Combining borehole logs and 2D post-stack seismic profiles by kriging with external drift to build a 3D geological model for CO_2 storage in the Bécancour area, Québec, Canada

SÉQUESTRATION GÉOLOGIQUE DU CO_2
CHAIRE DE RECHERCHE
INRS

Maxime Claprood[1], Erwan Gloaguen[1], Bernard Giroux[1], Mathieu Duchesne[1,2], Elena Konstantinovskaya[1], and Michel Malo[1]

[1]Institut National de la Recherche Scientifique, Centre Eau Terre et Environnement (INRS-ETE), 490, rue de la Couronne, Québec, Qc, Canada;

[2]Geological Survey of Canada (Québec), 490, rue de la Couronne, Québec, Qc, Canada;

Natural Resources Canada | Ressources naturelles Canada

SUMMARY

Deep saline aquifers are identified in the Bécancour area (Québec, Canada), where their potential for the geological storage of CO_2 is studied . The first step for evaluating and forecasting the injection of CO_2 in geological units is to build a 3D model. In contrast to Enhanced Oil Recovery (EOR) and other projects where CO_2 is injected in operating oil or gas fields or after their closure, the availability of new and coherent data is very limited due to financial considerations. In this study, we krige the tops of the geological formations recorded in the depth domain at 11 wells, using an external trend interpreted from 2D seismic horizons picked in two-way times, to build a 3D model of the geological units in Bécancour. The results obtained on the geological horizons show a good compromise between the small wavelength variations reproduced by the small scale variograms and the long wavelength reproduced by the external drift. The deterministic 3D geological model will be used as a starting point to geostatistically model the distribution of lithofacies and petro-physical properties within each formation unit.

1 - INTRODUCTION

Deep saline aquifers are identified in the sedimentary successions of the St. Lawrence Lowlands in the province of Québec, Canada (Figure 1a for location). Their potential for CO_2 storage is currently studied in the Bécancour area, half-way between Montréal and Québec on the south shore of the St. Lawrence River.

As opposed to EOR and others projects where CO_2 is injected in operating or after-closure oil or gas fields, the availability of new and coherent data above deep saline aquifers is limited due to financial considerations. The challenge of this project is to optimally use all kind of existing data to better estimate the reservoir storage capacity and geological variability. This poster presents the first step of the project: building a 3D model of the geological units of the St. Lawrence Lowlands in the Bécancour area.

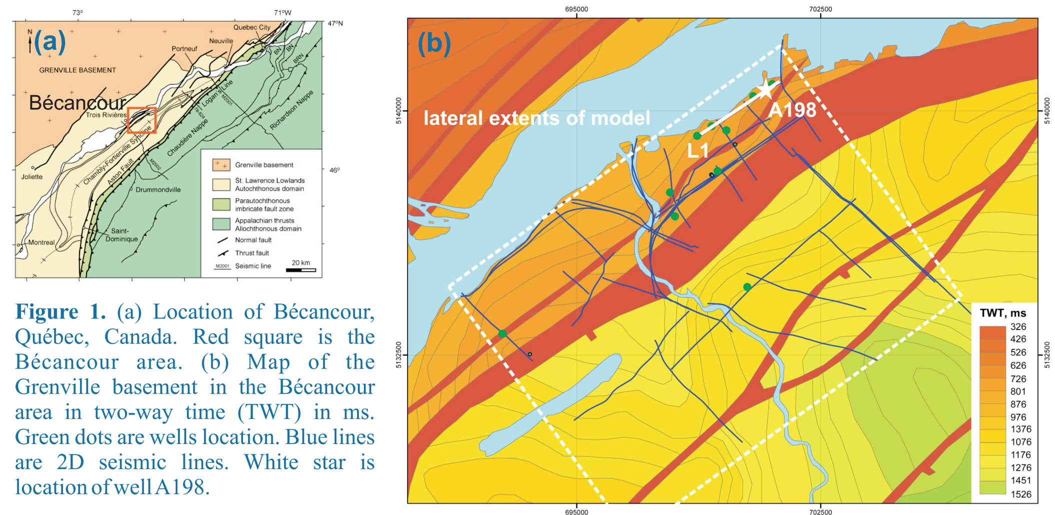

Figure 1. (a) Location of Bécancour, Québec, Canada. Red square is the Bécancour area. (b) Map of the Grenville basement in the Bécancour area in two-way time (TWT) in ms. Green dots are wells location. Blue lines are 2D seismic lines. White star is location of well A198.

