Mapping the Basement – Assessing the Potential for Hydrothermal Dolomitization in the Paleozoic of Eastern Canada

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Summary

Hydrothermal dolomites (HTD) host oil and gas accumulations in eastern North America and are actively explored for in the Canadian segment of the ancient continental margin of Laurentia (Fig. 1). Hydrothermal dolomitization is a process that implies early burial extensional to transtensional tectonism, efficient and rapid circulation of high temperature fluid along those basement-rooted faults and a major source of Magnesium to sustain the significant dolomitization observed in the world-class reservoirs in eastern North America (Davies and Smith, 2006).

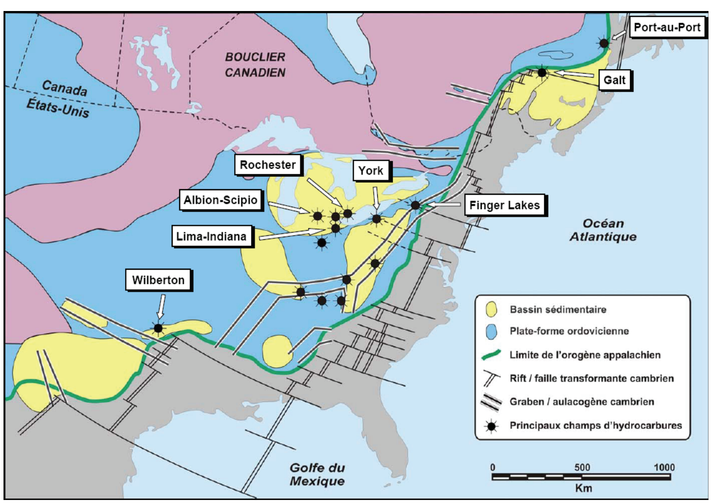

Figure 1: Distribution of HTD reservoirs in eastern North America

The identification of an efficient source of Magnesium could be one of the major elements to recognize areas with higher potential for extensive hydrothermal dolomitization. The recognition of Mg-rich domains in the underlying basement could provide a first hand tool to delineate prospective areas. The aim of this work is to discuss the relationship between extensive hydrothermal dolomitization in Lower Silurian units in the Gaspé Belt of eastern Canada and the presence of older mafic to ultramafic rocks (Lavoie and Morin, 2004; Lavoie and Chi, 2006).

Introduction

The Lower Silurian carbonates of the Sayabec and La Vieille formations in Gaspé and northern New Brunswick are the first shallow marine carbonates in the post-Taconian (Middle Ordovician) succession (Lavoie et al., 1992). These carbonates were deposited at the onset of the Acadian foreland basin in the Gaspé Belt.

Hydrothermal dolomites have been recognized at various localities in the Lower Silurian carbonate succession (Fig. 2). The best studied localities are: 1) the Ruisseau Isabelle section in northern Gaspé Peninsula (Lavoie and Chi, 2001), 2) the Saint-Cléophas quarry in western Gaspé (Lavoie and Morin, 2004), 3) the Petit-Rocher – Belledune area in northeastern New Brunswick (Lavoie and Chi, 2006) and 4) the New Richmond wharf section in southern Gaspé (Malo et al., 2008).

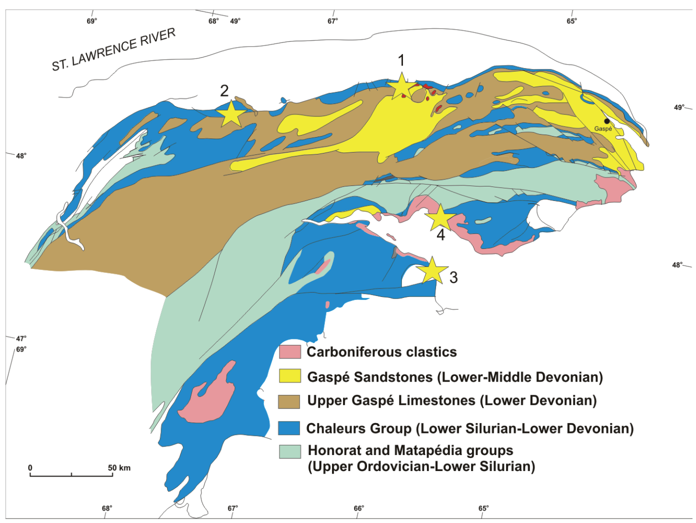

Figure 2: Simplified geological map of the Silurian-Devonian Gaspé belt with the location of four major HTD occurrences in Lower Silurian carbonates.

