Investigation on the origin of shallow hydrocarbons found in the Carboniferous sub-basin of southern New Brunswick

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ABSTRACT
The objective of this project is to assess potential impacts of shale gas activities on shallow groundwater via upward fluid migration. The study area is located in the Sussex region, in southern New Brunswick. Since very few data are available on the intermediate zone, located below shallow aquifers and above gas reservoirs, indirect multi-source data from five disciplines were integrated to provide a better understanding of the system. Dissolved methane in groundwater shows ambiguous isotopic composition. However, the geochemical interpretation based on multiple samples from regular monitoring seems to point towards a microbial origin for most of them. Geomechanical properties indicate that the intermediate zone acts as an efficient barrier to protect shallow aquifers.

RÉSUMÉ
L'objectif de ce projet est d'évaluer les impacts potentiels liés aux activités gazières sur l'eau souterraine via une migration de fluides vers la surface. La zone d'étude est localisée dans la région de Sussex, dans le sud du Nouveau-Brunswick. Étant donné que peu de données sont disponibles dans la zone intermédiaire, située sous les aquifères superficiels et au-dessus des réservoirs gaziers, des données indirectes et multi-sources issues de cinq disciplines ont été intégrées afin de mieux comprendre ce système. Le méthane dissous dans l'eau souterraine montre une composition isotopique ambigüe. Cependant, l'interprétation géochimique basée sur de multiples échantillons provenant d'un suivi régulier semble montrer que la majorité du méthane est d'origine microbienne. Les propriétés géomécaniques indiquent que la zone intermédiaire constitue une barrière efficace qui protège les aquifères de surface.

1 INTRODUCTION AND RATIONALE

New Brunswick banned hydraulic fracturing in 2014 until more science-based knowledge on health and environmental issues is available. The objective of this project is precisely to provide such scientific data and understanding on potential upward fluid migration that could impact shallow groundwater quality. The study area is located in the region of Sussex, southern New Brunswick, where unconventional reservoirs have been exploited since 2001 (Figure 1).

Although faulty casings appear to be the principal pathway for deep fluids to reach surficial aquifers, several authors have recognized that upward migration through fractures and fault zones could also represent a non-negligible potential migration pathway that should be investigated (Gassiat et al. 2013; Birdsell et al. 2015; Lefebvre, 2017). Such natural connection between deep units targeted by the industry and shallow aquifers would therefore need to cut through the units in between, referred to as "the intermediate zone". This intermediate zone thus constitutes a critical component of the system since it controls aquifer vulnerability to deep industrial activities.

However, little is typically known about this zone, as the latter has historically been dismissed, being located below units that have been characterized for water supply and above the units that have been characterized by the resource industry. Therefore, our approach for this project involved, in addition to geological data, the use of diverse indirect data from different disciplines, such as geophysics, geomechanics, hydrogeology and geochemistry. This paper specifically focuses on the geochemical study that includes both groundwater and rock.

2 DESCRIPTION OF THE STUDY AREA

The study area comprises two sub-regions (Figure 1): the McCully gas field, which has been active for the last 17 years and the Elgin area, which is a prospect field for condensates. Condensates are composed of hydrocarbons such as ethane, propane and butane, which make them more interesting for the industry than just methane because the price of (dry) gas is still low. However, the current moratorium on hydraulic fracturing impedes its exploration.

