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. The purpose of this study was to simulate the seismic response of the target formation 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. Based on the results the CO_2 plume could be detected in the seismic data after a year of injection.

Study area

The purpose of Quest project is to reduce the 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 (Figure 1). The selected geological formation for the CO_2 storage is Basal Cambrian Sands or BCS, which is a saline aquifer within Western Canadian Sedimentary Basin (WCSB) with an approximate depth of 2000 m from the surface (Shell, 2010).

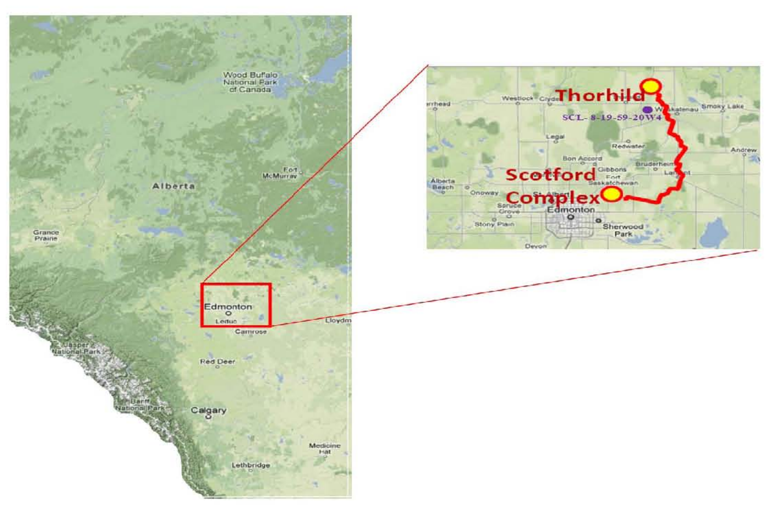

FIG. 1: Study area and the location of well SCL-8-19-59-20W4

Well SCL- 8-19-59-20W4

In this work the data set from well SCL- 8-19-59-20W4 (Figure 1) was used to make a model for seismic time lapse modeling. Figure 2 shows the logs from this well. There are 5 tracks that show density, P-wave velocity, S-wave velocity, Gamma-ray and seismic synthetics respectively from track 1 to 5. The synthetic seismograms were generated in Hampson-Russell using the velocity and density logs and a 50 Hz zero-phase wavelet.

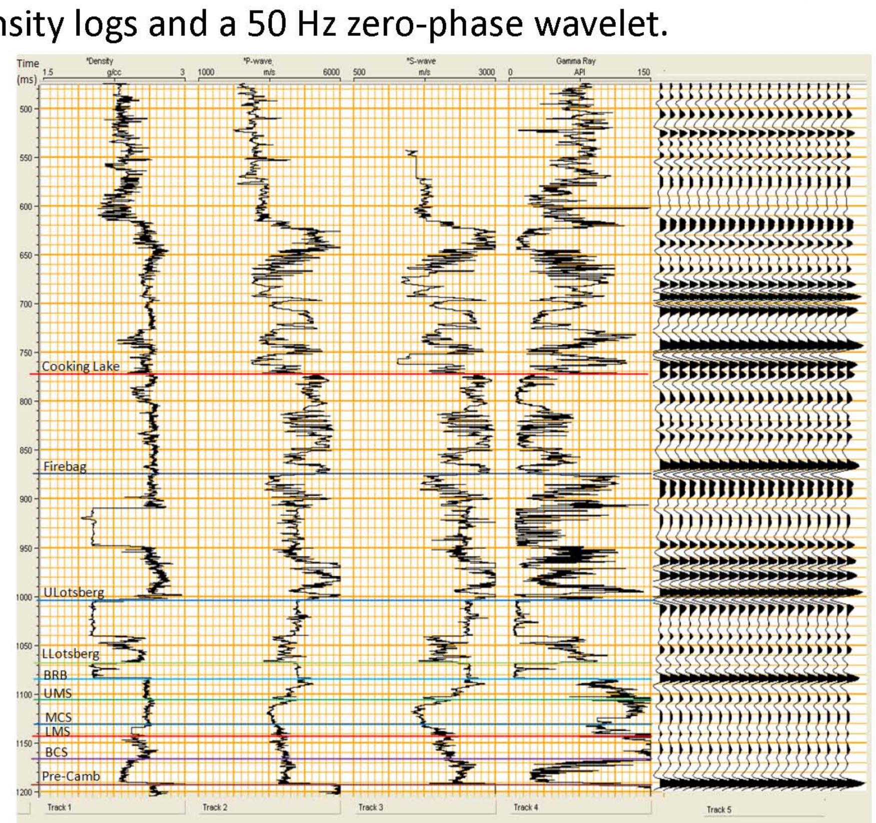

FIG. 2: Data from well SCL- 8-19-59-20W4 and some of the horizons in the zone of interest.

