Joint sonic log - 2D seismic analysis to model the petro-physical properties of aquifers for CO_2 storage in the Bécancour area, Québec, Canada

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Summary

The Intergovernmental Panel on Climate Change has identified deep saline aquifers as a promising geological storage option of carbon dioxide (CO_2). Saline aquifers are identified in the Bécancour area, Québec, Canada. 30 post-stack seismic lines acquired between 1970 and 2008 and 18 borehole logs are currently available to characterize the petro-physical properties of the reservoir. This paper describes the use of 2D post-stack seismic data to constrain subsurface velocities at boreholes in the Bécancour area. Problems encountered include the absence of check shot surveys to complete the time to depth conversion from seismic lines, the limited depth interval sampled on most sonic logs, and low resolution of seismic lines. Seismic signatures were identified for three saline aquifers targeted: the Trenton limestone, Beekmantown dolomite, and Potsdam sandstone. The seismic signatures were correlated to known gamma-ray signatures to complete the time to depth conversion. Coefficients of correlation between synthetic traces generated from sonic logs and observed seismic traces were used to fine-tune the time to depth conversion. Tying velocities to reflections corresponding to geological units by using available seismic lines is the first step necessary to build a geostatistical model of the deep saline aquifers in the Bécancour area. It is considered to implement the model with additional geophysical data which will be recorded during the summer of 2010.

Introduction

Deep saline geological formations are identified by the Intergovernmental Panel on Climate Change (IPCC, 2005) as one of the four principal geological storage options of CO_2. Such formations are identified in the sedimentary successions of the St. Lawrence Lowlands in the Bécancour area, Québec, Canada (Figure 1). Their potential for CO_2 storage is presently studied. This paper presents the valorization of post-stack seismic data acquired in Bécancour to constrain subsurface velocities to characterize the saline aquifers by geostatistical tools.

Three geological groups are targeted for the geological sequestration of CO_2: the clayey limestone of the Trenton Group; the massive and laminated dolomite of the Beekmantown Group; and the sandstone of the Potsdam Group (Clark and Globensky, 1976; Konstantinovskaya et al, 2009). The Trenton Group is overlain by the Utica Shale which acts as cap rock of the aquifer. The Utica Shale is overlain by several hundred meters of interbedded shale and sandstone from the Lorraine Group. The reader is referred to the companion paper by

Konstantinovskaya *et al.* (2010) for a preliminary geological study of the deep saline aquifers of the Bécancour area as potential CO_2 storage sites.