2 - DATA SETS

- 30 post-stack 2D seismic lines acquired between 1970 and 2008 (25 of them are used to build the 3D model, for a total of 100km of 2D seismic):
  - use to delineate the lateral and vertical extents of 9 horizons corresponding to major changes in geology.
- borehole logs (sonic, gamma-ray, density, porosity, electric) at 18 wells (11 with sonic log to build TD charts):
  - use to locate the formation tops with precision.

- Some horizons have characteristic signatures on seismic lines, corresponding to geological units identified on well logs. The sequence of reflexions picked on Figure 2 represents the following geological units:
  - Utica Shale (dark green);
  - limestone of the Trenton Group (dark blue, low coherency and low amplitude reflections);
  - Black River - Chazy (BRChazy, light blue) and Beekmantown (Bmt, massive dolomite in purple, dolomitic sandstone in pink) Groups, and sandstone of the Cairnside Formation (yellow) as 3 strong amplitude reflections.

- Sonic logs are used to generate TD charts, to tie seismic data acquired in TWT to well logs recorded in depth. An example of a joint sonic log - 2D seismic analysis completed at 5 wells located close to seismic line L1 (Figure 1) is presented in Figure 2.
- Synthetic traces (blue wiggles) are generated by convolving the reflection coefficients obtained from the product of the sonic (red curves) and density (not shown) logs with a seismic wavelet. The wavelet was modeled by extracting the 50 nearest shot points from each well from time-depths between 0.1 s to 1.2 s.

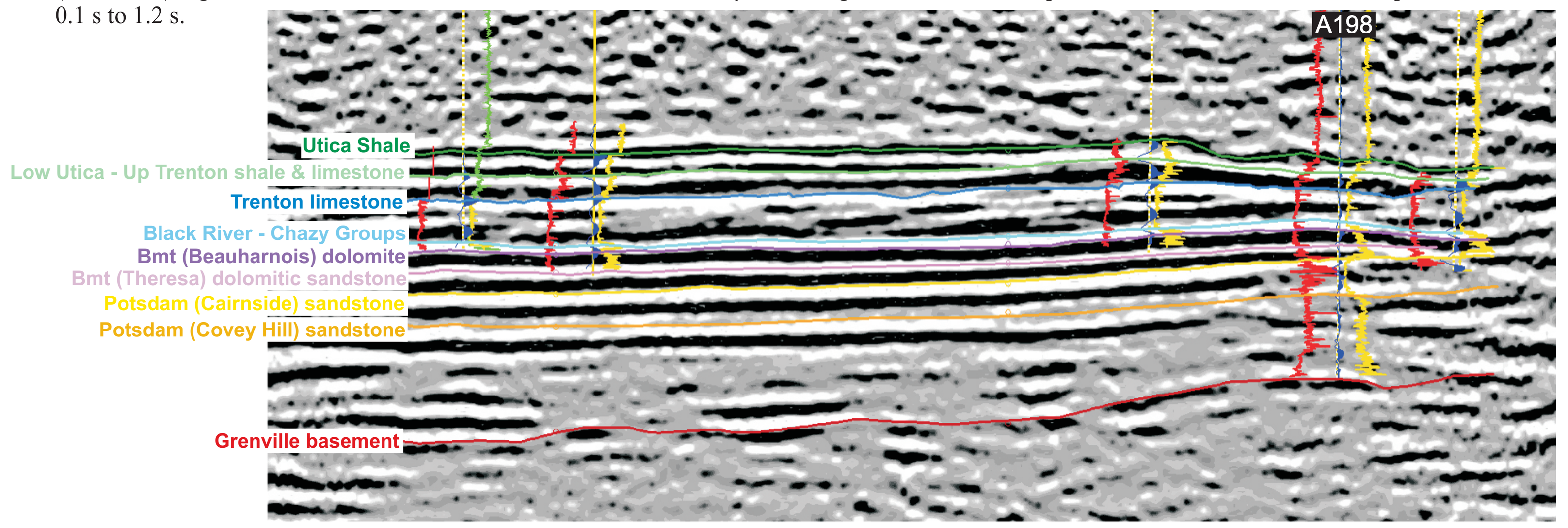

Figure 2. Seismic line identified L1 in Figure 1b, with sonic (red) and gamma-ray (yellow and green) logs at wells located at proximity to seismic line. 9 seismic horizons corresponding to geological units are identified. Vertical axis is two-way time (TWT).

