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# Hydrocarbon potential of source rocks of the Paleozoic (Cambrian to Devonian) petroleum systems of the Gaspé Peninsula (Québec, Canada)

Grundman G.
Institut national de la recherche scientifique (INRS), Québec, Québec, Canada
Gaelle.Grundman@ete.inrs.ca

and

Behar F.
Institut Français du Pétrole (IFP), Rueil-Malmaison, France

Malo M.
Institut national de la recherche scientifique (INRS), Québec, Québec, Canada

Baudin F.
Université Pierre et Marie Curie (UPMC), Paris, France

## Summary

Two petroleum systems can be described in the Gaspé Peninsula (Québec, Canada): Cambro-Ordovician and Siluro-Devonian systems. 350 rocks from eleven wells from the northeastern part the Gaspé Peninsula are studied. Rock Eval 6 studies are carried out on source rocks and 58 kerogen concentrates. Elemental analyses are performed on kerogens. Gas chromatography on DCM extracts and pyrolysis effluents of these kerogens is also performed. The Siluro-Devonian system is characterized by a low hydrocarbons potential. Rocks are immature to mature, the average TOC is low (0.53%), except for some local levels, where fair values may be found (values up to 2%). In the Cambro-Ordovician system, however, the TOC may exceed 1% for the overmature rocks, meaning that a substantial amount of petroleum has been already generated. Rock-Eval 6 profiles of source rock show an abnormal peak between the two standard $S_1$ and $S_2$ peaks. However, this peak, named $S_{2a}$ peak, usually disappears when analysis is performed on kerogens. As a consequence, it corresponds to heavy products not expelled from source rock during hydrocarbon migration. It is noteworthy that discrepancies exist between vitrinite reflectance (Ro), Tmax and H/C-O/C ratios to characterize stages of oil generation for the Siluro-Devonian petroleum system. No fair trend can be found between the Ro values and the Rock-Eval 6 parameters. Additional closed-system pyrolysis is performed to generate hydrocarbons and verify residual petroleum potential of rock. It enables to characterize yielded hydrocarbons of Cambro-Ordovician and Siluro-Devonian systems, which confirms results from previous studies. All analyses reveal gas potential for mostly Siluro-Devonian rocks system and Cambro-Ordovician rock system of northeastern part of the Gaspé Peninsula.

## Introduction

Eastern Canada and more precisely the Gaspé Peninsula is known for its petroleum potential since the observation of the first oil seeps in 1836 by Sir Williams Logan. With this evidence of hydrocarbon potential, a great number of wells were drilled throughout time and new hydrocarbons discoveries lead to improvements on explorations of the Gaspé Peninsula and on a better understanding of its complex stratigraphic and structural architecture.

The aim of the present work is to re-evaluate the hydrocarbon potential of petroleum systems of the Gaspé Peninsula. New geochemical data will help to constrain a basin modeling study which is the further step of the work. A 2D basin modeling will be built with the Temis software to provide the capacity generation, expulsion and migration and quantity of Gaspé Peninsula hydrocarbons.

## Geological setting

The Gaspé Peninsula belongs to the Canadian Appalachians. It is located in the innermost part of the Québec re-entrant and southeast of the St-Lawrence Promontory. The Gaspé Peninsula is made up of Paleozoic rocks which can be divided into three temporal rock assemblages: Early Cambrian to Late Ordovician rocks (the Cambro-Ordovician), Late Ordovician to Middle Devonian rocks (the Siluro-Devonian) and Carboniferous rocks (Bourque *et al*., 2000; Williams, 1995). The first rock assemblage was deformed by both the Taconian (Late Ordovician) and the Acadian (Middle Devonian) orogenies, whereas the second rock assemblage was deformed during the Acadian orogeny but also recorded structural features linked to the Late Silurian-Early Devonian Salinic disturbance. Carboniferous rocks remain largely unaffected by the Late Carboniferous-Permian Alleghanian orogeny.