Lower Silurian Hydrothermal Dolomites

Hydrothermal dolomitization at these four localities consists of pervasive dolomitization of the shallow marine (peritidal to shallow subtidal) facies. The dolomitization also occurs in fractured and locally highly brecciated zones (Fig. 3) and is associated with abundant pore-filling coarse-grained saddle dolomite. Petrographic examination of the dolomites has revealed that dolomitization was a relatively early process and in the case of localities 2 and 3, high temperature dolomitization occurred before the Late Silurian subaerial exposure and alteration (partial dissolution and meteoric calcite cementation) of the carbonate ramp (Lavoie and Morin, 2004; Lavoie and Chi, 2006).

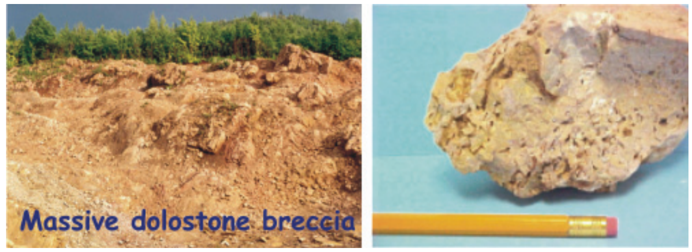

Figure 3: HTD at the Lac Matapedia syncline (Saint-Cléophas quarry; loc. 2 on fig. 2) in western Gaspé

The geochemical signatures of the dolomites indicate the presence of high temperature and very saline (21 to 24 wt.% $NaCl_{equiv.}$) fluids at the time of replacement and/or precipitation. The homogenization temperature (T_h) of the fluid inclusions in the dolomites range from 111 to 218°C (Lavoie and Chi, 2001 and unpublished data) and the associated $\delta^{18}O_{PDB}$ ratios of the dolomites range from little to strongly ^{18}O-depleted (−6.3 to −17.3‰). The paired T_h and $\delta^{18}O_{PDB}$ values from individual analysis indicate that the fluids responsible for the dolomitization were enriched in ^{18}O (Fig. 4). The $\delta^{18}O_{SMOW}$ values for the Silurian fluids were significantly more enriched in ^{18}O compared to the fluids responsible for the dolomitization of the Ordovician carbonates in Anticosti and western New York (Fig. 4).

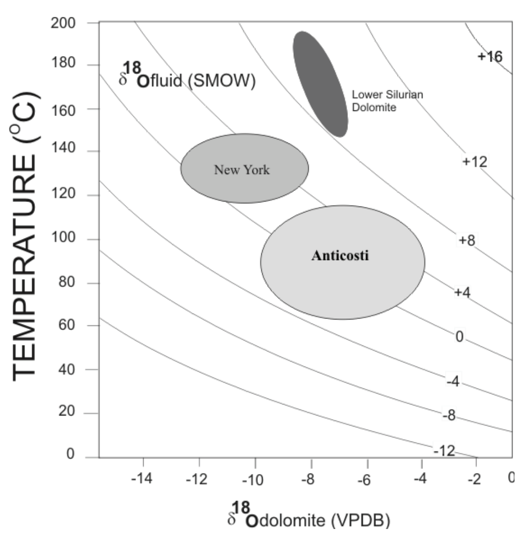

Figure 4: Plots of T_h and $\delta^{18}O_{PDB}$ values from individual analysis, these define the $\delta^{18}O_{SMOW}$ isotopic composition of the dolomitizing fluid. Note the similar $\delta^{18}O_{SMOW}$ values (-3 to +5‰) for Anticosti (Lavoie et al., 2005) and New York (Smith, 2006) and the very different values (+8 to +10‰) for the Lower Silurian HTD.

For three of the four localities (loc. 1, 2 and 3; figs. 2 and 5), the presence of an nearby mafic to ultramafic rock unit can be documented. At localities 1 and 2, the Lower Silurian HTD are closely field associated with Ordovician ultramafic units (Mont Albert and La Rédemption complexes, northern and western Gaspé respectively) that represent tectonic slivers of oceanic crust and mantle obducted on the continental margin during the Taconian Orogeny. The HTD at locality 3 unconformably sits less than 200 metres above Middle Ordovician mafic volcanic units preserved in the Elmtree Inlier. These ultramafic and mafic units would represent significant source of Mg^{+2} for dolomitization and it is proposed that the anomalous $\delta^{18}O_{SMOW}$ values for the pre-Late Silurian fluids responsible for the alteration was the result of extensive rock/fluid interactions with mafic/ultramafic units close to major fault zones.

