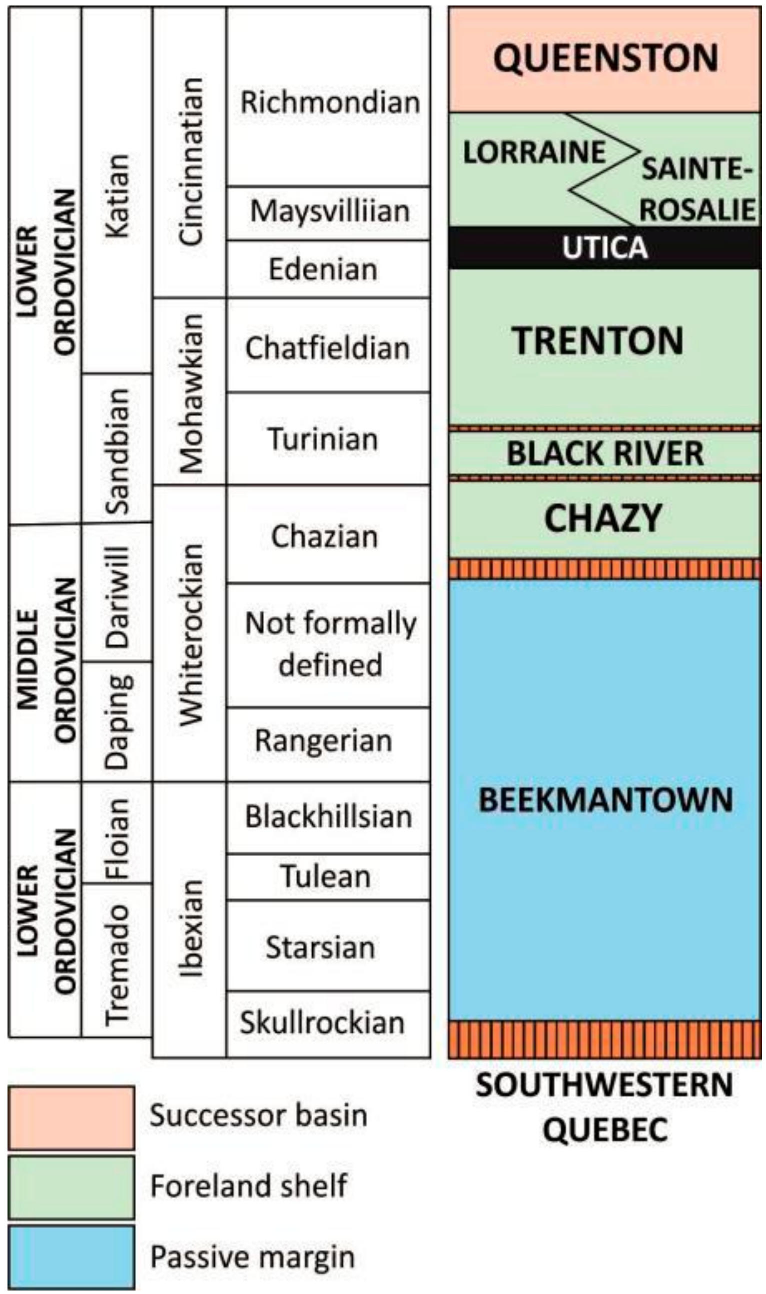

Figure 1. Stratigraphic framework for the St. Lawrence Platform of southwestern Quebec. Modified from Lavoie et al. (2009).

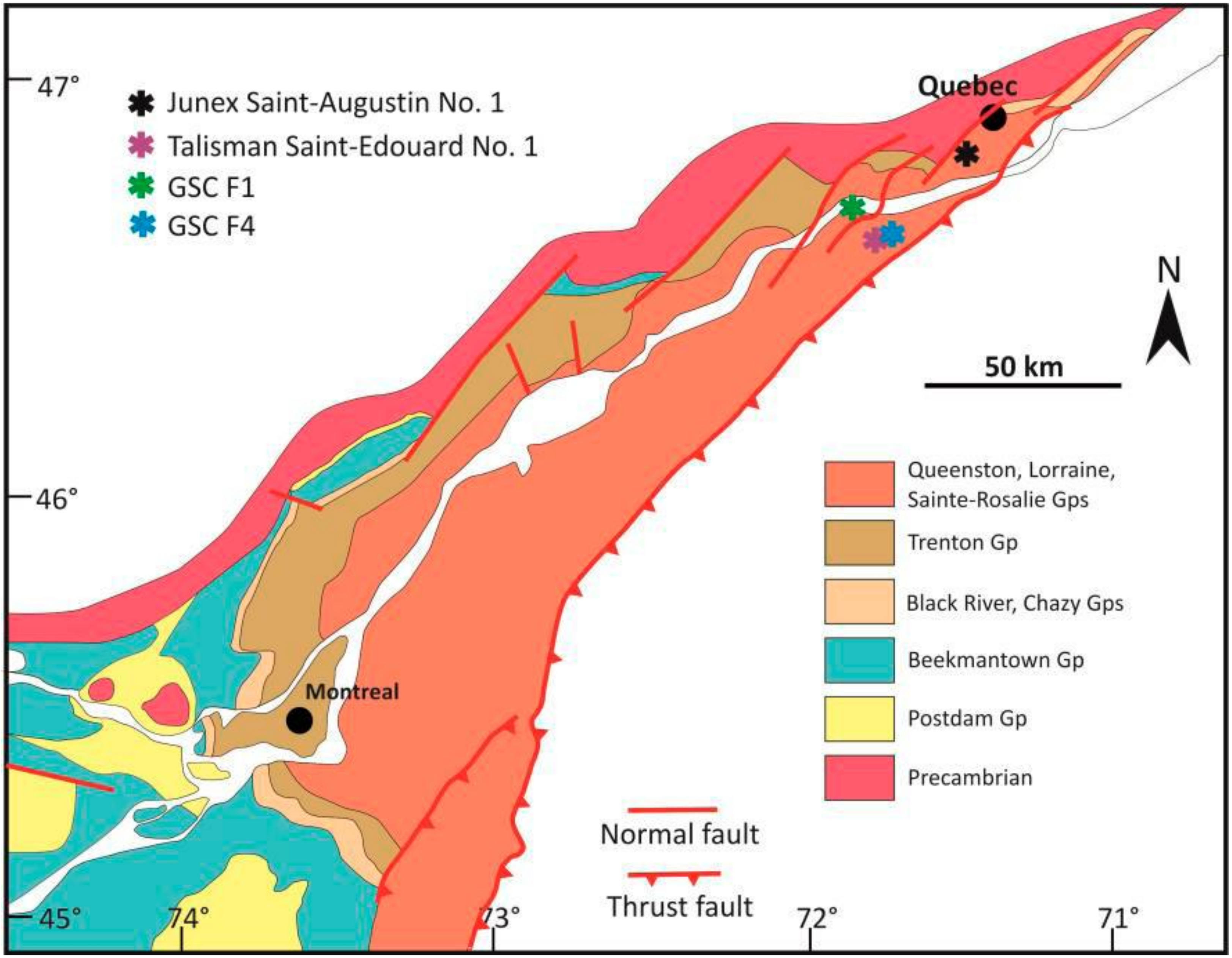

Figure 2. Simplified geological map of the St. Lawrence Platform in southern Quebec. Modified from Dietrich et al., 2011, with locations of studied well.