Two main petroleum systems were recognized in the Gaspé Peninsula. The Siluro-Devonian system presents values of vitrinite equivalent reflectance (Ro) ranging from 0.30 to 2.16%, which indicates immature to overmature rocks (Bertrand and Malo, 2001). This means that source rock reached sufficient maturity to generate petroleum fluids.The regional TOC is low and the HI of the most immature samples does not exceed 200mg/g C. In some local levels, however, higher TOC values may be found as well as a better petroleum potential. The Cambro-Ordovician system shows higher Ro values, ranging from 0.68 to 8.46% (Bertrand and Malo, 2001). Their TOC may exceed 1% for the overmature rocks, which means that a substantial amount of petroleum (oil and gas) has been already generated. This residual amount suggests a better initial petroleum potential for the Cambro-Ordovician system compared to the Siluro-Devonian ones.

## Samples and experiments

The selection of samples is based on location of existing seismic lines and boreholes and on studies of Bertrand and Malo (2001). Thus, 350 samples from eleven boreholes were collected (C001 Associated Developments Baillargeon, C016 Haldimand, C079 Tar Point, C081 York, C087 Sunny Bank, C093 Baie de Gaspé Sud, C099 Baie de Gaspé Nord, C097 Douglas, C126 Junex-Lemaire-Hydroquébec n°3, C131 Pétrolia-Haldimand n°1 and CZ03 Kennco Gaspé n°3.). The sampled geological formations range from Ordovician to Devonian in age. Moreover, one Ordovician rock was sampled from the Cap-Chat Mélange at surface.

The amount of expelled hydrocarbons is first estimated by the $S_2$ peak of Rock-Eval 6 on bulk rocks and isolated organic matter after mineral digestion and extraction by dichloromethane (kerogens). Then elemental analyses are performed on kerogens. Lastly chemical composition of expelled hydrocarbons is analysed for evaluating the real hydrocarbons potential. In that part, oil and gas potential is estimated by running artificial maturation in closed system following the method described by Behar *et al*. (1989). The amount of gas generated during the oil window is estimated with experiment at 350°C/24h. The recovered extract is fractionated by MPLC and the recovered saturates is analysed by gas chromatography.

## Results

Mineral matrix for source rocks can retain hydrocarbons which will decrease TOC and HI values. Checking of matrix effect with Rock-Eval data obtained out on both source rock and kerogen demonstrated that mineral matrix effect is minor. As a consequence, this parameter does not affect petroleum potentials of Gaspé Peninsula rocks. As a general trend, for source rock, TOC does not exceed 1% and HI is generally below 200 mg/g C, as shown by Bertrand (1987) and Bertrand and Malo (2001). However, Ro, described by these authors, is not correlated to HI values and Tmax. The pyrolysis profiles of $S_1$ and $S_2$ peaks of source rocks are not standard with an additional peak observed between these peaks. This additional peak, named $S_{2a}$ peak, disappears after extraction and thus corresponds to heavy compounds. Moreover, it is important to note that $S_1$ peak can be as high as $S_2$. All these observations suggest the Siluro-Devonian rocks (i.e. Forillon Formation) are lean source rocks and most of the hydrocarbon was not expelled. On the contrary, the Cambro-Ordovician rocks have residual TOC as high as 1%. The initial hydrocarbon potential of this petroleum system should be higher than the Siluro-Devonian system.

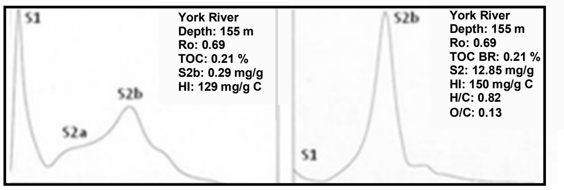


Figure 1: Rock-Eval profiles for source rocks and kerogens from Baie de Gaspé Sud well.

Elemental analyses of kerogen concentrates enable to obtain H/C and O/C ratios. These ratios are placed in a van Krevelen diagram (figure 2) and lead to distinguish five groups. The first group represents Siluro-Devonian immature source rocks and a rock from the base of Pétrolia-Haldimand n°1 well. The second group points out Siluro-Devonian mature source rocks, at the beginning of the catagenesis stage. The third group gathers together Cambro-Ordovician and Siluro-Devonian source rocks. The fourth group characterizes Cambro-Ordovician and Siluro-Devonian mature source rocks, at the end of the catagenesis stage. The fifth group shows Cambro-Ordovician and Siluro-Devonian mature rocks, in the metagenesis stage. As a consequence, Siluro-Devonian rocks are immature to mature rocks. On the contrary, Cambro-Ordovician rocks are mature to overmature mature and has residual TOC higher than 1%. This means that the immature equivalent of these rocks had a TOC around 2%. The hydrocarbon potential of the Cambro-Ordovician petroleum system was higher than the Siluro-Devonian system. Finally, Cambro-Ordovician and Siluro-Devonian rocks can potentially be considered more gas prone than oil prone source rocks.

