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Time-lapse seismic modeling of CO_2 sequestration at Quest CCS project

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Summary

A time-lapse analysis was carried out to investigate the theoretical detectability of CO_2 for the Shell Quest project. Quest is a Carbon Capture and Storage (CCS) project in Alberta operated by Shell Canada Energy and its partners. The target formation for injection is Basal Cambrian Sandstone (BCS) which is a deep saline aquifer at an approximate depth of 2000 meters below surface in the Quest project area. The purpose of this study was to simulate the seismic response of the BCS after injecting 1.2 million tonnes of CO_2 during a one-year period of injection. This was done using Gassmann fluid substitution and seismic forward modeling. A geological model for the baseline scenario was generated based on logs from well SCL-8-19-59-20W4. For the monitor case, Gassmann fluid substitution modeling was undertaken to model a CO_2 plume within BCS. Numerical stack sections for both scenarios were obtained and subtracted to study the change in the seismic response after injecting CO_2. The difference section shows the location and the spatial distribution of the plume. Based on these results the CO_2 plume could be detected in the seismic data after a year of injection, providing the data have good bandwidth and a high signal-to-noise ratio.

Introduction

Carbon Capture and Storage (CCS) is one of the methods for reducing the emissions of CO_2 in the atmosphere. In this process, the produced CO_2 from large emitters is captured before it can be released into the atmosphere. It is transported and then injected into a deep geological formation for permanent storage. Quest Carbon Capture and Storage is a joint CCS project between Shell Canada Energy, Chevron Canada Limited and Marathon Oil Canada Corporation. The purpose of this project is to reduce the CO_2 emission from Scotford Upgrader by storing it in a deep geological formation. The location of the Scotford Upgrader is about 5 km northeast of Fort Saskatchewan, Alberta, within an industrial zone (Shell, 2010). The selected geological formation for the CO_2 storage is the Basal Cambrian Sands or BCS, which is a saline aquifer within Western Canadian Sedimentary Basin (WCSB), with an approximate depth of 2000 meters below the surface in the Quest project area.

The goal of this study was to investigate the theoretical detectability of CO_2 for Quest project. For this purpose Gassmann fluid substitution (Gassmann, 1951) was undertaken to calculate the properties of BCS after injecting CO_2. When the in-situ pore fluid is substituted by a new fluid, physical rock properties such as density and seismic wave velocities would change (Gassmann, 1951; Smith et al., 2003). These changes will lead to changes in the amplitudes and traveltimes of the seismic data. In this study the monitor and baseline seismic sections were simulated to investigate the detectability of CO_2 in the Quest project.

Method

A geological model was generated based on logs from well SCL- 8-19-59-20W4. This model was used for the baseline numerical seismic survey. For more accuracy, BCS was divided into 7 thin layers with an average thickness of 7 meters for each layer. The detailed view of BCS and its physical properties are shown in Figure 1.The model was then modified to simulate the monitor survey by adding a CO_2 plume to BCS. The properties of the plume were calculated using Gassmann fluid substitution for BCS. Figure 2 illustrates the changes in P-wave velocity versus CO_2 saturation for all 7 layers within BCS. The maximum time lapse effect occurs at 40% CO_2 saturation and passed this value the velocity does not change considerably. Therefore, it was assumed that the plume had 40% CO2 saturation in the monitor model. The size of the plume was estimated based on the injected amount of 1.2 million tones of CO_2 after one year injection and also the porosity of BCS. This plume had a semi-conical shape (with a radius of 800 meters) to better describe the CO_2 distribution affected by the buoyancy force (Figure 3). Synthetic shot gathers were generated in NORSAR2D software package for both baseline and monitor scenarios and were processed in the VISTA seismic processing package to obtain the stacked CMP sections. The difference section was obtained by subtracting the baseline section from the monitor section to observe the changes in seismic response after injecting CO_2 (Figure 4).

