Seismic characterization of the Nisku Formation in the Wabamun area, Alberta, Canada for large-scale CO_2 sequestration

Abdullah Alshuhail, Don Lawton, and Helen Isaac, University of Calgary*

Summary

Seismic characterization of the Devonian Nisku Formation in the Wabamun area, Alberta, Canada has revealed two primary groups of anomalies. The first group is interpreted to be footprints of geological discontinuities which are induced by dissolution and karsting in a geologic formation shallower in the stratigraphy. Even though there is no evidence to indicate that the integrity of the Nisku Formation or the overlying caprock has been compromised, such geologic discontinuities should be taken into consideration if supercritical CO_2 were to be injected into the Nisku Formation. The second group is interpreted to be due to contrasts in lithology and/or porosity of the Nisku Formation. This interpretation is supported by constraints provided by well control and by seismic modeling. Finally, our analysis has identified favorable low-impedance, potentially high-porosity, locations that could be developed for a CO_2 injection site.

Introduction

The province of Alberta contributes more than 30% to the total Canadian CO_2 emissions, according to recent statistics by United Nations Framework Convention on Climate Change (2007). In an effort to offset the carbon emissions, several CO_2 sequestration projects were launched recently in the province. These include the Alberta Saline Aquifer CO_2 Project (ASAP), the Heartland Area CO_2 Sequestration Project (HARP), and the Wabamun Area CO_2 Project (WASP).

In the Wabamun area, the Nisku Formation has been advocated as a sink for large-scale CO_2 sequestration project (Michael et al., 2008) with injectivity in the order of 1 Mt/year. Seismic characterization was undertaken as part of the first phase of the project, with primary objectives to generate detailed attribute maps of the Nisku Formation and delineate any potential geologic discontinuities in the area that may compromise the integrity of the CO_2 storage within this formation. This abstract presents some of the results of the study.

Study Area

The proposed CO_2 sequestration area is located in the central plains of Alberta, approximately 50 km southwest of the capital Edmonton. The injection target is the Devonian brine-bearing Nisku Formation. The Nisku aquifer sits on the edge of a carbonate shelf and consists predominantly of dolomite minerals. The aquifer ranges in thickness from 40 to 80 m and occurs at a depth between 1800 - 2000 m and its properties, such as temperature and salinity, make it a favorable candidate for CO_2 storage (Michael et al., 2008). Furthermore, the overlying Calmar shale makes a good cap rock, which prevents supercritical CO_2 from migrating upwards into shallow aquifers. The seismic characterization is focused on a local area, where favorable conditions in terms of seismic coverage and other factors exist.

Approach and Results

The seismic characterization is based on analyzing and interpreting a poststack seismic dataset consisting of more than two hundred 2D lines and seven 3D volumes distributed over an area of approximately 20,000 km^2. This enormous dataset was available from various exploration programs in the area, and therefore has different acquisition and processing vintages. Thus, prior to interpretation, two primary steps were necessary: data calibration and amplitude normalization. These steps were necessary to account for the vintage differences between the various 2D and 3D datasets. Following these two steps, regional 2D seismic lines were used to delineate the long-wavelength character of the Nisku Formation whereas mapping of detailed attributes was achieved using the high quality 3D seismic volumes.

Figure 1 shows the Nisku time structure and normalized root-mean squares (NRMS) amplitude maps, respectively, after data calibration and normalization. The NRMS amplitude map exhibits strong variations compared to the time structure map. In addition to time and amplitude maps, the acoustic impedance of the Nisku Formation was estimated using two poststack inversion schemes, namely recursive and model-based inversions (Figure 2). Clearly there is a good correlation between the amplitude and acoustic impedance anomalies. However, it is insufficient to separate lithology-driven variations from discontinuity - induced anomalies based on those attributes alone. Furthermore, since the seismic volumes exhibit signs of discontinuities, it was deemed appropriate to invoke a coherency-sensitive attribute, namely the difference method (Luo et al., 1996), to discriminate impedance contrasts associated with lithology variations from those resulting from footprints from overlying geologic discontinuities (Figure 3).

