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Geochemical and petrographic characterization of the Upper Ordovician Utica Shale, southern Quebec, Canada

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ABSTRACT

The Utica Shale is a potential unconventional tight gas reservoir from southern Quebec. The Utica Shale is a calcareous shale with intervals of fine-grained siltstone with total organic content of 1.2 wt.% (median, n = 408). The major organic matter constituents are migrabitumen and zooclasts (chitinozoan and graptolite) macerals. The primary kerogen is characterized as marine due to the presence of chitinozoan and marine-derived prasinophyte algae such as *Tasmanites*. A significant portion of the bulk organic matter is dominated by migrabitumen. The present hydrocarbon potential (S2, mg HC/g Rock) of the Utica Shale is largely controlled by distribution of solid migrabitumen throughout the unit. Hydrogen Index (HI) declines with increasing maturity, which is controlled by greater burial from shallow to deep sections. Oxygen Index (OI) remains low in most samples, which is attributed to lack of terrestrial input. However, organic lean intervals show significantly inflated OI due to interference of mineral carbon (possibly siderite).

Random reflectance measurements on matrix/solid bitumen and chitinozoans are robust indicators of thermal maturity. The maturity ranges from the late oil window in the shallow Utica to the wet and dry gas windows in the intermediate and deep Utica, respectively.

The results suggest that matrix bitumen formed during migration and dissemination of hydrocarbon into the clay fraction of the rock. This is associated with significant bacterial sulfate reduction possibly in the early stages of generation and migration of oil. It appears that the porous siltstone facies in the deeply buried section of the Utica Shale acts as a reservoir for the migrated bitumen from organic-rich strata within the section and/or possibly overlying source rock.

1. Introduction

The Upper Ordovician Utica Shale in southern Quebec has been considered as an excellent hydrocarbon source rock since the early days of hydrocarbon exploration in this area (Lavoie et al., 2009; Dietrich et al., 2011). In eastern Canada, significant industry interest has recently focused on the Upper Ordovician black shales in southern Quebec and Anticosti Island for their unconventional reservoir potential, including the Utica Shale, Lorraine Group and Macasty Shale (Castonguay et al., 2010; Dietrich et al., 2011; Lavoie et al., 2013; Chen et al., 2014). Shale gas exploration in the Utica Shale began in 2006 in southern Quebec. Extensive testing through high pressure hydraulic fracturing has shown that the calcareous shales of the Utica Shale have the capacity to release a significant volume of natural gas (Chen et al., 2014). Based on information gathered through drilling of vertical and horizontal wells and following detailed re-examination and reinterpretation of well logs, drilling reports and seismic lines, Thériault (2012a) has proposed three exploration fairways for the Utica Shale in southern Quebec, based on the depth of the Utica Shale and their location in respect to different structural domains (Fig. 1). The first fairway consists of the shallow domain of the Utica Shale and occurs north and northwest of the Yamaska Fault, where the Utica is found between 0 and 800 m in depth (Fig. 2). The second exploration fairway occurs between the Yamaska Fault to the northwest and Logan's Line to the southwest; in this area, the Utica Shale is between 1200 and 2500 m in depth (Fig. 2). The third fairway is located east of Logan's Line where the Utica Shale occurs in thrust slices and also, most likely, deeper in the autochthonous platform (Fig. 2).

Knowledge of organic-rich shale resource systems is important since they act as both a source and host for hydrocarbons (Jarvie, 2012). Dispersed organic matter within these systems can provide

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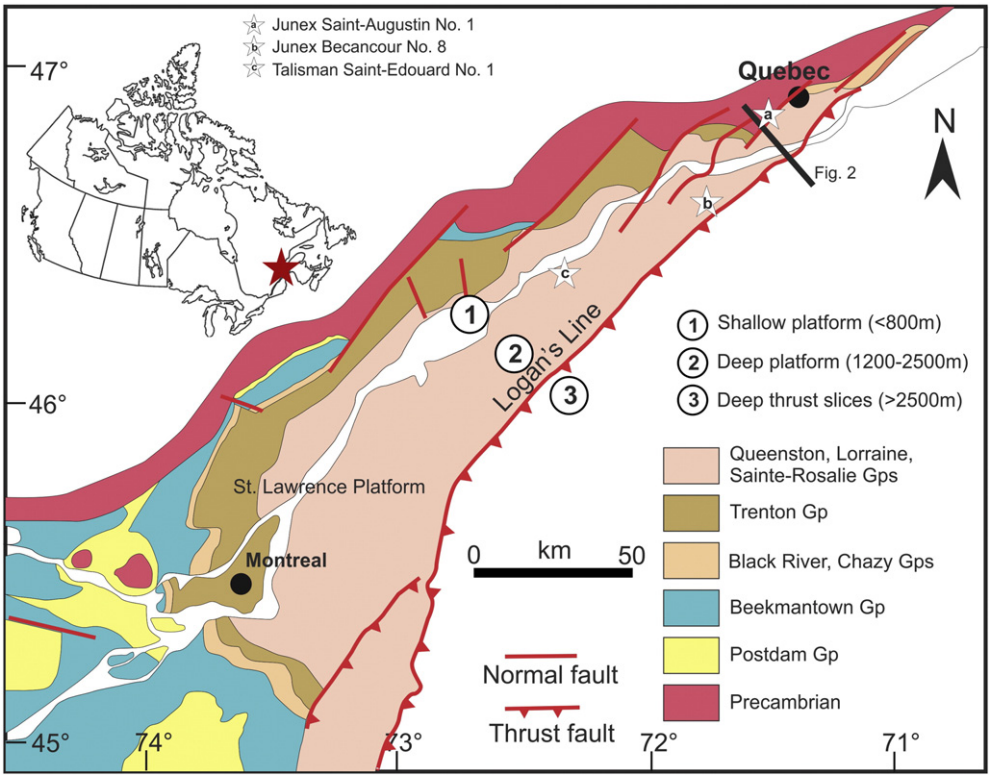