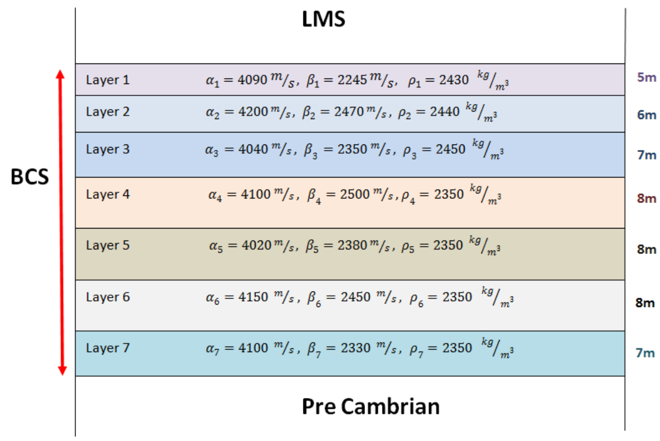

Figure 1: A detailed view of BCS in the model, where it is divided to seven thin layers. BCS is overlain by Lower Marine Sands or LMS and underlain by Pre-Cambrian.

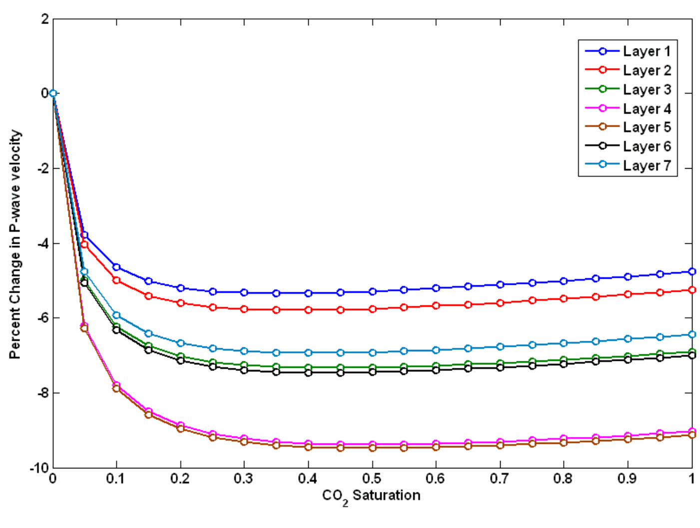

Figure 2: Relative change in P-wave velocity versus CO_2 saturation for each of the 7 layers within BCS.

