Preliminary geological and geophysical study of a potential CO_2 storage site in deep saline aquifers of the Bécancour area, St. Lawrence Lowlands, Québec

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Summary

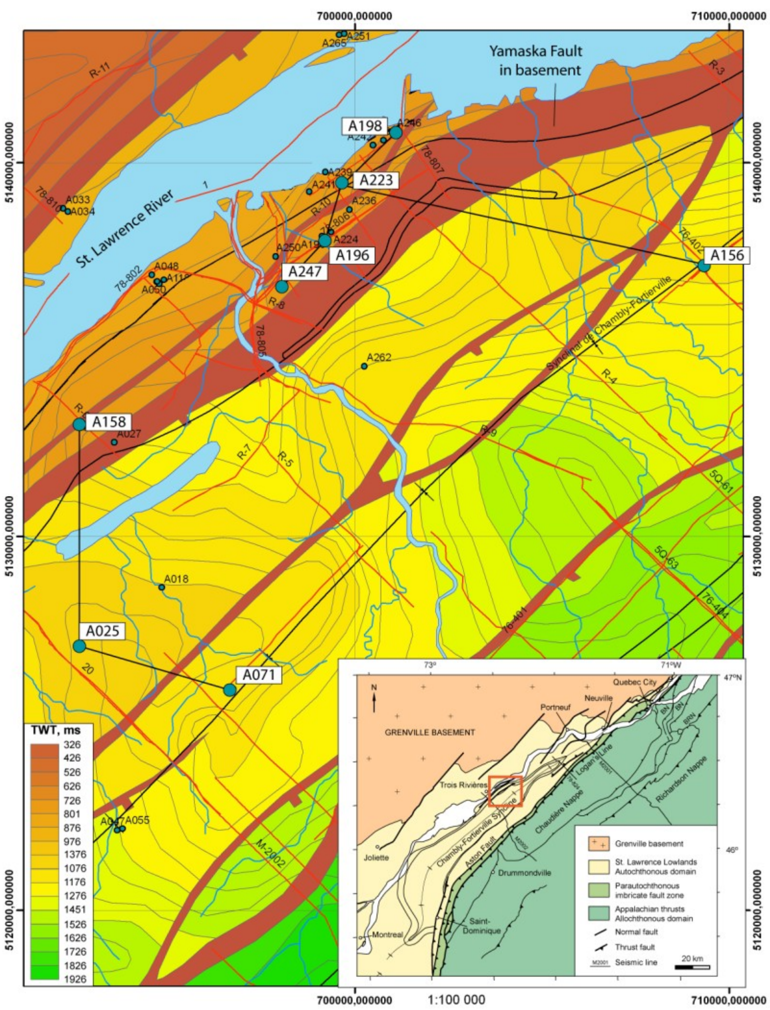
Deep saline aquifers of the Bécancour area represent one of potential reservoir types for CO_2 storage in the St. Lawrence Lowlands. The saline aquifers are recognised at three stratigraphic levels, which include from top to bottom: limestones of the Trenton Group, dolomites of the Beekmantown Group and sandstones of the Potsdam Group. The aquifers are found at medium depths varying from 795 m for Trenton limestones to 1224 m for the Potsdam sandstones. The thin-bedded gas reservoir in dolomitic sandstones of the Beekmantown Group is localised at 968.5-982 m. Generally, the intervals of saline aquifers and potential reservoir rocks in the Bécancour area are characterised by relatively small thicknesses (1-15 m) and limited extension with rather random distribution of porosity in the permeable zones. To localise and trace out high porosity and permeability stratigraphic levels, analyses of well logs and seismic profiles have been undertaken. Identification of fault and fractured zones in the area may help to assess potential CO_2 cross-formational and land surface leakage. The Cambrian-lower Upper Ordovician sedimentary successions of the St. Lawrence Lowlands in the Bécancour area are mostly flat-lying dipping gently to the NW above the rotated blocks in the Grenvillian basement separated by the SE-dipping normal faults. The regional Chambly-Fortierville syncline principally affects the Upper Ordovician foreland basin units above the Trenton-Utica Shale level. The regional Yamaska normal fault affects the Grenvillian basement and the overlying sedimentary successions with progressive deepening of the top of the basement from the NW (1250-1350 m) to the SE (>2600 m). Thicknesses and facies variations in sedimentary units across the Yamaska normal fault testify that a syn-sedimentary displacement (about 800 m) along the fault occurred likely during its load-induced syn-Taconian reactivation ahead of the developing Appalachian thrusts. The SE-vergent reverse fault that locally affects the Lower-Middle Ordovician units in the Bécancour area is likely related to graben inversion during the late Taconian shortening. The gentle anticlines occur in the Potsdam-Trenton units above isometric or slightly SW-NE extended uplifts in the Grenvillian basement. The anticlines that contain permeable levels under cap rock units of Utica shale and Lorraine turbidites could represent potential traps for CO_2 storage.

