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The Utica Shale and gas play in southern Quebec: Geological and hydrogeological syntheses and methodological approaches to groundwater risk evaluation

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ABSTRACT

The risk of groundwater contamination from shale gas exploration and development is a major societal concern, especially in populated areas where groundwater is an essential source of drinking water and for agricultural or industrial use. Since groundwater decontamination is difficult, or nearly impossible, it is essential to evaluate exploration and production conditions that would prevent or at least minimize risks of groundwater contamination. The current consensus in recent literature is that these risks are primarily related to engineering issues, including casing integrity and surface activities, such as truck traffic (equipment and fluid haulage), waste management (mainly drill cuttings), and water storage and treatment when hydraulic fracturing is utilized. Concerns have also been raised with respect to groundwater contamination that could result from potential fracture or fault interconnections between the shale unit and surficial aquifers, which would allow fracturing fluids and methane to reach the surface away from the wellbore. Despite the fact that groundwater resources are relatively well characterized in some regions, there is currently no recognized method to evaluate the vulnerability or risks to aquifers resulting from hydrocarbon industry operations carried out at great depths.

This paper focuses on the Utica Shale of the St. Lawrence Platform (Quebec), where an environmental study aiming to evaluate potential risks for aquifers related to shale gas development has been initiated. To provide the context of these research efforts, this paper describes the regional tectono-stratigraphic evolution and current stress regime of the Cambrian–Ordovician St. Lawrence Platform, as well as the Utica Shale internal stratigraphy, mineralogy and thermal maturation. Then, the hydrogeological context of the St. Lawrence Platform is discussed. Finally, the methodology for this environmental study, based on geological, geophysical, geomechanical, hydrogeological and geochemical data, is presented.

1. Introduction

Improved production techniques are unlocking huge volumes of natural gas from shale in North America. In 2000, shale gas represented only 2% of U.S. natural gas production; by 2012 it was over 40% and this percentage is expected to increase in the near future (Hughes, 2013). In Canada, production is increasing rapidly in British Columbia and almost all provincial jurisdictions have shale targets currently being explored and evaluated with highly variable technical successes and issues. From multiple independent government and society estimates, Canada has an endowment of close to 5000 Tcf of in-place natural gas in shale (ERCB/AGS, 2012; Hayes and Ferri, 2013; Heffernan and Dawson, 2010).

In areas where water is relatively abundant, such as in Quebec and many regions of Canada and the U.S., groundwater quality is probably one of the highest concerns related to shale gas development. Contamination risks, mainly linked to engineering issues, are primarily related to the casing integrity and surface activities (e.g. truck traffic, water storage) (Jackson et al., 2013; MIT, 2011; Osborn et al., 2011; The Royal Society, 2012; US EPA, 2011, 2012). Concerns have also been raised with respect to groundwater contamination that could result from potential fracture or fault interconnections between the frac-stimulated shale unit and surficial aquifers, which would allow fracking and/or flowback fluids and methane to reach the surface away from the wellbore. Although groundwater resources are relatively well characterized in a few regions (see Rivard et al., 2014–this issue), there is currently no recognized method to evaluate the vulnerability or risks to aquifers resulting from hydrocarbon exploration/exploitation

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activities carried out at great depths. There are also worries about long-term (hundreds or thousands of years) migration of gas or fracturation fluids into aquifers or due to poor well abandonment practices.

This paper presents the regional tectono-stratigraphic evolution and setting, current stress regime and structural framework of the Cambrian–Ordovician St. Lawrence Platform. It takes a closer look at the Utica Shale, the shale gas play in southern Quebec, particularly to its internal stratigraphy, structural characteristics, mineralogy and thermal maturation. This paper then describes the hydrogeological context of the St. Lawrence Platform and a methodology currently being developed to evaluate the potential for preferential pathways linking a deep-seated fractured shale interval (generally located at a depth greater than 1 km) to surficial aquifers (less than 300 m) at a given site. The method involves the use of geological, geophysical, geomechanical, hydrogeological and geochemical data. The Utica Shale of the St. Lawrence Platform was targeted for this research because 1) initial data from unconventional gas exploration have shown significant potential for natural gas production, but no large-scale exploration and production have taken place so far, 2) it occurs in a rural, but relatively populated area, where groundwater represents an essential water supply, and 3) it is affected by abundant geological features (e.g. faults, folds and magmatic intrusions). A site previously explored by the industry was selected to provide a case study for hazard assessment based on actual geological constraints of a specific region.

2. Geological context of the St. Lawrence Platform

2.1. Regional setting

Rocks ranging in age from the Neoproterozoic to the Late Mesozoic are found onshore eastern Canada and record a circa 550 Ma long Wilson's cycle. The major Paleozoic tectonic events documented in the Appalachians are related to the obduction of ophiolites (oceanic crust) and progressive accretion of volcanic arcs, microcontinents and ultimately continents to the paleo-craton Laurentia (van Staal, 2005). The main compressive deformation phases climaxed during the Ordovician (Taconian Orogeny), the Devonian (Acadian Orogeny) and the Late Carboniferous–Permian (Alleghenian Orogeny). The post-Pangea Mesozoic–Cenozoic history of the eastern margin of Laurentia marked the onset of a new Wilson's cycle that consisted primarily of rift and passive margin development leading to the opening of the Atlantic Ocean.