3 - CREATION OF TD CHARTS

Apply running average on sonic logs and compute the seismic velocity

↓

Apply running average on density log

↓

Multiply velocity and density logs to obtain the acoustic impedance

↓

Compute the reflection coefficients from the acoustic impedance

↓

Convolve the reflection coefficients with a seismic wavelet to obtain the synthetic seismic traces

↓

Tie the synthetic traces with the appropriate reflections on observed seismic traces

↓

2 possibilities

Use of the coefficient of correlation to find best tie between synthetic and observed seismic traces
- many solutions possible when DT log recorded on limited depth interval.
- imprecision in final estimation of TD charts

Use formation tops identified with other borehole logs (GR) to tie synthetic traces to seismic signatures of some geological units on observed seismic
- better identification of reflections on seismic lines.
- improved precision in estimation of TD charts.

- Formation tops are identified by Konstantinoskaya et al. (2009) from well logs analyses, mostly using gamma-ray (GR), sonic (DT), density porosity (DPHI), neutron porosity (NPHI), and photo-electric factor (PEF) from the methodology described by Doveton (1986).

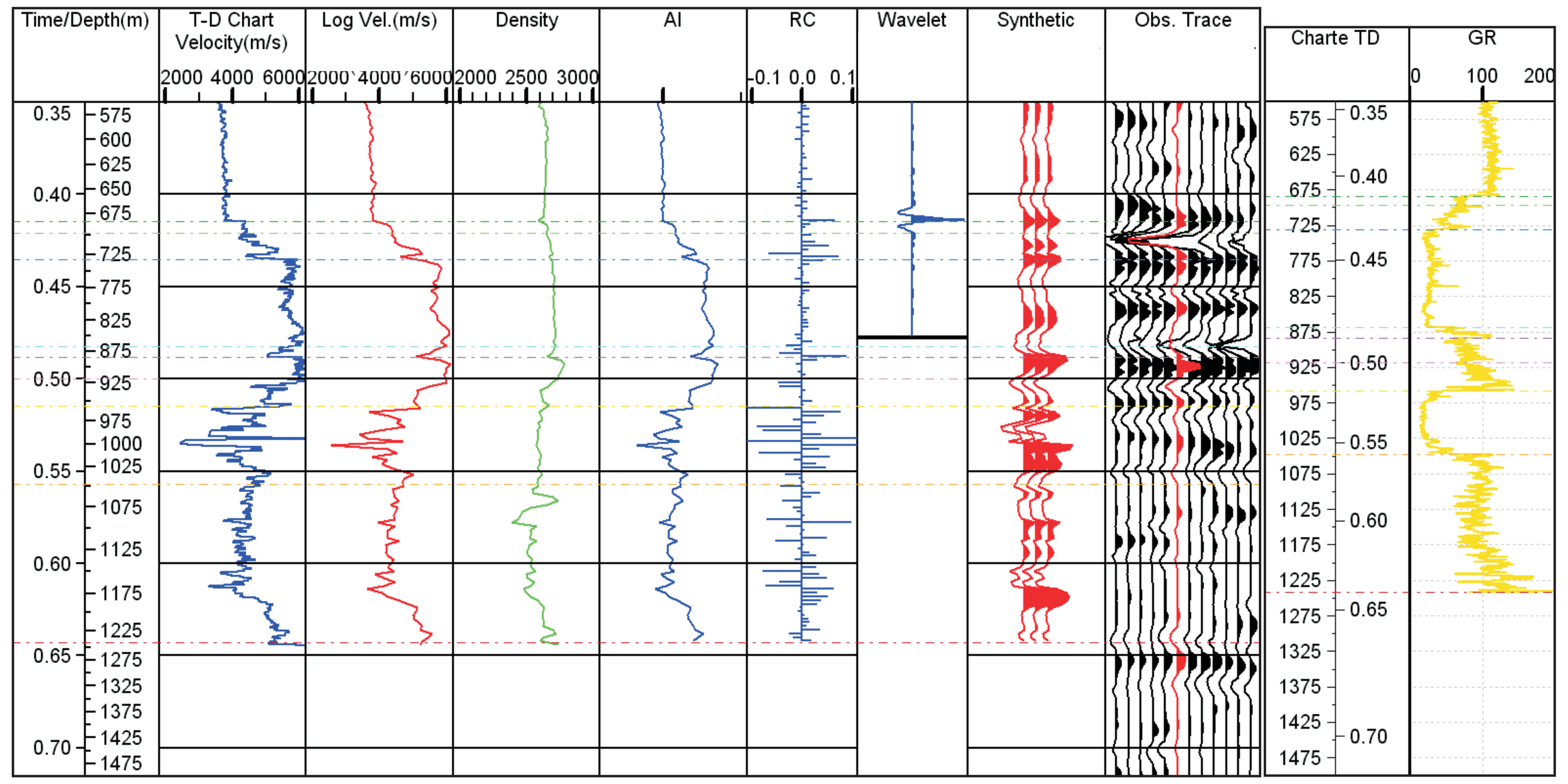

