Using kriging with external trend for time to depth conversion of seismic horizons to characterize deep saline reservoirs for CO_2 storage in Bécancour, Québec.

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Summary

The characterization of deep saline reservoir is an important step to evaluate the potential for CO_2 storage in the St. Lawrence Lowlands in the Bécancour area, Québec. Due to the limited quantity of boreholes and seismic lines available in the area, accurate modeling of stratigraphic units is not realistic. In this study, we kriged the tops of the geological formations recorded in the depth domain at 11 boreholes using an external trend interpreted from 2D seismic horizons picked in two-way. Results obtained on the geological horizons show a good compromise between the areal structure expressed by the variograms and the external trend evaluated on the modeled horizons.

Introduction

Deep saline aquifers are identified in the sedimentary successions of the St. Lawrence Lowlands in Québec and are studied for their potential for the geological storage of CO_2 at the Bécancour area (Figure 1a). We refer the reader to Konstantinovskaya *et al.* (2010) for a description of the preliminary geological study of the deep saline aquifers of the Bécancour area as a potential CO_2 storage site. The first step to evaluate and forecast the injection of CO_2 in geological units is to build a 3D model (Dubrule, 2003). However, contrary to EOR and others projects where the CO_2 is injected in operating or after-closure oil or gas fields, the availability of new and coherent dataset is not possible due to financial considerations. One of the challenges is to build a workflow that optimally uses all kind of existing data to better estimate the reservoir storage capacity and geological variability.

Data and Geological Setting

30 seismic lines acquired in Bécancour between 1970 and 2008 are used to delineate the lateral and vertical extents of 9 horizons corresponding to changes in the geological units of the sedimentary successions. The 2D seismic data available are post-stack and contain little information concerning the processing sequence applied on the raw 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 1b) in the Bécancour area and were used to locate with precision the depth of all formation tops. The simplified stratigraphy of the St. Lawrence Lowlands is presented in Figure 2. The Potsdam Group resting uncomformably on the Precambrian Grenville basement comprises the Covey Hill (conglomerates and sandstones) and the Cairnside (quartzose sandstone) formations. The Beekmantown is made up of the Theresa (dolomitic sandstone) and the Beauharnois (dolostones) formations. The Chazy and Black River Groups which are

grouped on seismic profiles are made up mainly of dolostones and fossiliferous limestones, and minor calcareous sandstones. The Trenton Group consists of well-bedded limestones. The Trenton Group is overlain by the Utica Shale and several hundred meters of interbedded shale and sandstone from the Lorraine Group. The lower Utica Shale comprises limestone beds and is more calcareous than the Upper Utica Shale. The limestones of the Trenton Group, the dolomites of the Beekmantown Group, and the sandstones of the Potsdam Group are targeted for the geological storage of CO_2.

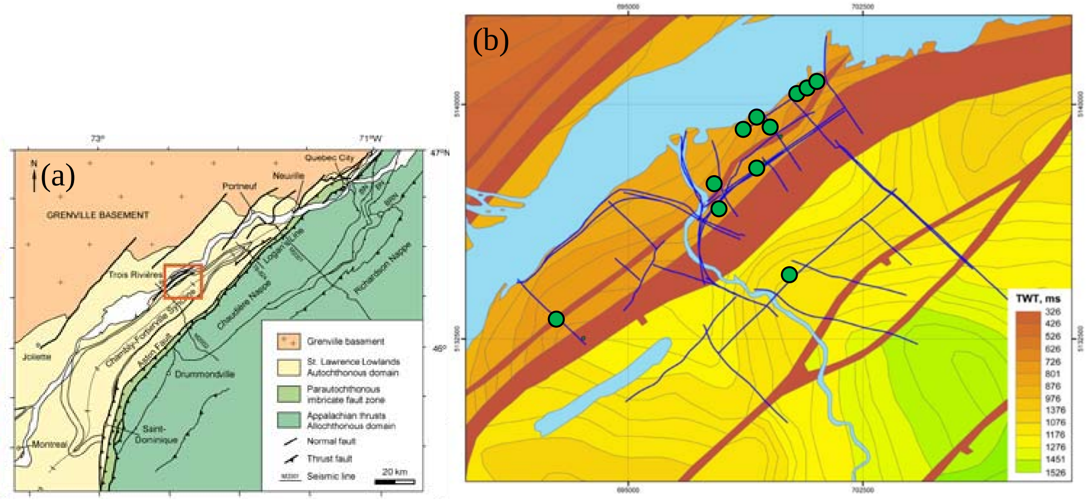

Figure 1: (a) The Bécancour area along the St. Lawerence River in Québec. Red square is the studied area presented in b. (b) Map of the Grenville basement in the Bécancour area in TWT (modified from Thériault et al., 2005). Blue lines are 2D seismic profiles used to model the horizons of geological units. Green dots are boreholes used as primary variable in the kriging scheme.