Geological model

Using the velocities and densities from the logs, a geological model was generated in NORSAR2D. Figure 3(a) shows the velocity model generated for baseline scenario where CO_2 saturation in BCS was 0%. For more accuracy the BCS and its upper layers LMS, MCS and UMS, were divided into a set of thin layers. Specifically in BCS there were 7 layers with the average thickness of 7 meters. The detailed view of BCS is shown in Figure 4.

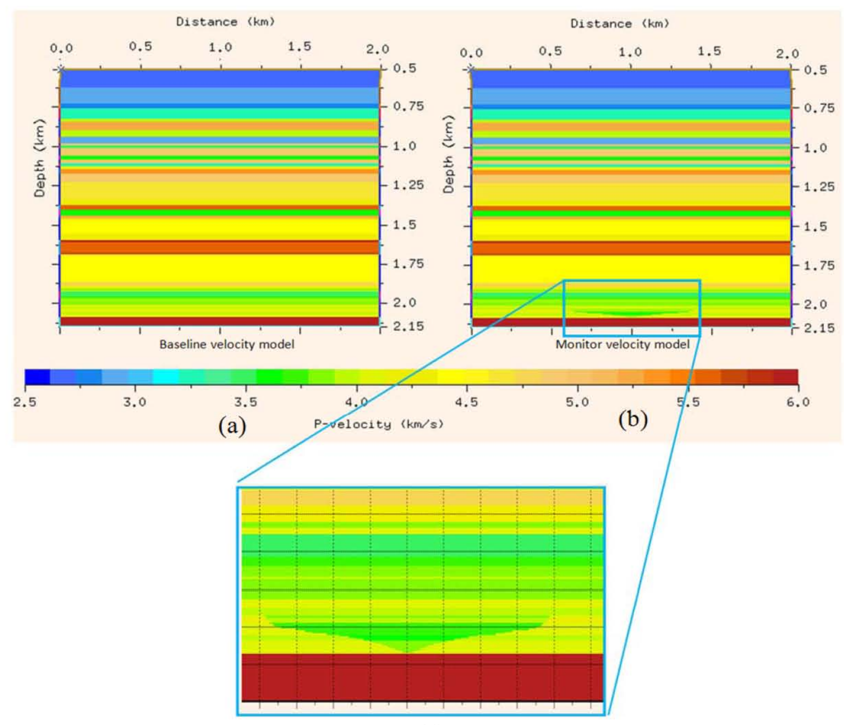

FIG. 3: The P-wave velocity model for baseline (a) and monitor (b) scenarios, and a closer view of the CO_2 plume in BCS(c).

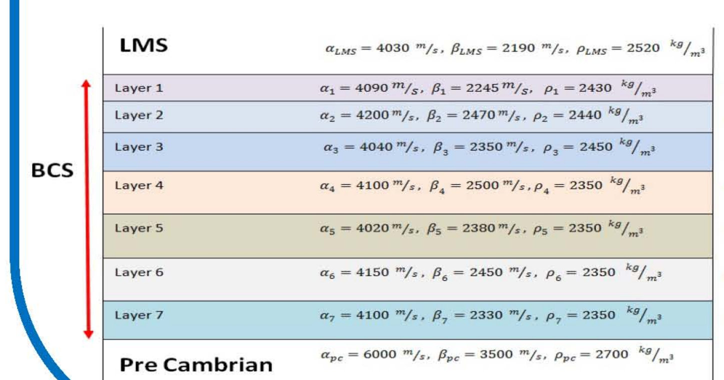

FIG. 4: A detailed view of BCS in the model, where it is divided to seven thin layers.

Gassmann fluid substitution

It is found that the P-wave velocity decreases once the CO_2 injection starts (Gassmann, 1951, Smith et al., 2003). This could be detected in the seismic data in the form of reflection time shift and amplitude change. Gassmann fluid substitution for BCS was performed to obtain the changes in P-wave velocity and density after injecting CO_2. The parameters needed for calculations, such as V_P, V_S, ρ and φ(porosity) were obtained from the well data. In addition, the fluid properties were estimated using the CREWES Fluid Property Calculator. Figure 5 illustrates the changes in P-wave velocity versus CO_2 saturation for all 7 layers within BCS. For all layers the maximum change occurs between values of 40% to 45% CO_2 saturation. Therefore for time lapse modeling we chose the amount of 40% CO_2 saturation for the monitor model to obtain a better time-lapse seismic response.