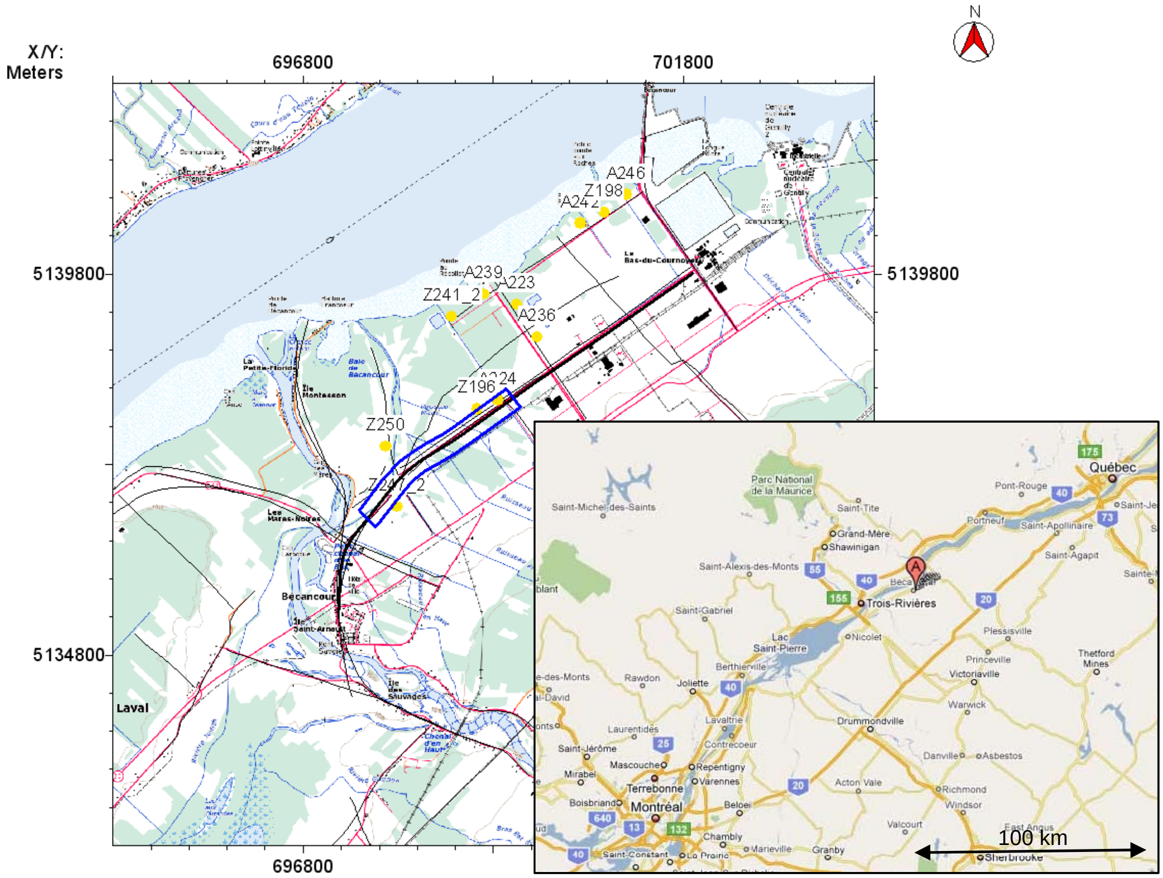

Figure 1: Bécancour area with location of boreholes (yellow dots) and seismic lines (black lines). Blue outline is seismic line n806mg shown in Figure 2. Red lines are roads. Inset: Location of the city of Bécancour (A), Québec, Canada.

Methodology

30 seismic lines acquired in Bécancour between 1970 and 2008 are used to delineate the lateral and vertical extents of the saline aquifers. The seismic data available are post-stack, with little to no information concerning the processing sequence applied on the raw data. As mentioned in Yilmaz (2001), this limits the possibility for re-processing, and thus restricts the type of analysis that can be performed on the data. A whole array of downhole logs (electric, sonic, gamma-ray, density) were also recorded at 18 boreholes (the location of 11 of them are visible on Figure 1) in the Bécancour area.

In this study, velocity logs are used to tie seismic data acquired in two-way time to borehole logs recorded in depth. Time to depth conversion charts (TD charts) are generated using sonic logs (DT) recorded at 11 of the 18 boreholes. Difficulties to generate TD charts arose because no check shot surveys were available to tie velocities directly on the seismic lines, and because only few sonic logs are recorded for the whole depth interval. Seismic signatures, corresponding to geological formations identified on borehole logs, could be recognized on seismic lines. Such seismic signatures were used to position incomplete sonic logs on seismic lines and complete velocity ties as presented in Leguijt (2009).

Constraining subsurface velocities is the first step to complete the geostatistical modeling for characterizing the spatial distribution of the petrophysical properties (porosity, permeability) of saline aquifers in the Bécancour area. The initial model of porosity and permeability uses 2D surface seismic and downhole logs, following the concepts presented in Stright *et al.* (2009) and Tuttle *et al.* (2009). Seismic data allows defining the continuity of interfaces between geological units of the model and determining the presence of structural events such as faults or folds. In addition, multivariate analysis of downhole logs and permeability/porosity measurements allows generating multiple geostatistical scenarios of the permeability field within each seismically defined facies. In the next phase of the project, the model will incorporate additional geophysical data such as seismic and electric tomographies, and magnetotelluric measurements, which are planned to be recorded in summer 2010 to better characterize the saline aquifers. These spatially continuous data will help constraining the interpolation between wells. The geostatistical assimilation of all the petro-physical data allows generating multiple high-resolution permeability fields. Each of them will be compared with the historical dynamic data measured at wells during CO_2 injection tests.