Seismic characterization of the Nisku Formation

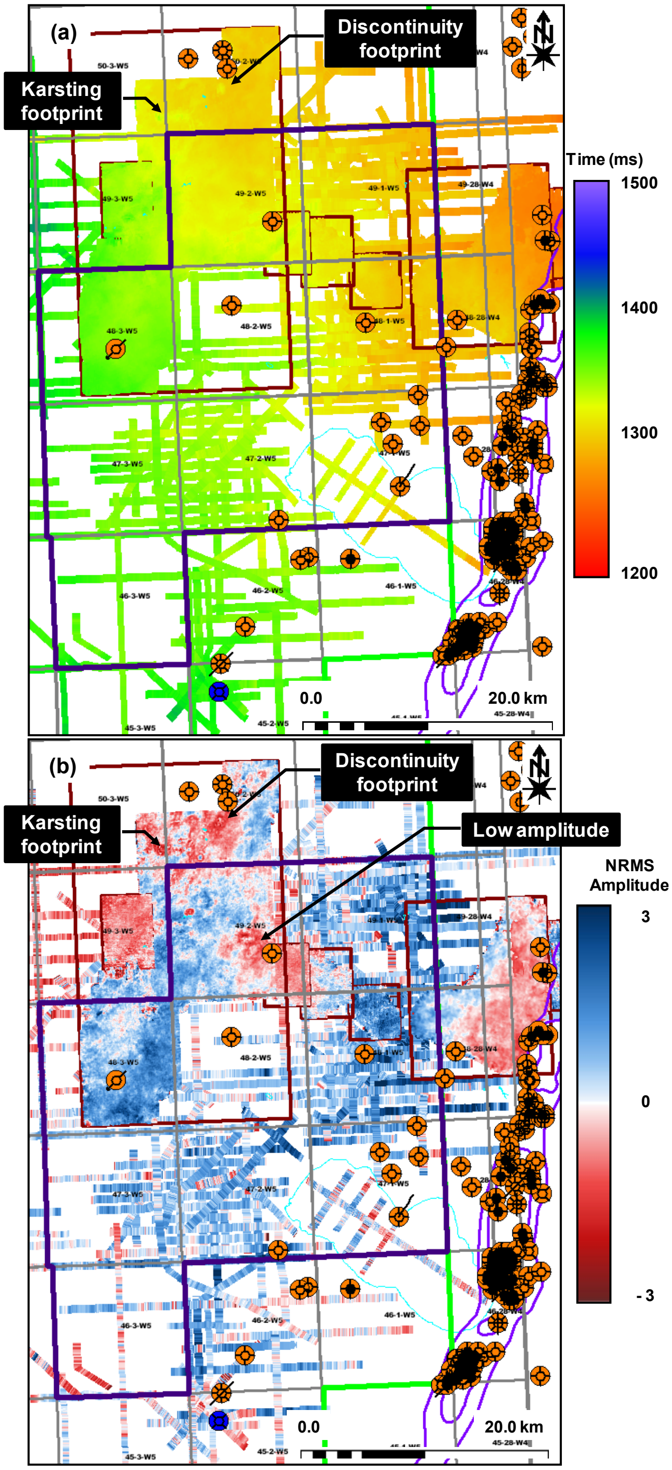

Figure 1: (a) time structure map, and (b) normalized root-mean squares (NRMS) amplitude map of the Nisku Formation.

With the discontinuity-driven anomalies identified, the next step was to gain a better understanding of the amplitude variations due to changes in lithology (porosity) and thickness. This is important since substantial emphasis was placed on the amplitude to provide one approach for favorable site selection due, in part, to the lack of well control to constrain the inversion. Moreover, since the Nisku is a tuned event, insight was needed into the principle factors affecting its reflection amplitude. Hence, the seismic amplitude of the Nisku Formation was modeled, using a simple convolutional model, as a function of thickness and velocity (Figure 4) as these were found, from well control, to be the principle entities affecting the Nisku amplitude. In addition, the acoustic impedance of the synthetic model was reconstructed, as a function of these parameters, using the same inversion schemes employed in estimating the acoustic impedance of the real data (Figure 5).