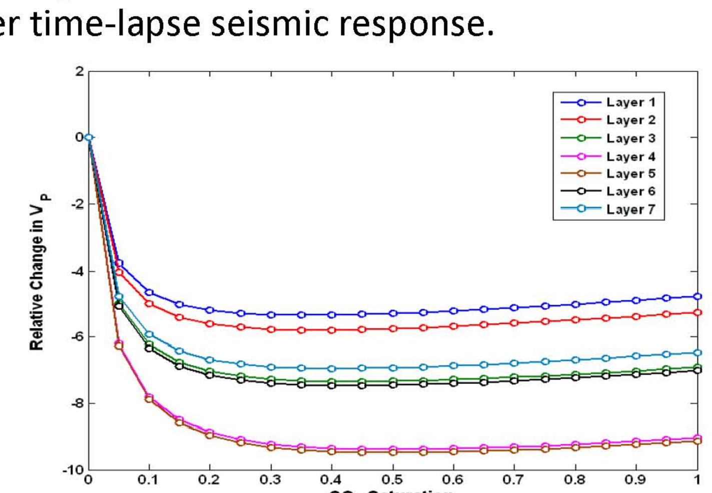

FIG. 5: Relative change in P-wave velocity versus CO_2 saturation for each of the 7 layers within BCS.

CO_2 Plume size estimation

To study the time lapse response of the Quest project, a simulation of the CO_2 plume was required. The plume was assumed to have a semi-conical shape as shown in Figure 6. Due to the buoyancy force, CO_2 tends to migrate towards the top of the formation (Negara et al., 2011). Consequently, the plume would have a shape similar to what is illustrated in Figure 6. From simple volumetric calculation the estimated radius of the plume after one year injection of CO_2 was approximately 800 meters.

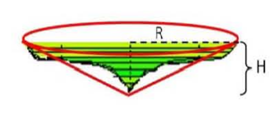

FIG. 6: The CO_2 plume in the monitor model is approximated with a cone to estimate the plume radius after one year of injection.

Time-lapse seismic modeling

For the time lapse analysis two seismic datasets were generated for the baseline and monitor surveys. The baseline model represents the model with zero percent CO_2 saturation in BCS. In the monitor model a semi-conical shape CO_2 plume with a radius of 800 meters and CO_2 saturation amounted to 40% was added to BCS (Figure 3). The rock properties inside the plume were obtained from the Fluid substitution results. The changes in P-wave velocity and density cause a change in the amplitude and traveltimes in the monitor seismic response relative to the baseline.

A 2D survey designed for this study was composed of 101 shots with 500 live receivers for each shot with a symmetrical split spread layout. The receiver and shot spacing were respectively 10 and 100 meters. Therefore, the survey covered a line with the total length of 10000 meters with the maximum fold of 25 at the centre. For generating the shot gathers the model was extended to 10000 meters where for the monitor model the CO_2 plume was added to BCS at the centre of the line. The synthetic shot gathers for both baseline and monitor scenarios were generated using NORSAR2D which is seismic ray-tracing modeling software. The wavelet used was a zero phase Ricker wavelet with the dominant frequency of 50 Hz. The generated shot gathers were then processed in VISTA seismic processing package. After NMO correction the traces were sorted into CMP and stacked. The CMP stack sections are shown in Figures 7 and 8 for the baseline and monitor surveys respectively. It is evident that there are some changes in the seismic response of BCS for the monitor scenario. To see the changes more clearly, the baseline section was subtracted from the monitor section to obtain the difference section. Figure 9 illustrates the difference of the two sections.

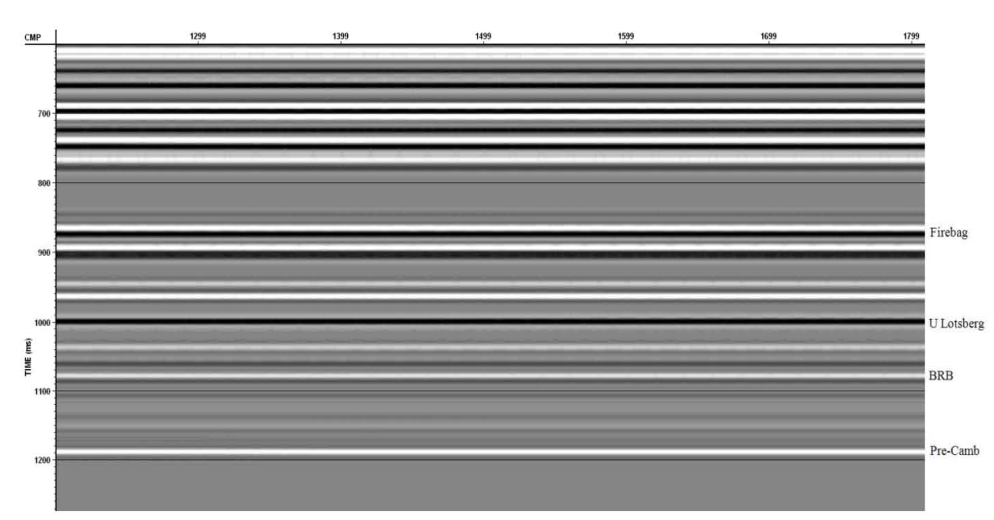

FIG. 7: Baseline stack section.