Joint Sonic Log - 2D Seismic Analysis

An example of a joint sonic log - 2D seismic analysis completed at two boreholes located at proximity of the seismic line n806mg is presented in Figure 2. The figure shows the synthetic traces (blue wiggle) generated by convoluting the reflection coefficients obtained from the sonic (red curves on Figure 2) and density logs with an initial seismic wavelet. The wavelet was modeled by extracting the 50 nearest shot points from each borehole on line n806mg between two-way times ranging from 0.1 s to 1.2 s.

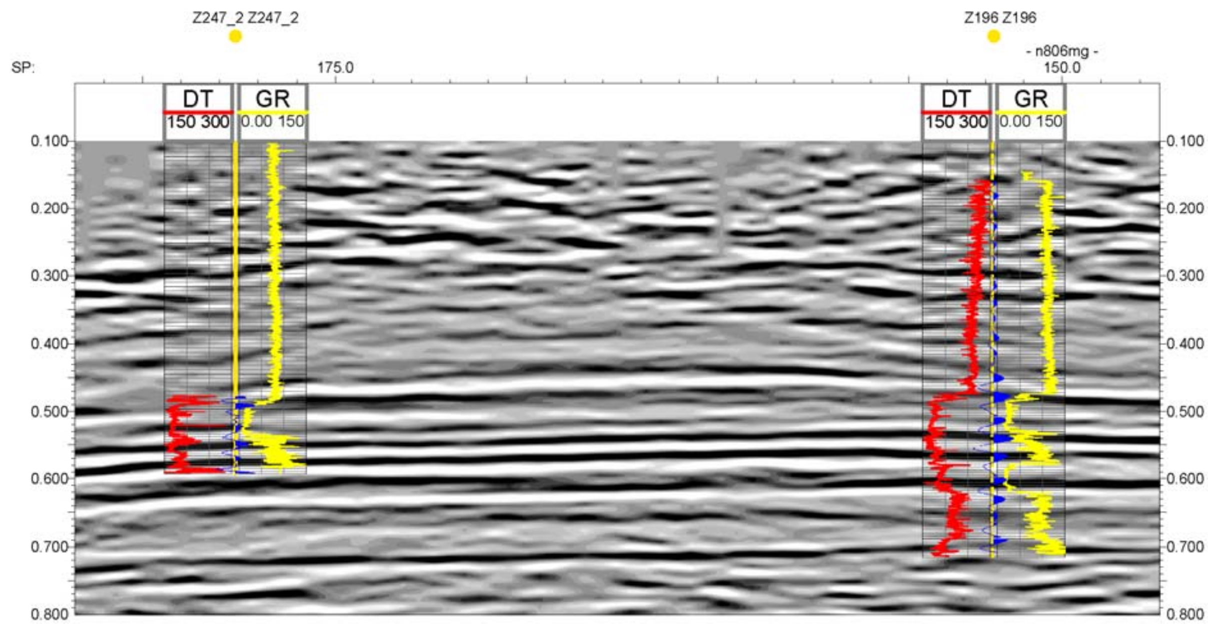

Figure 2: Seismic line n806mg (Figure 1 for location). Blue wiggles are synthetic traces computed from sonic logs (DT, red curves) at boreholes Z247_2 and Z196. Yellow curves are gamma-ray logs (GR). X-axis is shot point (SP). Y-axis is two-way time in seconds.