Introduction

Deep saline aquifers are used or studied for CO_2 storage in sedimentary basins in different geological settings in Canada, USA, France, Norway and Denmark. In the province of Québec, it is the first time that deep saline aquifers are studied for their potential CO_2 storage capabilities.

The sedimentary successions of the St. Lawrence Lowlands in Québec are interesting for the CO_2 storage because they possess porous and permeable rocks overlain by cap rocks and are located in tectonically stable area (Fig. 1). The successions include Cambrian–Lower Ordovician rift-drift and passive-margin series (subaerial to shallow marine Potsdam sandstones and shallow-water Beekmantown dolomites) and Middle–Upper Ordovician foreland basin units (shallow-water Chazy, Black River and Trenton argillaceous limestones overlain by deep-water Utica shale and syn-orogenic Lorraine turbidites) capped by post-Taconian Upper Ordovician Queenston molasse (Fig. 2). The Sauk-Tippicanoe unconformity in the Middle Ordovician has been suggested to record the beginning of the Taconian (Middle–Upper Ordovician) orogeny (Lavoie, 1994).

The Grenvillian basement and the St. Lawrence Lowlands sedimentary units are affected by a series of the SE-dipping normal faults (Castonguay et al., 2006; Konstantinovskaya et al., 2009), which are interpreted to be initially rift-related and to have formed during the Iapetian rift event (Hibbard et al., 2007). The regional Yamaska normal fault in the Bécancour area (Fig. 1) controls thicknesses of both passive margin and foreland basin units and shows the 800 m of displacement for the top of the Trenton limestones across the fault (Fig. 2) that suggests the growth fault remained active during syn-sedimentary and syn-Taconian stages. The Yamaska normal fault also likely extends into the overlying Lorraine turbidites and Queenston molasse (Castonguay et al., 2006) that could resulted from the late post-Taconian reactivation (Lavoie, 1994).



The reverse reactivation along the SE-dipping normal faults recognised in the St. Lawrence Lowlands units is correlated with the Taconian compression (Faure et al., 2004; Konstantinovskaya et al., 2009). In the Bécancour area, the SE-vergent reverse fault locally affects the Lower - Middle Ordovician units.

Fig. 1. Map of the Grenvillian basement in the Bécancour area, Quebec, after Thériault et al. (2005). Location of wells at Fig. 2 is shown. Red lines are available seismic profiles.

The St. Lawrence Lowlands sedimentary units in the Bécancour area are generally flat-lying gently dipping to the north-west above the rotated blocks of the Grenvillian basement. The gentle anticlines occur in the Potsdam-Trenton units above isometric or slightly SW-NE extended uplifts in the Grenvillian basement (Fig. 1). The anticlines that contain permeable levels under cap rock units of Utica shale and Lorraine turbidites could represent potential traps for the CO_2 storage.

CO_2 storage in deep saline aquifers and methodology

The preferred concept for the CO_2 storage in deep saline aquifers is to inject supercritical CO_2 into a porous and permeable reservoir (> -800 m of depth) capped by impermeable rock units. Particular problems for the this type of storage include: presence of aquifers and aquitards in the sedimentary succession, CO_2 behavior in brine formation, fluid–rock chemical interactions at the supercritical CO_2–brine interface, leakage through faults, fracture zones, leaky abandoned wells intercepting into overlying aquifers or shallow groundwater aquifers, and plume evolution.

In the Bécancour area, Cambrian-Ordovician sedimentary successions including the saline aquifers are studied by geological and geophysical analysis. The analysis is based on the 18 well logs and 30 seismic profiles available for the Bécancour area covering 400 km^2 (Fig. 1). The well logs (computed gamma ray, bulk density, density and neutron porosity, photoelectric factor) are used to calculate mineral volumes of silica, limestone, dolomite and shale, and total, apparent and effective porosity (Doveton, 1986). Comparison of well-log derived lithology with core descriptions in seven wells showed good qualitative agreement between the lithologies. The log-derived lithology data are used to complement conventional petrophysical interpretation and contribute to lithofacies mapping. The gamma ray, density, neutron and photoelectric factor logs are correlated with sonic log to trace formation tops on seismic profiles across the study area (Claprood et al., 2010).