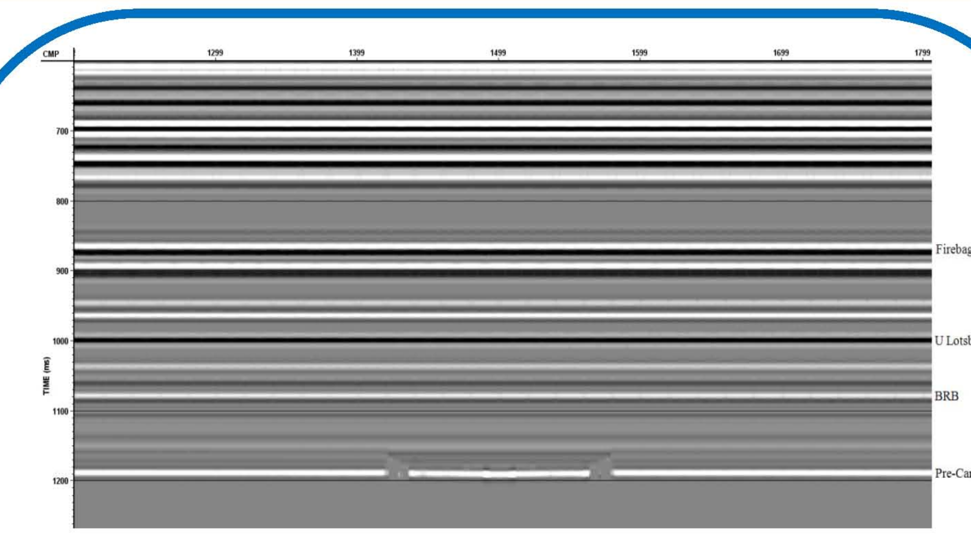

FIG. 8: Monitor stack section.

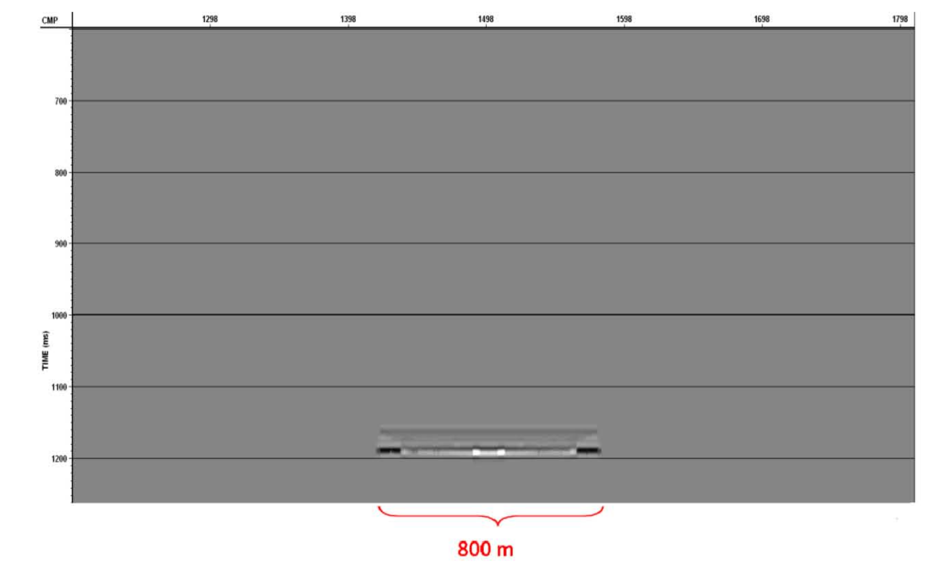

FIG. 9: Difference section.

Conclusion

A geological model was generated based on the well data and was used for modeling the baseline seismic survey. The model was modified to simulate the monitor survey by adding a CO_2 plume to BCS. The properties of the plume was calculated using Gassmann fluid substitution and assuming 40% CO_2 saturation which causes the maximum time lapse effect. This plume had a semi-conical shape to better describe the CO_2 distribution affected by the buoyancy force. Synthetic shot gathers were generated in NORSAR2D for both baseline and monitor scenarios and were processed in VISTA seismic processing package to obtain the stacked CMP sections. The result showed that the injection of CO_2 caused a change in amplitude and the traveltimes within and underneath the plume which caused a difference in the monitor seismic response. The spatial distribution and also the top of the plume were clearly observable in the difference section. It could be concluded from this results that BCS could be monitored based on its seismic response after the injection of CO_2.

References

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