Discussion and Conclusions

Although the data calibration and normalization were successful in reconciling the differences between the vintage data, only 3D data were reliable when it comes to the detailed attribute mapping. The 2D data, on the other hand, was useful in delineating the long-wavelength structure of the Nisku Formation. The time structure map of the Nisku is consistent with the regional NE-SW dip and is almost featureless except for a few subtle anomalies induced by the discontinuities.

The NRMS amplitude and acoustic impedance maps, on the other hand, show strong variations across the study area. These anomalies are interpreted to be either discontinuity induced or lithology driven. Furthermore, by comparing these attributes with the coherency attribute, it is feasible to isolate those anomalies associated with discontinuities induced as footprints due to dissolution and karsting in the overlying Wabamun Formation. Even though these do not necessarily reflect physical discontinuities within the Nisku Formation itself, they should be taken into consideration in any future CO_2 sequestration program in the area.

As for the other group of anomalies observed in the NRMS amplitude and acoustic impedance maps, the modeling results suggests that such anomalies are associated with variations in lithology and/or porosity rather than being a tuning effect. Furthermore, these conclusions were calibrated against a good quality brine-bearing section of the Nisku Formation near the south-eastern corner of the study area. The seismic data around this water source well show significant variations in the NRMS amplitude and acoustic impedance but insignificant variation in the Nisku thickness as verified by neighbouring wells.