Figure 3. TD Charts at well A198 (Figure 1b for location) created with the help of the gamma-ray log (GR, last column in yellow). Dashed-dotted lines are formations tops identified on logs, with same color code used in Figure 2. Vertical axis is TWT (ms), except for GR log which is depth (m). TD charts are used to tie formation tops identified in depth with seismic horizons interpreted in TWT.

Velocity ties are mostly based on qualitative fit between 2D post-stack seismic lines and sonic logs using synthetic seismograms. While there is a lack of quantitative validation of the obtained TD charts, the continuity of seismic signatures suggests that the velocity analyses are reliable.

4 - MODELING HORIZONS IN TWT

- 2D surfaces corresponding to the geological horizons are interpolated between seismic picks using the discrete smooth interpolator (DSI) (Mallet, 2002) implemented in the software SKUA. To avoid repetitions, only the modeled horizon of the Trenton Group is presented in this poster.
- Figure 4a presents the picked geological horizons and structural elements identified in TWT on the seismic profiles.
- Figure 4b presents the modeled horizon of the Trenton Group in TWT.

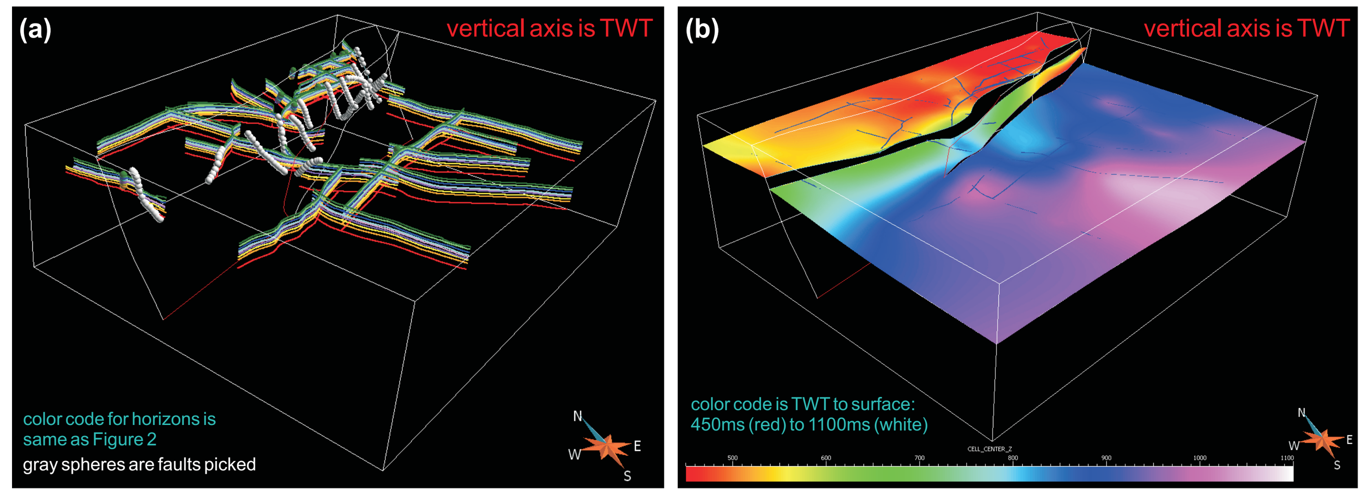

Figure 4. (a) Geological horizons and structural elements picked on 2D seismic lines in TWT. (b) Modeled horizon of the Trenton Group. Color bar is TWT in ms from short time (red) to late time (white). White cube defining the model is 13.6km x 10.5km x 1750ms. Vertical extension not to scale.