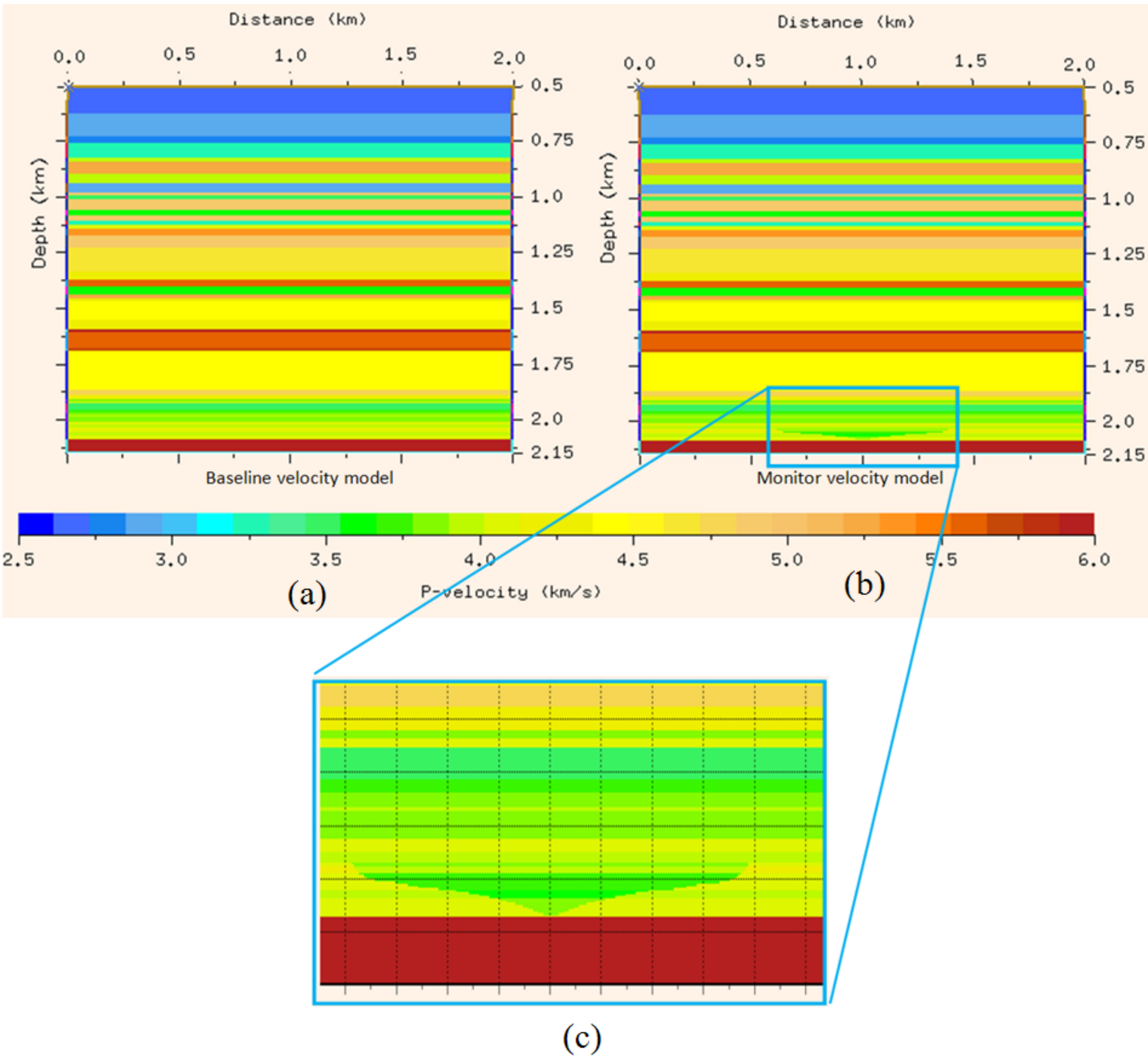

Figure 3: The P-wave velocity model for baseline (a) and monitor (b) scenarios, and a closer view of the CO_2 plume in BCS(c).

Results

The results showed that the injection of CO_2 caused a change in amplitude and traveltimes within and underneath the plume which caused a difference in the monitor seismic response. In order to measure these changes, the traces at CMP location 1499 were pulled out from the baseline and monitor sections. Figure 5 shows these traces plotted on top of each other. The reflection from the top of Pre-Cambrian (approximately at 1.2 s) showed a time shift of 0.003 s after injecting CO_2. Also the RMS amplitude between the times 1.15 s and 1.21 s increased about 30 percent in the monitor section.

The horizontal distribution and also the top of the plume were clearly observable in the difference section (Figure 4). However, the shape of the plume did not appear in a semi-conical shape since there were time shifts in the reflectors underneath the plume ends.

Conclusions

- The changes in rock properties of the BCS after one-year period of injection are large enough to be detected in seismic sections. These changes appear as change in amplitude and traveltimes in the monitor section and could be better observed when the baseline section is subtracted from the monitor section.
- Gassman's equation is a useful method for modeling the changes in the rock properties of the storage formation after injecting CO_2.
- The shape of the plume could not be precisely determined but the spatial distribution and the top of the plume could be observed in the difference section.