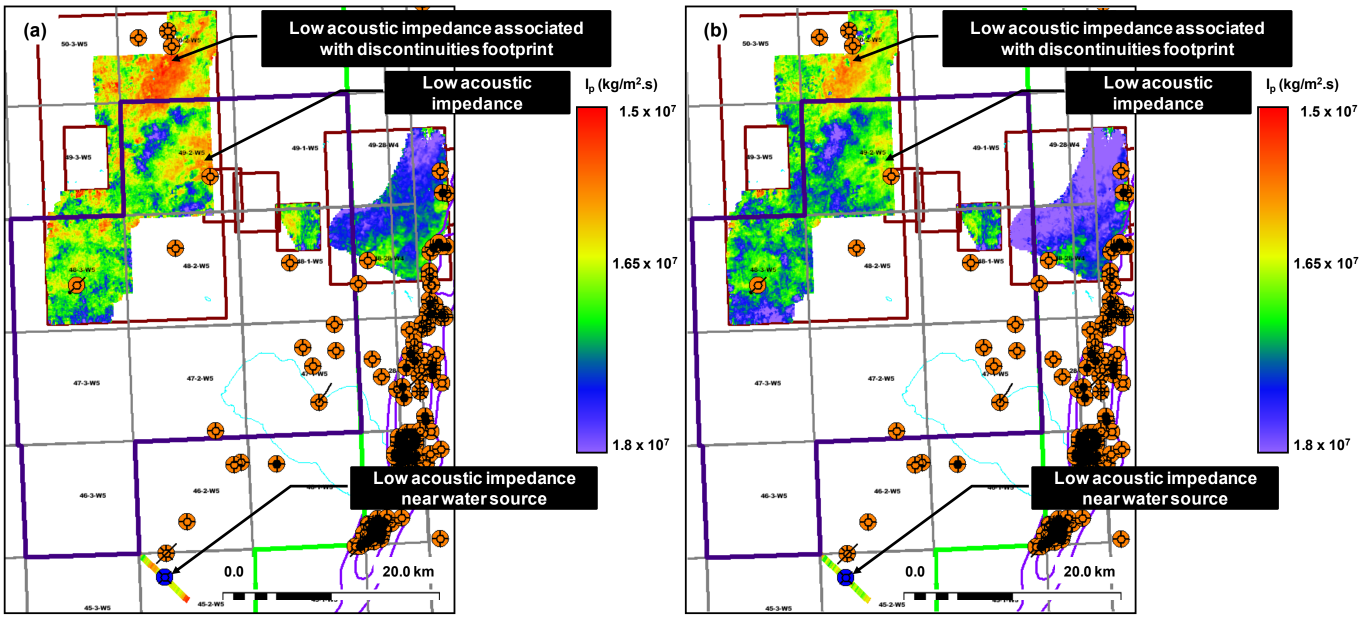

Figure 2: Acoustic impedance map of the Nisku Formation using (a) recursive (or bandlimited), and (b) model-based inversion. The two inversion schemes operate on different principles and, therefore, in a sense complement each another. Except for minor scaling difference, they both show strong similarities in spatial variations in acoustic impedance.

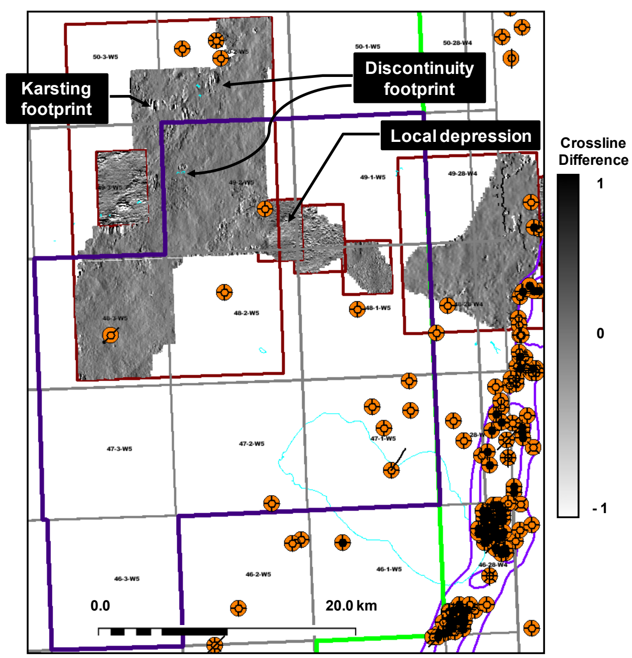

Figure 3: Coherency map of the Nisku Formation using the difference method (Luo et al., 1996). The arrows point to the location of footprints associated with overlying geologic discontinuities, such as Wabamun karsting,