5 - KRIGING FORMATION TOPS WITH EXTERNAL DRIFT

- Geological horizons are modeled in depth by kriging the formation tops identified on well logs (Figure 5a), using the horizons modeled in TWT (such as the example of the Trenton Group in Figure 4b) as an external drift to guide the conversion to the depth domain between the wells (Delhomme et al., 1981; Dubrule, 2003).

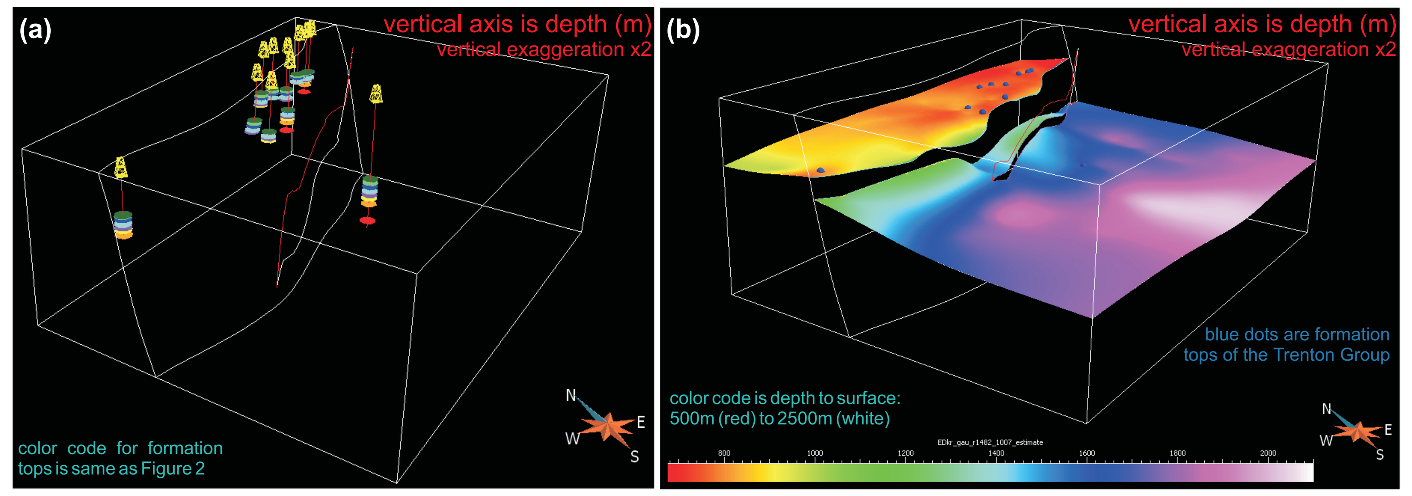

Figure 5. (a) Formation tops identified at 11 wells in depth. (b) Kriged geological horizon of the Trenton Group in depth. White cube defining the model is 13.6km x 10.5km x 3200m.

- Formation tops identified from the interpretation of selected logs at 11 wells are the only information available in depth in the Bécancour model.
- 2D variograms (Figure 6) defining the geometric structure of the primary variable (formation tops) are computed on the interpolated 2D seismic horizons due to limited amount of hard data available for the formation tops from well logs.
- Model variogram is fitted to the experimental variogram over a limited distance (< 2000m). Small scale variograms will reproduce the small wavelength variations, and the external drift will support the long wavelength of the extrapolation.