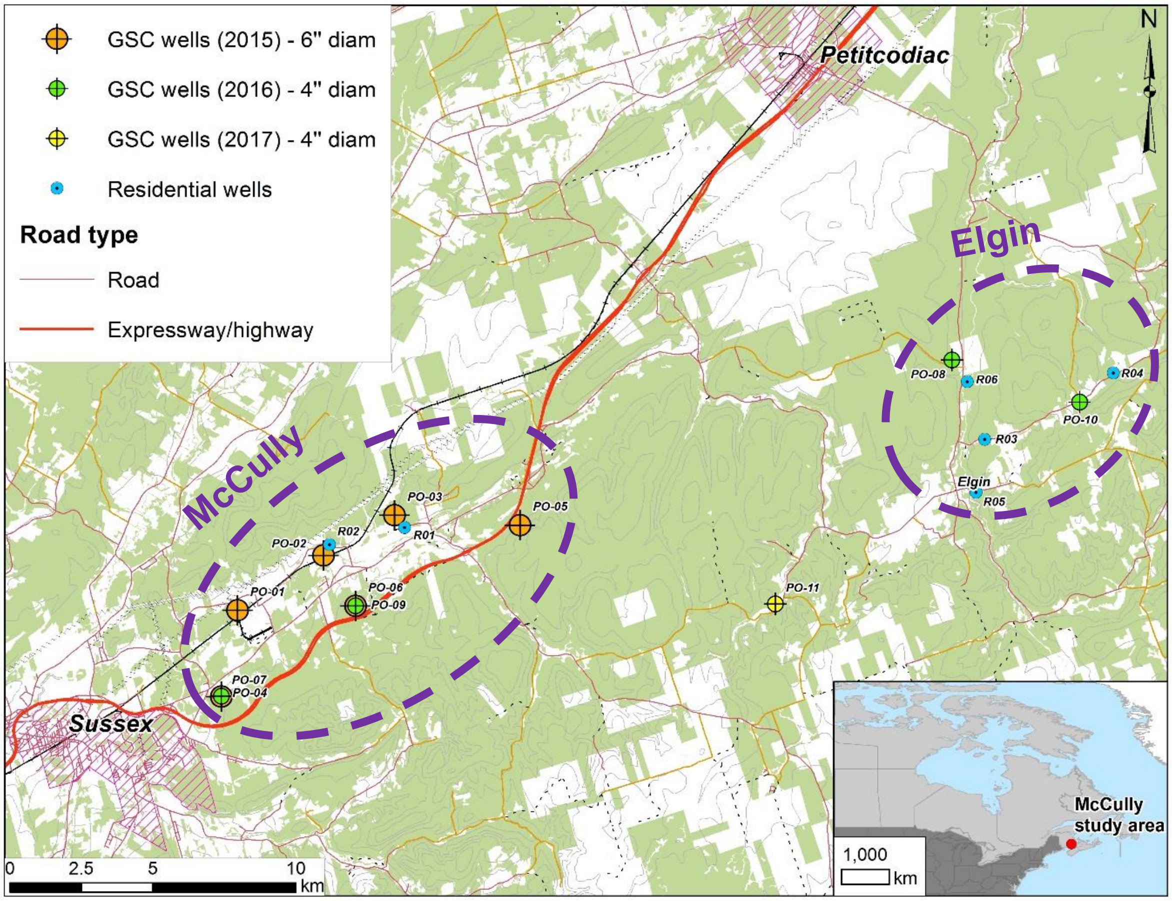

Figure 1: Location of the study area, 11 observation wells and 6 residential wells

This study area is located in the Carboniferous Moncton sub-basin (Wilson and White, 2006). The two units of interest for the industry are the Hiram Brook tight sandstone and the Frederick Brook shale, which are two members of the Albert Formation of the Lower Carboniferous Horton Group. Except at the faulted SE margin of the sub-basin, these units are generally located at a depth of more than 2 km (Figure 2). The overlying units, which form the intermediate zone, belong to 1) the Sussex Group composed of conglomerate, sandstone and shale, 2) the Windsor Group evaporites (includind potash deposits that were exploited by PotashCorp until December 2015) and 3) the Mabou Group mainly composed of sandstone and siltstone. The regional bedrock aquifer is located in the upper part of the Mabou Group, generally in the first 100-150 m.

A total of about 50 gas wells have been drilled so far, mostly in the Hiram Brook Member of the McCully gas field. These gas wells are all vertical or inclined, except for one horizontal well.

Surficial sediments of the two watersheds in which gas fields are located (the Kennebecasis River watershed for the McCully gas field and Pollet River watershed for the Elgin prospect) are usually quite thin and mainly composed of tills. These tills are generally sandy and cover about 90% of the area. The median thickness is about 3 m, but can locally reach 25 to 30 m in the Kennebecasis River valley (Rivard et al., 2017). Outcrops represent only about 1% of the area.

3 FIELDWORK AND ANALYSES

Fieldwork for the geochemical study has included drilling of observation wells (6 hammer- and 5 diamond-drilled so far, with 3 additional wells planned for summer 2018), core and cutting sampling, groundwater sampling and borehole geophysical logging that, among other things, has identified individual flowing fractures. The location of the 11 observation wells and 6 residential wells where groundwater sampling has been carried out is shown in Figure 1. Additional fieldwork for this project comprised hydraulic tests in the observation wells, permeameter tests in surficial sediments and a structural survey to investigate fracture patterns on outcrops. However, since outcrops are sparse, information on surficial fractures mainly relied on borehole geophysical logging. Groundwater monitoring is being carried out every 3 to 4 months. However, when no hydrocarbons were detected after one year, monitoring for this well was abandoned.