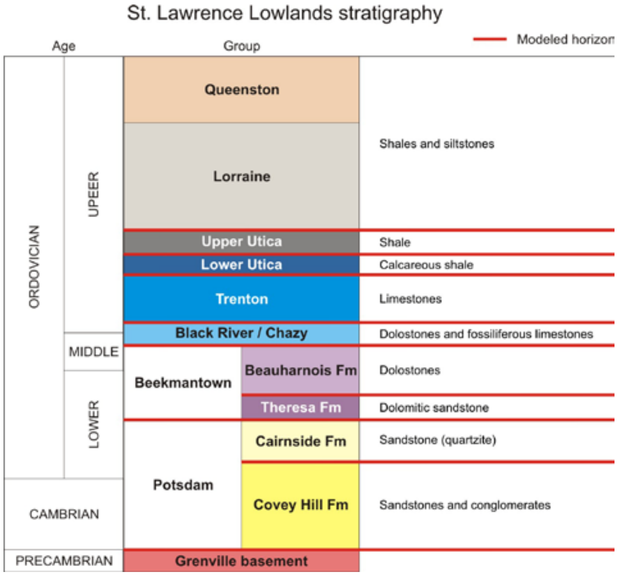

Figure 2: Simplified stratigraphy of the St. Lawrence Lowlands (modified from Konstantinovskaya *et al.*, 2009). Thick red lines are modeled horizons.

Seismic horizons picked in two-way time (TWT) are tied to borehole logs recorded in depth to generate time to depth conversion charts (TD charts) at 11 boreholes. The methodology followed to generate the TD charts is explained in Claprood *et al*. (2010). Building on the results, we develop a methodology to build a 3D model of the geological units of the St. Lawrence Lowlands in the Bécancour area, by kriging the formation tops identified on the boreholes logs using the horizons modeled in TWT from seismic data as an external trend.

Method & Results

The formation tops identified in depth from the interpretation of selected logs at 11 boreholes are the only information available in depth in the Bécancour model (Figure 3a). The formation tops are the primary variable used to interpret the geological horizons in depth by kriging with external trend as explained in Dubrule (2003).

The horizons picked on the seismic profiles allow defining the continuity of interfaces between geological units of the model and determining the presence of structural events such as faults or folds. Figure 3b presents the picked geological horizons and structural elements identified in TWT on the seismic profiles. 2D surfaces corresponding to the geological horizons are interpolated between seismic picks by the interpolator DSI or discrete smooth interpolator (Mallet, 2002) implemented in the program SKUA. Figure 3c presents the modeled horizon of the Trenton Group in TWT as an example. The modeled surfaces in TWT will be used as the external trend to guide the extrapolation of geological horizons in depth domain between the boreholes. This technique was of common use in petroleum industry before the development of 3D seismic data acquisition (Delhomme *et al*., 1981; Dubrule, 2003).

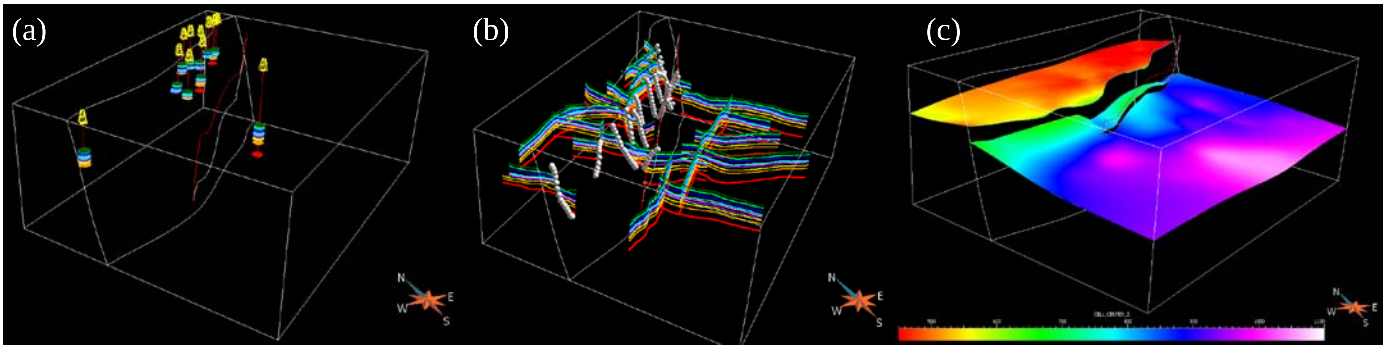

Figure 3: (a) Formation tops identified at 11 boreholes in depth. Outlines of two major faults identified and modeled in the Bécancour area are also shown. (b) Geological horizons and structural elements picked on 2D seismic lines in TWT. (c) Modeled horizon of the Trenton Group. Color bar is TWT in ms from short time (red) to late time (white). White cube defining the model is 13.6km x 10.5km x 1750ms. Vertical extension not to scale.