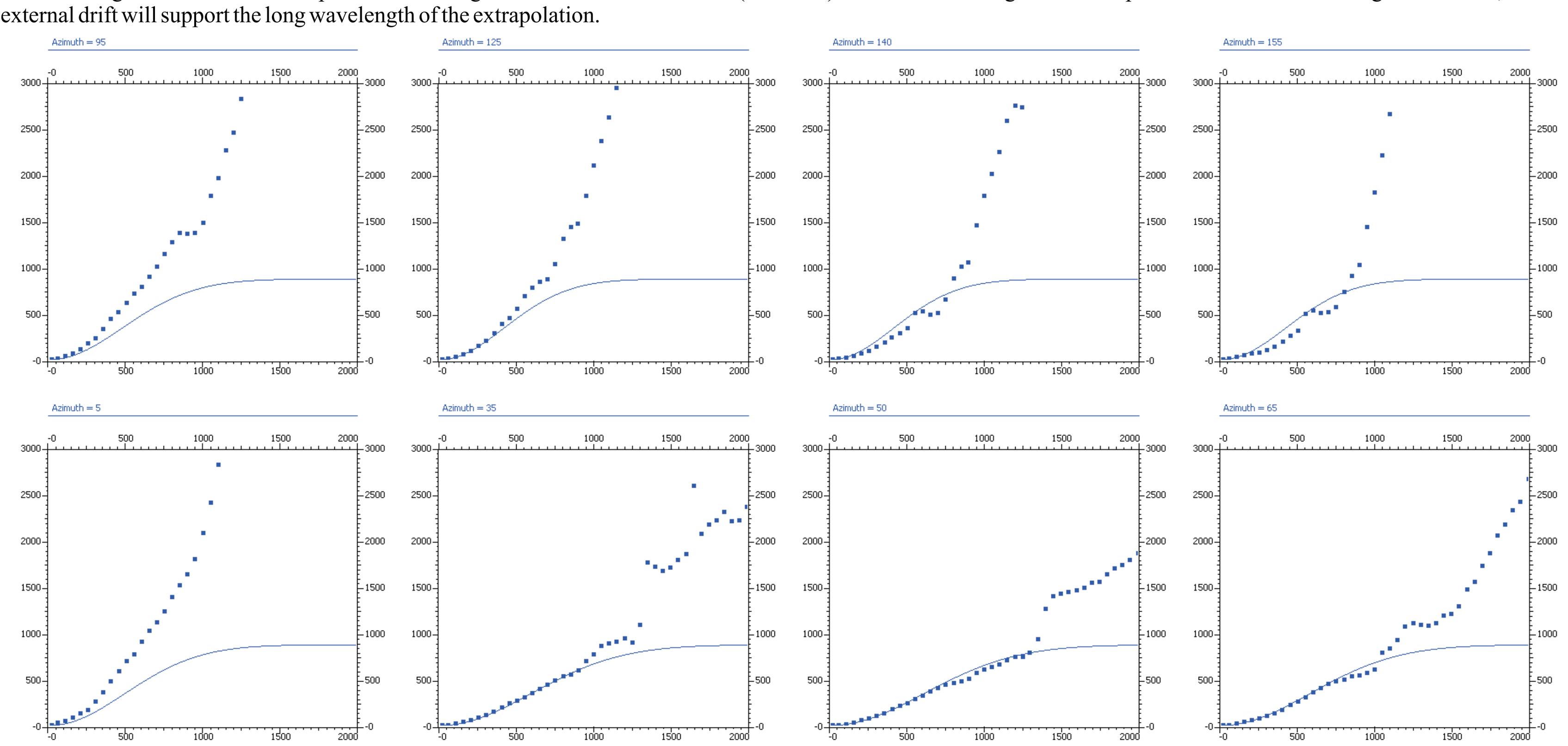

Figure 6. Experimental (blue squares) and modeled (blue lines) areal variograms at azimuths 95°, 125°, 140°, 155°, 5°, 35°, 50°, and 65° computed from the seismic picks of the Trenton Group. X-axis is the range in meters. Modeled variograms is a gaussian model with geometrical anisotropy, with maximum range a_1 = 1482m, minimum range a_2 = 1007m, azimuth of maximum axis = 48°, and sill = 882.

6 - BUILDING 3D GEOLOGICAL MODEL IN DEPTH

- The methodology presented in Sections 4 & 5 is applied to all 9 horizons to construct a deterministic 3D geological model of the sedimentary succession of the St. Lawrence Lowlands from the top of the Grenville basement (red in Figure 7a) to the top of the Utica Shale (cap rock, dark green in Figure 7a).