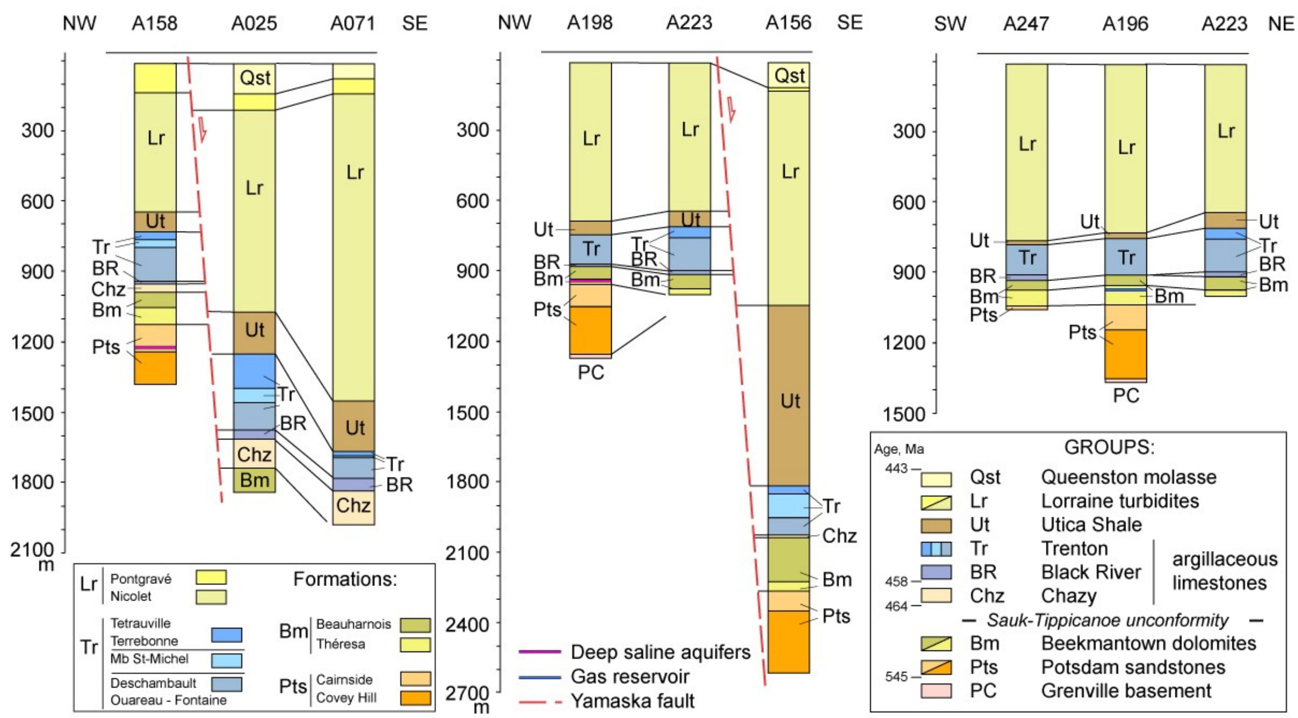


Fig. 2. Lithostratigraphic correlations of the St. Lawrence Lowlands successions based on well data reports from the MRNF Quebec database. The location of wells is given in Fig. 1.

Prospective saline aquifers in the Bécancour area

The saline aquifers in the Bécancour area are recognised at three stratigraphic levels (Fig. 2): in limestones of the Trenton Group, in dolomites of the Beekmantown Group and in sandstones of the Potsdam Group (Massé, 2009). Limestones of the Trenton Group form a sequence of 120-

150 m thick with the top of formation at 760-815 m. A porosity of 10%, a permeability of 400 mD and the presence of gas shows of 20-30% characterise the limestones (A239). The brine in the Trenton limestones is found at 795-796.6 m, its density is 1.13 g/cm^3 and salinity STD is 200 g/l. Dolomites of the Beekmantown Group are up to 90 m thick and the top of formation is located at 895-937 m. The dolomites are characterised by a porosity of 5-10% and a permeability varying from 45 mD to 270 mD (A198). The brine in Beekmantown dolomites is located at 938-950 m (Theresa Fm) and has a density of 1.18 g/cm^3 and a salinity STD of 270 g/l. Sandstones of the Potsdam Group are 300 m thick with the top of formation at 950-1040 m. The sandstones are characterised by a porosity of 5% and a permeability of 200 mD (A158). The brine in Potsdam sandstones is found at 1224-1225 m (Cairnside Fm) and has a density of 1.22 g/cm^3 and a salinity STD of 340 g/l. The thin-bedded gas reservoir in the dolomitic sandstones of the Beekmantown Group (Theresa Fm) is found at 968.5-982 m (Lavoie, 1992). The level 980-982 m is characterised by 9% of effective porosity and 27% of water saturation. This level is connected to the inferior (1039-1047 m) level of fractured sandstones of the Potsdam Group (Cairnside Fm).