The first step of the kriging scheme is to compute 2D variograms to define the geometric structure of the primary variable (formation tops). Due to the limited amount of data available for the formation tops (11 boreholes), the variograms are computed on the interpolated 2D seismic horizons. Figure 4a presents the experimental and modeled variograms computed from the seismic horizon of the Trenton Group. The model variogram was fitted to the experimental variogram for a limited distance in the direction perpendicular to the trend (1000m to 2000m). The effect of the trend is clearly visible on the top left variogram of Figure 4a. The trend tends to erase the short scale structure of the variables resulting in continuously increasing variogram. This choice is supported by the fact that the external drift will support the long wavelengths of the extrapolation, and the small scale will reproduce the small wavelength variation represented by the variogram. Only the external trend defined from the modeled geological horizons would then be taken into consideration to model the surface in depth. Figure 4b presents the kriged geological horizon of the Trenton Group in depth. We observe that the kriged surface in depth represents well the external trend away from the borehole as presented in Figure 3c and fits exactly the primary borehole data in the depth domain. Its variations are influenced by both the variogram and the external trend at distances to boreholes smaller than the range of the model variogram. Figure 4c presents the computed kriging variance which is an evaluation of the uncertainty in the variogram model and the data spatial configuration. As expected by the theory of kriging, the variance drops to zero at boreholes location, where the kriging scheme respects exactly the values of the primary variable.

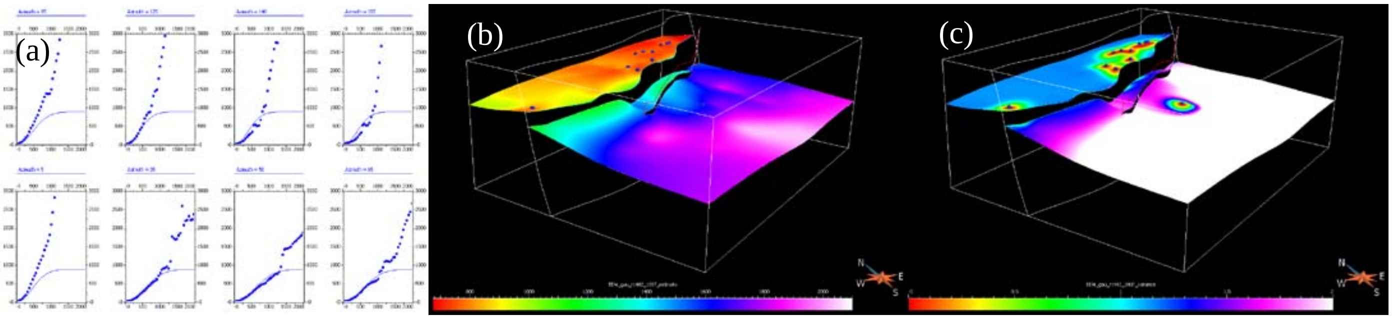

Figure 4: (a) Experimental (blue dots) and model (blue lines) variograms computed on the seismic horizon of the Trenton Group for various azimuths. (b) Kriged geological horizon of the Trenton Group. Blue dots are formation tops of the Trenton Group evaluated at 11 boreholes. Color bar is depth of the horizon in meters, red (shallow) to white (deep). (c) Kriging variance in the horizon of the Trenton Group. Color bar is the kriging variance, from 0 (red) to 2 (white). Vertical extension not to scale.

Conclusions

The results obtained by kriging of formation tops with modeled horizon as an external trend are very encouraging for the reservoir characterization in the Bécancour area, considering the limited amount of seismic and borehole logs information available. The horizons modeled in depth exactly match the formation tops identified at the 11 boreholes located within the limits of the model. The variations of the horizons were evaluated from the seismic data in TWT and were transferred to the depth domain by the use of an external trend during the kriging process. While the use of limited amount of data implies increased uncertainty, its variability can be quantified by the kriging variance. We think it is a very promising workflow in non-EOR CO_2 storage projects where the amount of funds will be a limited factor.

The next step will consist in integrating all kriged horizons of the sedimentary successions of the St. Lawrence Lowlands into a 3D model of the geological units in the Bécancour area to geostatistically model the distribution of petro-physical properties (porosity, permeability) within each formation unit, and for flow simulations of the deep saline reservoirs in the Bécancour area.

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