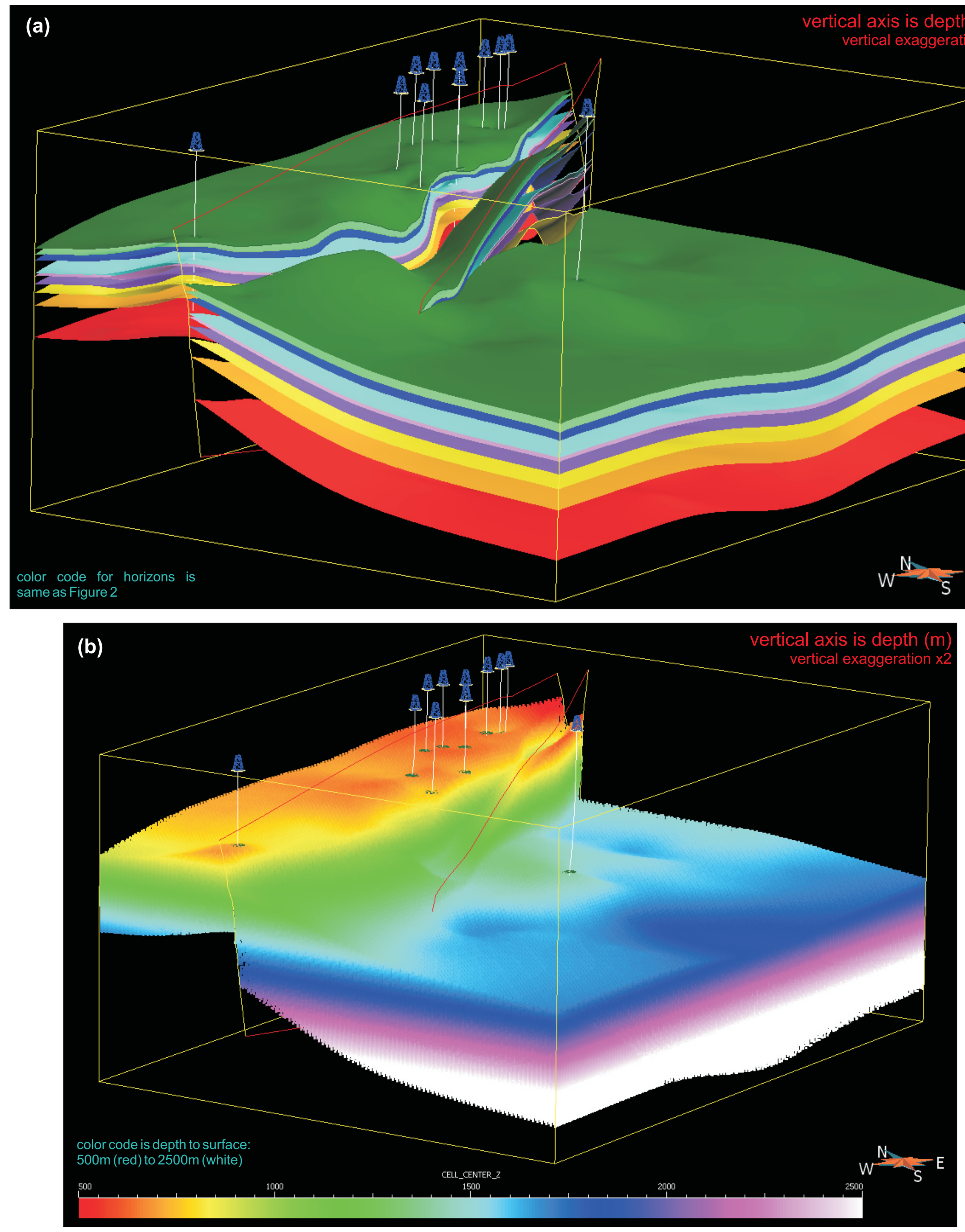

Figure 7. Two different representations of the 3D geological model of the St. Lawrence Lowlands with a color code representing (a) each modeled horizon and (b) the depth below sea level. Thin red lines are limits of 2 faults included in the model. White cube defining the model is 13.6km x 10.5km x 3200m.

7 - CONCLUSION

The results obtained by the kriging of formation tops with modeled horizons as an external trend are very encouraging, considering the limited amount of available seismic and well logs. The horizons modeled in depth exactly match the formation tops identified at the 11 wells located within the limits of the model. The spatial variations of the horizons are evaluated from the seismic data in TWT and transferred to the depth domain by using an external trend during the kriging process. We think that this approach is a very promising workflow in non-EOR CO_2 storage projects where the amount of funds and thus available existing data sets will be a limiting factor.

The next step will consist in integrating all kriged horizons representing the sedimentary successions to geostatistically model the distribution of lithofacies and petro-physical properties (porosity, permeability) within each formation unit that will later be used for flow simulations in the deep saline reservoirs in the Bécancour area.

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