In southern Quebec, the Cambrian–Late Ordovician sedimentary rocks preserved in the St. Lawrence Platform (Fig. 1) have recorded the initial events of the Paleozoic Wilson's cycle, from the Neoproterozoic rifting of Rodinia (Allen et al., 2009), to the development of a Cambrian–Early Ordovician passive margin (Lavoie et al., 2012) and of a Middle–Late Ordovician foreland basin (Lavoie, 2008).

2.2. Stratigraphy and structure of the St. Lawrence Platform

2.2.1. Stratigraphy

In southern Quebec, the St. Lawrence Platform corresponds to a Cambrian–Lower Ordovician siliciclastic and carbonate platform having a maximum thickness of ca. 1200 m, overlain by a minimum of ca. 1800 m of Middle–Late Ordovician foreland carbonate-clastic deposits (Fig. 2) (Lavoie, 2008).

The base of the platform succession consists of the Upper Cambrian Potsdam Group, which unconformably overlies the Precambrian basement. The base of the Potsdam Group is dominated by a rift to early-drift fluvial to shallow marine succession of conglomeratic arkose and

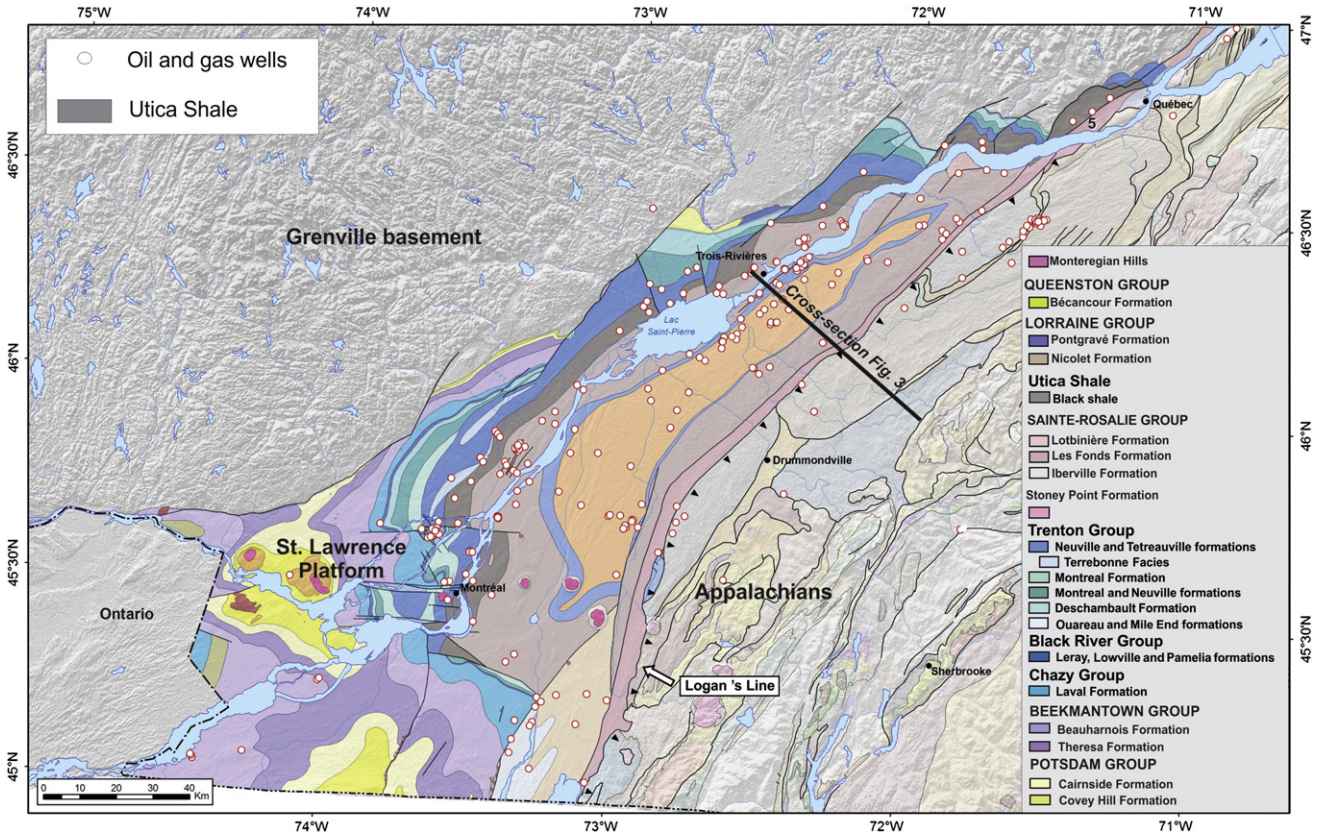

Fig. 1. Simplified geological map of southern Quebec with the Cambrian–Ordovician St. Lawrence Platform between the Precambrian Grenville basement and the Cambrian–Devonian Appalachians. Logan's Line marks the limit between the platform and the Appalachians whereas the platform is either in fault contact or unconformably overlying the Grenvillian basement. The map shows the location of oil and gas wells drilled in southern Quebec. The cross-section is on Fig. 3. Stratigraphic legend is for St. Lawrence Platform units. Modified from Thériault (2012a).