Seismic characterization of the Nisku Formation

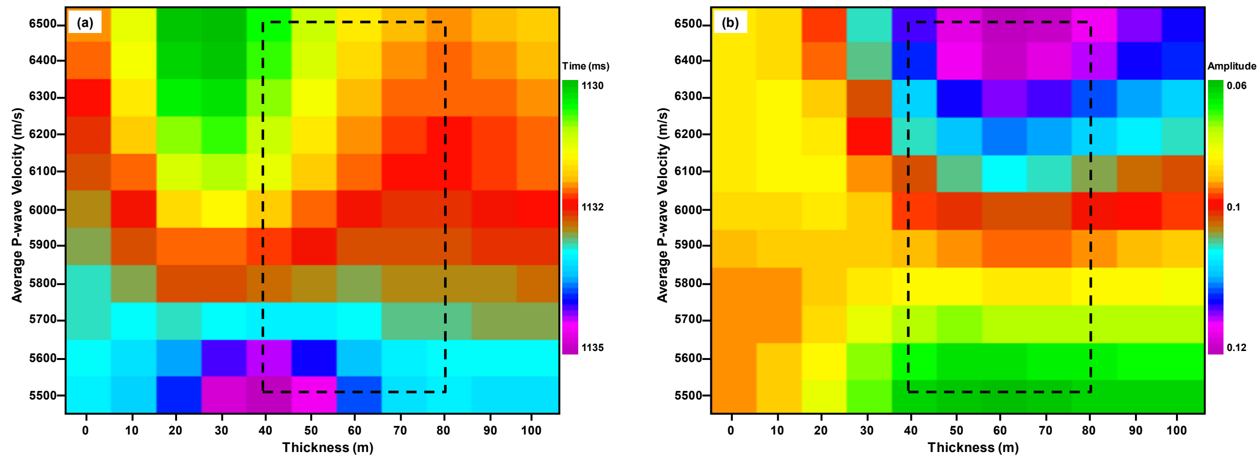

Figure 4: Nisku Formation two-way traveltime (a) and normalized amplitude (b) as a function of its thickness and average P-wave velocity. The maps are extracted from synthetic seismograms, which were generated by convolving a zero-phase Ricker wavelet with a reflectivity series from a control well log. The black dashed rectangle outlines the likely Nisku thickness and velocity within the study area based on well controls. Sensitivity is higher along the vertical axis, which indicates that the thickness effect is small compared to the variations in P-wave velocity.

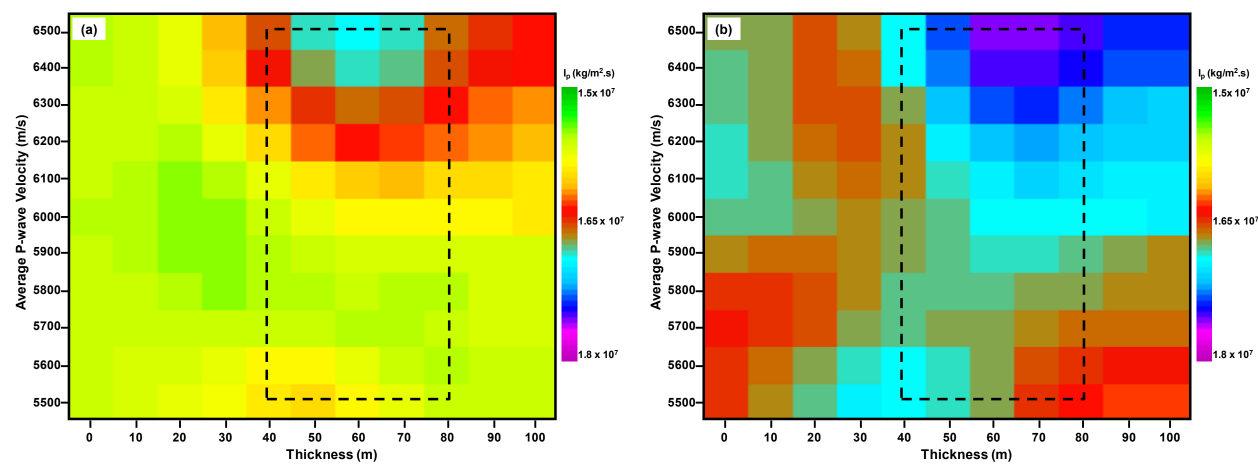

Figure 5: Nisku Formation acoustic impedance corresponding to the synthetic model in Figure 4 using (a) recursive and (b) model-based inversion. The black dashed rectangle outlines the likely Nisku thickness and velocity within the study area based on well control. Sensitivity is higher along the vertical axis, which indicates that the thickness effect is small compared to the P-wave velocity effect. In addition, the same scaling difference observed between the acoustic impedance retrieved from recursive and model-based inversion in the field data (Figure 2) is also present in the synthetic data.

Finally, based on lithology driven anomalies, potentially high porosity areas of the Nisku Formation were interpreted on the acoustic impedance maps. In addition, the modeling results suggest that it is feasible to invoke seismic amplitude in pursuing favorable sites for CO_2 injection in areas where acoustic impedance inversion was hindered by the scarcity of well control.

Acknowledgments

The authors would like to thank WASP sponsors and the Natural Sciences and Engineering Research Council of Canada (NSERC) for funding the project; WASP technical team for valuable discussions; The CREWES project for technical support; EnCana for access to the seismic data; Jimmy Haszard (EnCana) and Ian Reglar (formerly EnCana); KFUPM for A. Alshuhail scholarship.