VSP imaging of CO_2 plume growth at CMC's Newell County Facility

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Summary

At Carbon Management Canada's Newell County Facility, injection of CO_2 into the Basal Belly River Sandstone (BBRS) reservoir of 11% porosity at 300 m depth simulates a leak scenario in which CO_2 has migrated upward from a deeper storage interval. VSP monitoring previously detected the CO_2 plume by 1 March 2021, following 32 t of injection. As the injected mass of CO_2 increased from 32 t to 52 t, subsequent VSP surveys acquired in September 2021, January 2022, and March 2022 have detected increased lateral and vertical extent of the time-lapse reflection amplitude residual caused by the CO_2 plume. 2D VSP forward modeling indicated that the time-lapse residuals observed in the field data were most likely caused by discrete gas-phase CO_2 plumes in porous sandstone layers in the Belly River Fm.

Method

To monitor the pilot-scale CO_2 injection at the Newell County Facility, a variety of geophysical and geochemical monitoring technologies are deployed at surface and in two observation wells at the (Macquet et al., 2022), including permanently installed 3-C geophones and distributed acoustic sensing (DAS) fiber in observation well #2 (Obs 2). Walk-away vertical seismic profiles (VSP) have been acquired between 2017 and 2022 (Figure 1). Initial detection and delineation of the plume was achieved with high quality geophone VSP data following 32 t of injection (Kolkman-Quinn, 2023). The 2021 monitoring data indicated a discrete gas-phase CO_2 plume contained within the perforated BBRS interval.

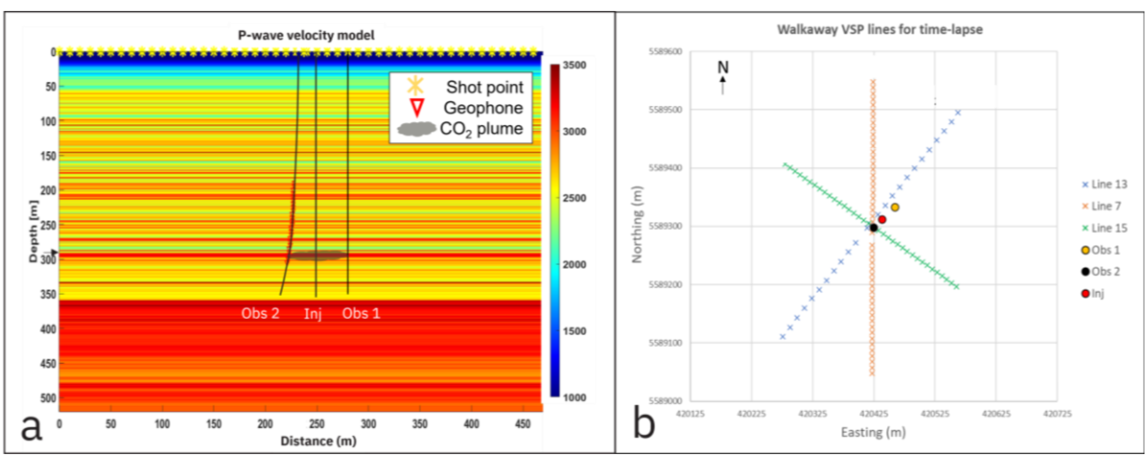

FIG. 1. Panel (a) shows a schematic of CO_2 injection in the BBRS reservoir overlain on a P-wave velocity model. Geophones and DAS in the deviated monitor well monitor the plume. Standard walk-away VSP survey lines are shown in (b).