The reflection package found between 0.45 s and 0.65 s represents the stratigraphic successions comprising, from top to bottom: the Utica shale, the Trenton limestone, the Beekmantown dolomite, and the Potsdam sandstone. Konstantinovskaya *et al.* (2009) identified the Trenton Group as low amplitude reflectors on seismic data, characteristic of a limestone formation (Sangree and Widmier, 1979). It is recognized in Figure 2 as the low amplitude seismic reflections between 0.50 s and 0.54 s at shot point 175.0. The Trenton limestone is underlain by the Chazy and Beekmantown Groups (dolomite and dolomitic sandstone), and the Cairnside Formation (sandstone), which are recognized by three strong reflections (0.54 s to

0.62 s at shot point 175.0). At both wells, the Utica shale is characterized by strong reflections directly overlying the Trenton limestone (0.46 s to 0.49 s at shot point 175.0).

Boreholes were positioned in two-way time by using the gamma-ray log. The Trenton limestone is recognized as low stable values on gamma-ray logs (Konstantinovskaya *et al.*, 2009). The logs were adjusted in two-way time axis to match seismic signatures with known log characteristics. Fine-tuning was completed to improve the coefficient of correlation between the observed and synthetic traces. Coefficients of correlation of 0.476 and 0.565 are respectively computed for logs Z247_2 and Z196 on the time interval 0.45 s to 0.65 s. While low values of the coefficients of correlation would suggest little confidence in the velocity analysis, we prefer to base our interpretation on the agreement between the sonic and gamma-ray logs and the seismic signatures of geological formations.

Conclusions

The velocity ties are mostly based on qualitative fit between 2D post-stack seismic lines and borehole sonic logs using synthetic seismograms. While there is a lack of quantitative validation of the TD charts obtained, the continuity of seismic signatures suggests that the velocity analyses are reliable. Recognized seismic signatures are the low amplitude reflections of the Trenton limestone, and the three strong amplitude reflections of the Chazy and Beekmantown dolomite and dolomitic sandstone and Cairnside sandstone. These analyses will be used to model geostatistically the distribution of petro-physical properties of the deep saline aquifers in the Bécancour area.

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References

Clark, T.H. and Globensky, Y., 1976, Région de Bécancour et partie nord-est de la région d'Aston - Bécancour area and northeastern part of Asten area: Geological report No.165, Ministère des Richesses Naturelles - Geological Exploration Service, 66 pages.

IPCC, 2005, In: Metz, B., Davidson, O., de Coninck, H.C., Loos, M., and Meyer, L. (Eds), IPCC Special Report on Carbon Dioxide Capture and Storage, Prepared by Working Group III of the Intergovernmental Panel on Climate Change, Cambridge, UK, Cambridge University Press, 442 pages.

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, 34-62.

Konstantinovskaya, E.A., Claprood, M., Duchesne, M., Malo, M., Bédard, K., Giroux, B., Massé, L., and Marcil, J.-S., 2010, Preliminary geological and geophysical study of a potential CO_2 storage site in deep saline aquifers of the Bécancour area, St. Lawrence Lowlands, Québec: GeoCanada 2010 Conference, Working with the Earth, Calgary, Canada, May 10-14, submitted for publication.

Leguijt, J., 2009, Seismically constrained probabilistic reservoir modeling: The Leading Edge, 28, no.12, December, 1478-1484.

Sangree, J.B. and Widmier, J.M., 1979, Interpretation of depositional facies from seismic data: Geophysics, 44, no.2, 131-160.

Stright, L., Bernhardt, A., Boucher, A., and Mukerji, T., 2009, Revisiting the use of seismic attributes as soft data for subseismic facies prediction: Proportions versus probabilities: The Leading Edge, 28, no.12, December, 1460-1469.

Tuttle, C., Pelissier, M., Barnes, M., Tribe, J., and Persad, K., 2009, A seismically constrained reservoir modeling workflow: Case study: The Leading Edge, 28, no.12, December, 1492-1497.

Yilmaz, Ö., 2001, Seismic data analysis: Processing, inversion and interpretation of seismic data, Society of Exploration Geophysicists, Series Investigations in Geophysics No.10, Tulsa, USA, 2027 pages.