Fig. 1. Simplified geological map of the St. Lawrence Platform in southern Quebec. Modified from Dietrich et al. (2011), with locations of studied wells and exploration fairways (adopted from Thériault, 2012a).

information about thermal maturity, hydrocarbon potential, and organic micro-porosity availability for hydrocarbon storage, predominant sediment source locality and depositional conditions. This study integrates organic geochemistry and petrology in high resolution Utica Shale core samples from three exploration wells drilled in the first two exploration fairways in southern Quebec. These analyses provide information about the chemical composition of the rocks as it relates to the overall characteristics of this unconventional hydrocarbon reservoir as well as variations of organic matter among different exploration fairways.

2. Geology of the Utica Shale in Quebec

The collision of the eastern continental margin of North America during the Ordovician Taconic Orogeny with a volcanic arc situated above a SE-dipping subduction zone, initiated the development of the Taconian foreland basin. This consequently caused the tectonic collapse, subsidence and transgression of the Middle Ordovician carbonate platform along the length of the Appalachian Orogen (Hiscott et al., 1986).

The Upper Ordovician deep-marine clastic sediments of Utica Shale (50 to 300 m thick) and Lorraine Group (500 to 2000 m thick) overlie

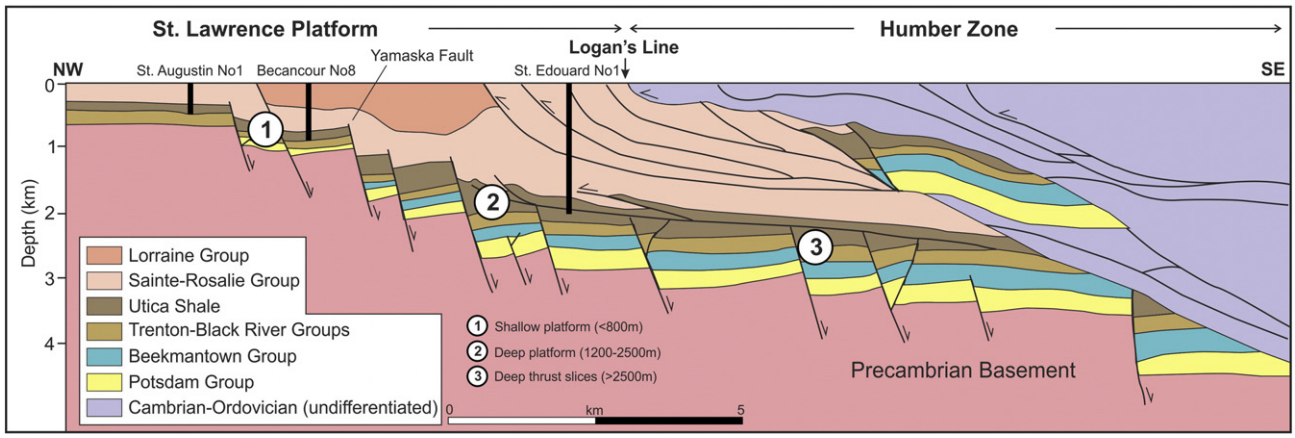

Fig. 2. Geological cross-section of the St. Lawrence Platform and external Humber Zone in southern Quebec, with locations of the studied wells (cross-section location in Fig. 1; modified from Castonguay et al., 2010) and exploration fairways (adopted from Thériault, 2012a). The Utica Shale is progressively thicker and deeper from NW to SE and is remobilized and imbricated in thrust stacks beneath the Appalachian Humber Zone.