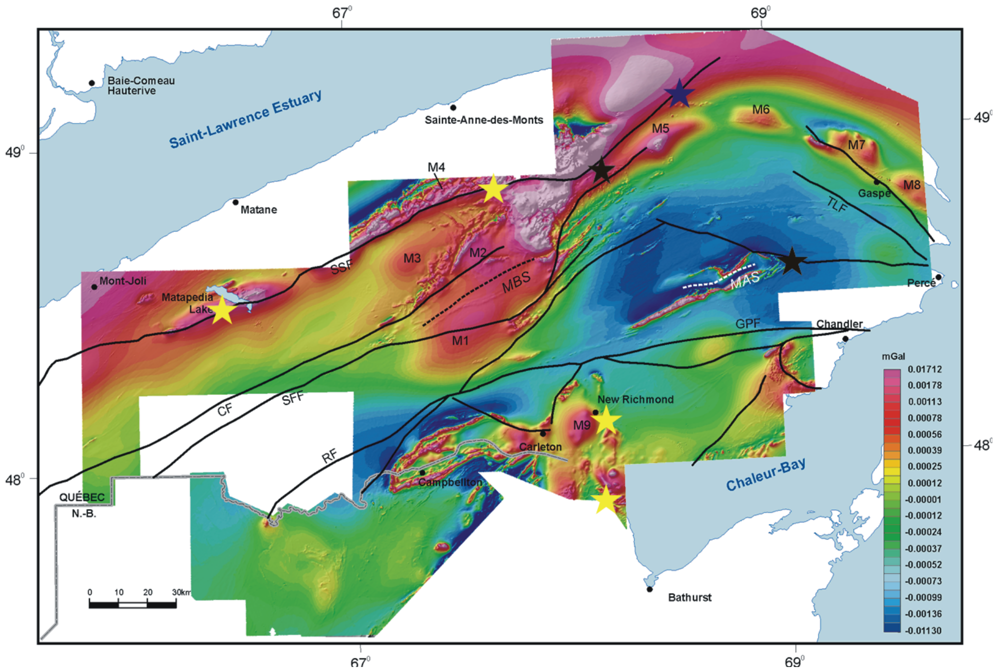

Figure 5: Map of the residual total magnetic field of part of Gaspé and Northern New Brunswick (Pinet et al., 2005). All HTD localities in the Lower Silurian succession (yellow stars) are associated with positive residual magnetic anomalies related to the presence of mafic to ultramafic rocks. Lower Ordovician (blue star) and Upper Silurian-Lower Devonian (black stars) HTD localities are also associated with positive residual magnetic anomalies.

The HTD at locality 4 differs from the previous ones as there is no nearby known occurrence of Ordovician mafic or ultramafic units. However, the map of the residual total magnetic field (Fig. 5) documents significant magnetic anomalies in the area beneath localities 3 and 4, on both side of Chaleurs Bay that separates northern New Brunswick and southern Gaspé Peninsula. It is interpreted that the Ordovician mafic units that outcrop in northern New Brunswick are the source of these magnetic anomalies; their presence beneath the Lower Silurian succession at locality 4 is proposed, a presence also supported by other studies (Dupuis et al., submitted).

The relationship between residual magnetic anomalies and other occurrences of HTD in the Gaspé Peninsula can be observed on figure 5. One Lower Ordovician (Rivière Ouelle Formation) and two Upper Silurian – Lower Devonian (West Point Formation) occurrences are associated with such magnetic anomalies. A relationship can also be recognized between the Bouguer gravimetric anomaly (Pinet et al., 2005) and the location of Gaspé – northern New Brunswick HTD occurrences. Therefore, dense and magnetic bodies associated with mafic and/or ultramafic volcanic material are present beneath these HTD occurrences and likely provided the significant volume of Mg^{+2} needed for extensive dolomitization. This supports the critical importance of detailed field mapping and potential field data to not only locate fracture conduits for fluid circulation but also to identify areas with greater dolomitization potential based on the nature of the basement. However, some Mg-rich domains (e.g., Mg-rich marbles) could remain undetected.

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