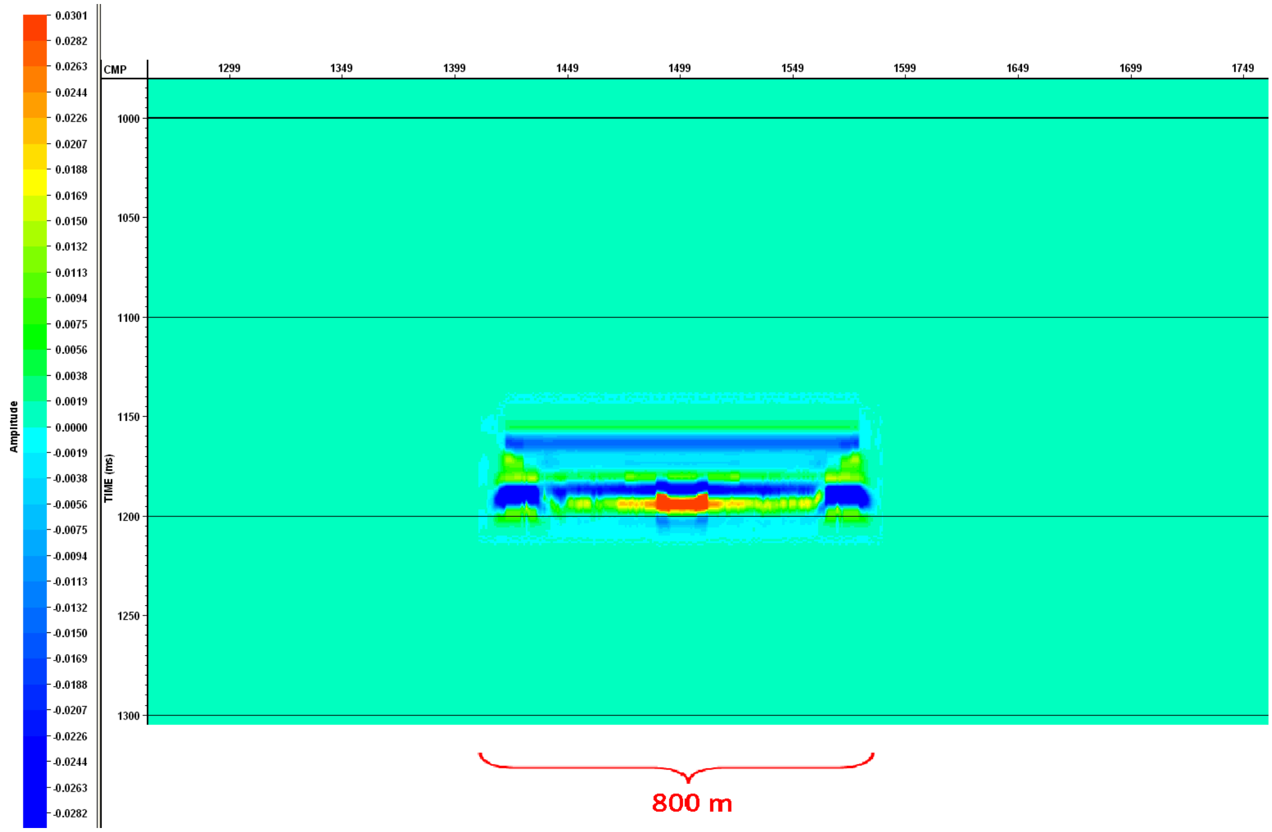

Figure 4: Difference between 0% and 40% CO_2 saturation stack sections.

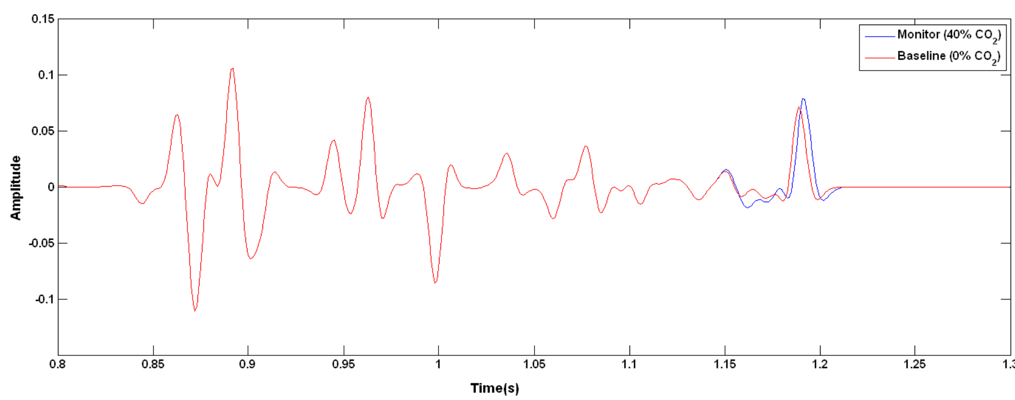

Figure 5: Traces at CMP location 1499 from the baseline and monitor sections.

Acknowledgements

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