The lithostratigraphic correlations constructed for the St. Lawrence Lowlands successions in the Bécancour area (Fig. 2) help to determine geometry of stratigraphic units including the deep saline aquifers. Lateral continuity and thickness and facies variations are evaluated for the units deposited in the relatively deeper and shallower parts of Cambrian-Ordovician basin. The grain size tendencies are determined within each formation. The results obtained from the well logs analysis are used in the seismic profiles interpretation to create a detailed geological model of the basin and trace out the stratigraphic levels of potential interest for CO_2 storage. Identification of fault and fractured zones in the area may help to assess potential CO_2 cross-formational leakage and ultimately leakage to the land surface.

Conclusions

Deep saline aquifers of the Bécancour area include limestones of the Trenton Group, dolomites of the Beekmantown Group and sandstones of the Potsdam Group, which are found at medium depths varying from 795 m to 1224 m. The geological and geophysical analysis of well logs and seismic profiles is used to localise and trace out high porosity and permeability stratigraphic levels and to identify fault and fractured zones that may lead to potential CO_2 cross-formational and land surface leakage. The gentle anticlines occur in the Potsdam-Trenton units above isometric or slightly SW-NE extended uplifts in the Grenvillian basement. The anticlines that contain permeable levels under cap rock units of Utica shale and Lorraine turbidites could represent potential traps for the CO_2 storage.

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References

Castonguay, S., Dietrich, J., Shinduke, R. and Laliberté, J-Y., 2006, Nouveau regard sur l’architecture de la Plate-forme du Saint-Laurent et des Appalaches du sud du Québec par le retraitement des profils de sismique réflexion M-2001, M-2002 et M-2003 : Geological Survey of Canada, Open file 5328.

Claprood, M., Konstantinovskaya, E., Duchesne, M., Giroux, B., Gloaguen E., Malo, M., Massé, L., and Lavoie, J., 2010, Joint sonic log-2D seismic analysis to model the petro-physical properties of aquifers for CO2 storage in the Bécancour area, Québec, Canada: GeoCanada 2010 Conference, Working with the Earth, Calgary, Canada, May 10-14, submitted for publication.

Doveton, J.H., 1986, Log analysis of subsurface geology - Concepts and computer methods: John Wiley & Sons, New York, 273 p.

Hibbard, J.P., van Staal, C.R. and Rankin, D.W., 2007, A comparative analysis of pre-Silurian crustal building blocks of the northern and the southern Appalachian orogeny: American Journal of Science, 307, 23–45.

Faure, S., Tremblay, A. and Malo, M., 2004, Reconstruction of Taconian and Acadian paleostress regimes in the Quebec and northern New Brunswick Appalachians: Canadian Journal of Earth Sciences, 41 (5), 619–634.

Konstantinovskaya, E.A., Rodriguez, D., Kirkwood, D., Harris, L.B., and Thériault, R., 2009, Effects of basement structure, sedimentation and erosion on thrust wedge geometry: an example from the Quebec Appalachians and analogue models: Bulletin of Canadian petroleum geology, 57 (1), 34–62.

Lavoie, J.-Y., 1992, Évaluation potentiel gazier de la propriété St-Laurent d'Intermont (permis 780, 789 et 822) couvrant 35 300 hectares, et recommandations quant à la mise en valeur du réservoir gazier rencontré entre les cotes 968,5 m et 982 m dans le puis Soquip-Petrofina-Bécancour No. 1. Les Ressources Naturelles Jaltin Inc., Rapport 1980OA196-05.

Lavoie, D., 1994, Diachronous tectonic collapse of the Ordovician continental margin, Eastern Canada; comparison between the Quebec Reentrant and St. Lawrence Promontory: Canadian Journal of Earth Sciences, 31, 1309–1319.

Massé, L., 2009, Geological storage in Québec: 1er colloque de la Chaire en séquestration géologique du CO_2 : La technologie du CSC au Québec: Qui sont les acteurs, Québec, 20 Avril 2009. http://chaireco2.ete.inrs.ca/sites/chaireco2.ete.inrs.ca/files/Junex_CSC_Quebec_20-04-09.pdf

Thériault, R., Laliberté, J.-Y., Brisebois, D., and Rheault, M., 2005, Fingerprinting of the Ottawa-Bonnechère and Saguenay grabens under the St. Lawrence Lowlands and Québec Appalachians: prime targets for hydrocarbon exploration: Geological Association of Canada, Abstracts, Halifax, Nova Scotia, 65.