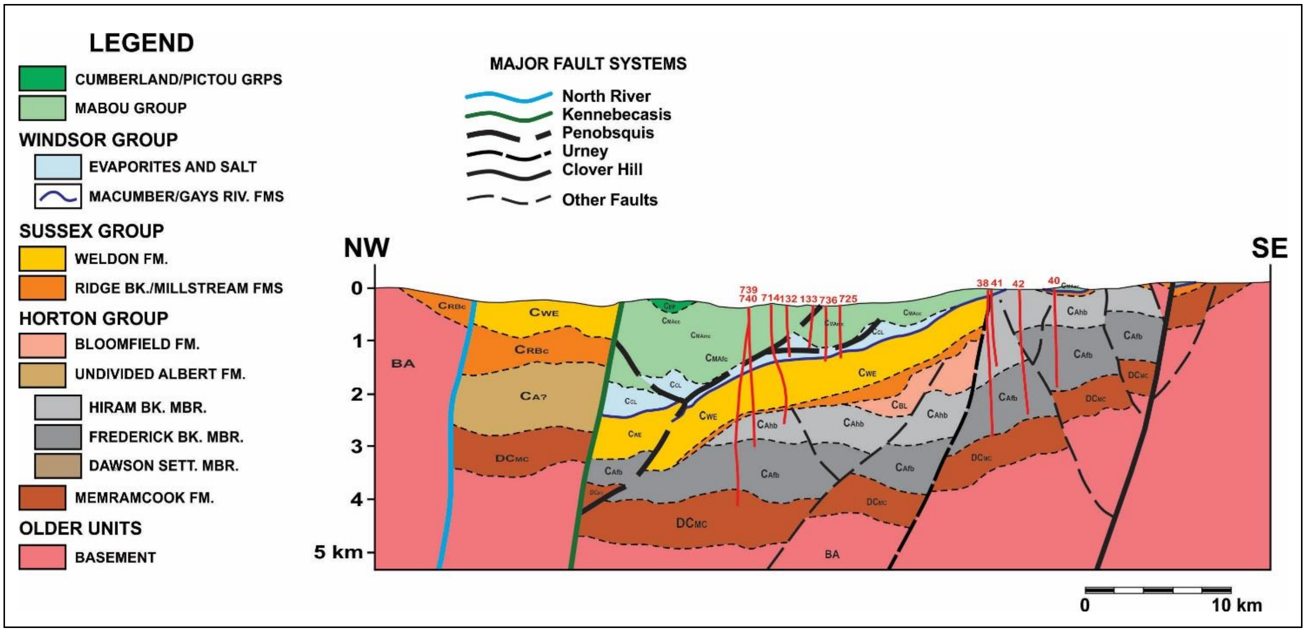

Figure 2: Geological cross-section of the study area (Hinds and Parks, 2017)

Geochemical analyses for groundwater included: major and minor ions and trace metals, alkane (methane, ethane, propane) concentrations, dissolved inorganic carbon (DIC), water isotopes (δ^2H and δ^{18}O), methane isotopes (δ^2H and δ^{13}C), DIC isotope (δ^{13}C), tritium and carbon 14. Groundwater monitoring mainly focuses on alkane concentrations and methane isotopic composition. For rock, analyses on cuttings and core samples included Rock-Eval pyrolysis, alkane gaseous concentrations and isotopic composition.

4 RESULTS AND FUTURE WORK

4.1 Organic geochemistry

Hydrocarbons have been found both in groundwater and rock at shallow depths in this region, but only in small concentration and in a few locations. In general, gas concentrations in the Elgin area are slightly higher than in the McCully gas field. Due to these low concentrations, very few samples could be analysed for their isotopic composition. Additionally, many dryness ratios (corresponding to the ratio of methane over ethane and propane) have undefined values (shown within the red rectangle in Figure 3) because groundwater typically contains much less ethane and propane than methane. Figure 3 shows that most groundwater samples show an ambiguous isotopic composition, which could correspond either to thermogenic or oxidized microbial methane (Figure 3).

Regular monitoring and calculations based on isotopic fractionation show that the majority of methane would be of microbial origin, but affected by different processes. Only few wells would contain a thermogenic component. Hydrocarbons in shallow rock samples included short- (methane and ethane), as well as long-chain (C19+) bitumen in one well. The origin of this bitumen is unclear (immature kerogen or biodegraded oil). Possible bitumen sources are shales from the Horton Group, Macumber Formation or the Mabou Group itself.

The uncertain origin of the thermogenic hydrocarbons has led us to investigate a region located in between the two sub-regions, where a relatively shallow mining well had shown the presence of flowing hydrocarbons and where hydrocarbon seeps have recently been discovered. A 130 m well was thus drilled in the proximity of a normal fault near the SE margin of the Carboniferous basin to sample and analyse groundwater and rocks for their hydrocarbon concentrations and isotopic compositions. Organic geochemical analysis will be performed on seeps and bitumen in rocks for biomarkers, which will allow their correlation with known source rocks in the area for which biomarker analyses are in progress. This information, along with geomechanical and geophysical data, will provide critical information on the source of hydrocarbons in the basin and their migration pathways.