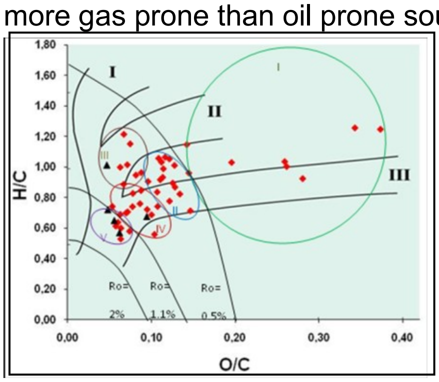


Figure 2: Van Krevelen diagram. Black arcs represent vitrinite reflectance isovalues.

Gas chromatography enables to characterize hydrocarbons distribution of rocks. Studied Ordovician and Devonian natural extracts show low quantities of hydrocarbons expelled from source rock. Gold tube experiments generate hydrocarbons which come from thermal cracking. Figure 3 shows examples of hydrocarbons distribution of Siluro-Devonian source rock from Forillon Formation from Baie de Gaspé Sud well (a), Cambro-Ordovician source rock, from an outcrop of the Ordovician Cap-Chat Mélange (b) and a source rock from an undefined formation and age from the base of Petrolia-Haldimand n°1 well (c). Siluro-Devonian rock profile (Forillon Formation) presents little peaks of heavy compounds and ranges of molecule are tight. As a consequence, the profile indicates low hydrocarbons potential for the rock. On the contrary, Cambro-Ordovician rock (Cap-Chat Mélange) profiles demonstrate a fair potential, as well as the unknown Formation from the base of Pétrolia-Haldimand n°1 well.

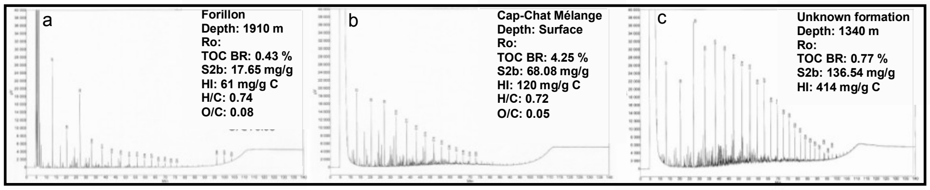


Figure 3: Chromatograms of effluents acquired by closed system pyrolysis of samples from a) Siluro-Devonian petroleum system (Forillon Formation from Baie de Gaspé Sud well), b) Cambro-Ordovician petroleum system (from Cap-Chat Mélange) and c) unknown formation from the base of Pétrolia-Haldimand n°1 well.

## Conclusions

Gaspé Peninsula is characterized by two distinct types of source rock from the Cambro-Ordovician and Siluro-Devonian systems. Siluro-Devonian rocks are divided into two types of potential source rocks: poor and fair source rocks. Identified Ordovician fair potential source rocks come from the Cap-Chat Mélange of the northeastern Gaspé Peninsula. Fair potential source rocks are also identified at the base of the Pétrolia-Haldimand n°1 well in a mudstone of unknown age.

Bulk rock Rock-Eval profiles present atypical peak, linked to heavy compounds not expelled from source rock. Elemental analyses enable the separation of rocks into five groups according to their maturity range and their potential type of kerogen. Rocks appear to be in immature stage to gas formation stage. Results from the closed-system pyrolysis confirm that Siluro-Devonian rocks have no petroleum potential, and Ordovician rocks still present a fair petroleum potential. All analyses reveal a gas potential for mostly Siluro-Devonian rocks system and Cambro-Ordovician rock system of northeastern part of the Gaspé Peninsula.

The different parameters discussed in this study will be used in a 2D basin modeling study. Geochemical (TOC, HI) and maturity data enable to provide the capacity generation, expulsion and migration and quantity of Gaspé Peninsula hydrocarbons.

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