4.2 Structural geology and geomechanics

The geological interpretation based on the 3D seismic data showed that the evaporite layer of the Windsor Group varies in thickness, but is always present in the McCully gas field (Rivard et al., 2017). These deposits offer good aquifer protection because evaporites have a low brittleness index and are usually considered nearly impermeable. The upper part of the Sussex Group does not seem to be affected by any major brittle structures at the seismic scale (Figure 4). In fact, faults appear to be present only in the Horton Group, where the two units of interest to the industry are located. These results suggest that a connection between the hydrocarbon-loaded Hiram Brook Member tight sandstone and the Frederick Brook Member shale and the surface is very unlikely.

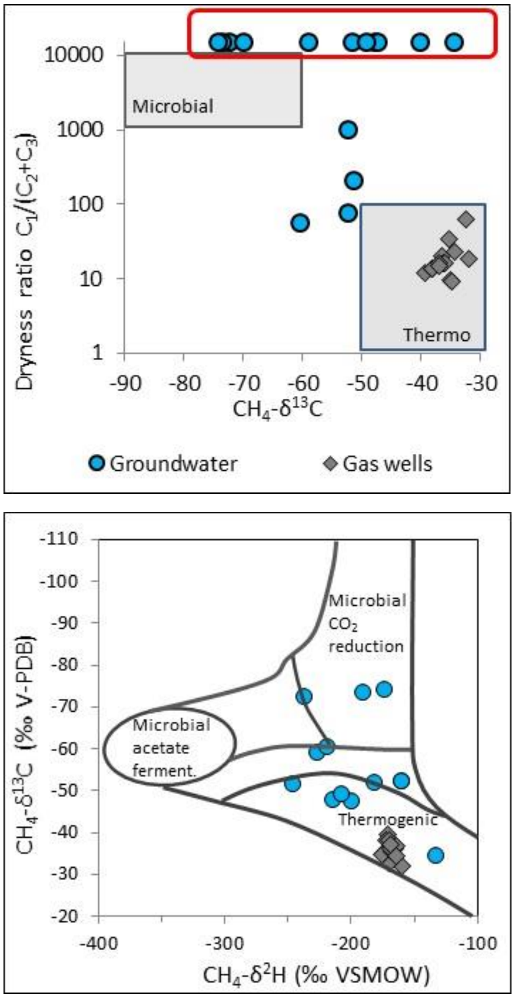

Figure 3: Graphs used for the interpretation of methane origin in groundwater. Top: Bernard graph; Bottom: Whiticar (1999) graph

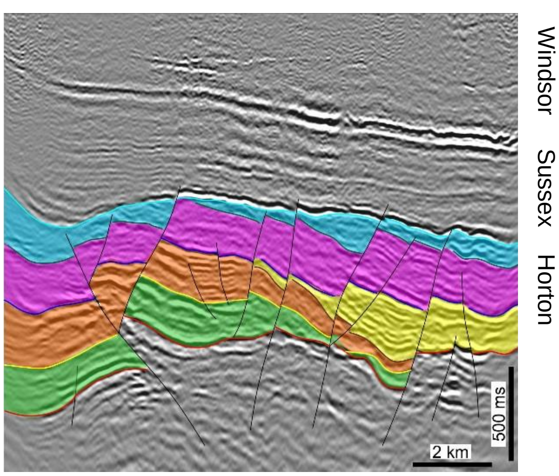

Figure 4: Seismic signature of the Carboniferous succession in the McCully gas field area. Note the complex sedimentary architecture of the Horton Group (colored) and the fact that faults do not affect the upper part of the Sussex Group. Modified from Rivard et al. (2017)

In agreement with the geological interpretation, results of the geomechanical study (including the estimation of Poisson's ratios, Young's Modulus and minimum horizontal stress) have highlighted marked geomechanical contrasts f between the two gas reservoirs and some units within the intermediate zone. In a context of hydraulic fracturing, the presence of more ductile layers, such as the evaporites, provides an efficient barrier that should limit or stop the propagation of induced fractures.

Future work will include the investigation of the fracture network to better understand the role played by natural fractures and fault zones in the possible fluid migration through the intermediate zone.

5 CONCLUSION

In the Carboniferous basin of southern New Brunswick, the presence of hydrocarbons has been noticed in both groundwater and rock, but their origin is unclear. Although most methane appears to be of microbial origin, a few wells likely contain a thermogenic component. The study of the intermediate zone integrity has provided evidence that it offers good protection for shallow aquifers to deep industrial activities. However, this work has mainly focused on the McCully gas field, where 3D seismic data were available. Work for 2018-2019 will focus on identifying the gas origin and possibility of upward migration by studying a specific faulted region in between the McCully gas field and Elgin area where hydrocarbon seeps have recently been discovered.

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