The VSP processing workflow reported by Kolkman-Quinn et al. (2023) relies on deterministic deconvolution to produce directly comparable baseline and monitor amplitudes while mitigating stationary subsurface filtering effects such as attenuation. Seasonal differences in the physical properties of the surface and near-surface at each shot location produce spectral differences between baseline and monitor data. These differences are mitigated by designing bandpass filters for each pair of baseline and monitor shot gathers to selectively remove differences in high frequency amplitudes. Time-lapse differences of baseline and monitor VSP CDP sections from walk-away survey line 13 are shown in Figure 2. A trough-peak residual with side-lobes is evident in Figure 2b, caused by semi-patchy partial-saturation of gaseous CO_2 within the saline BBRS aquifer (Brie et al., 1995; Macquet et al., 2019). By late 2021 and early 2022, VSP monitoring showed both expected lateral growth and vertical growth of the time-lapse residual in Figure 2 (d-f) indicating migration of CO_2 within the storage complex.

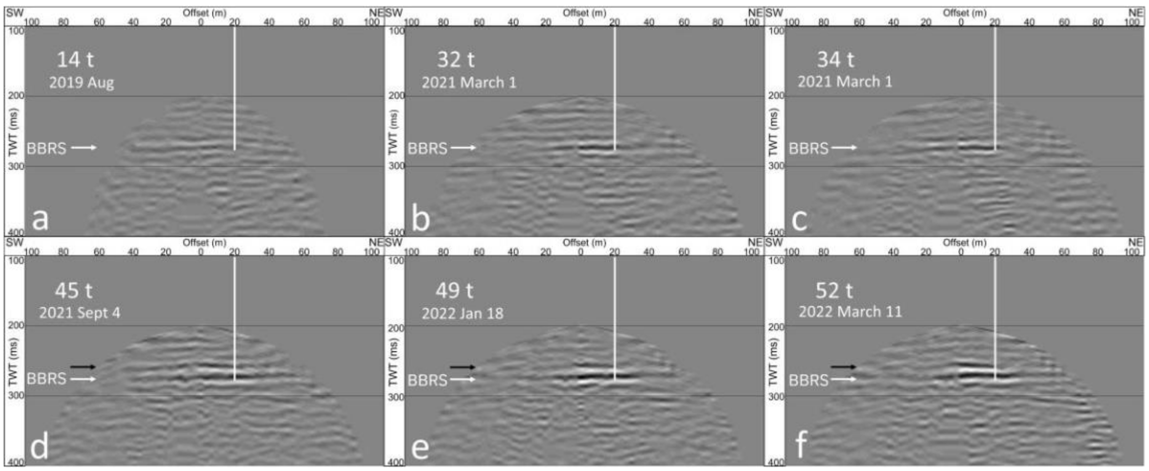

FIG 2. VSP CDP time-lapse sections showing the difference between baseline 2017 May data and monitor data acquired on (a) 2019 August 27 (b) 2021 March 1, (c) 2021 March 25, (d) 2021 September 4, (d) 2022 January 18, and (f) 2022 March 11. The injection well's projected location is indicated by a vertical white line. The white arrow indicates the BBRS interval, and the black arrow indicates the appearance of an earlier time-lapse anomaly from a shallower interval.

To aid in interpretation of the field data, a finite-difference VSP forward model was developed in MATLAB® using the CREWES Toolbox. Simulating acquisition of the NE-SW VSP line 13 shown in Figure 1, synthetic VSP shot gathers were generated using a baseline density and velocity model derived from well logs. The synthetic gathers were then processed with the same workflow as the field data. The models had 1 m layering but were not smoothed, in order to preserve sharp impedance contrasts from thin 1m – 2 m coal layers above the perforated interval. Reservoir and fluid-substitution models developed by Macquet et al. (2019) were used to model the P-wave velocity and density reductions from a 30 t CO_2 plume to generate synthetic monitor data. By placing secondary density and velocity anomalies at other intervals, various scenarios of CO_2 migration were compared against the field data time-lapse results.

Results

Figure 3 shows the best match obtained between the field data and VSP forward model, following multiple iterations of placing velocity and density anomalies in the sandstones, siltstones, and coals of the storage complex. The time-lapse residual in the 2022 VSP monitoring data was likely caused by partial saturation of gas-phase CO_2 in a 4 m thick sandstone and a 2 m thick siltstone, 22 m and 14 m above the perforated interval, respectively. As seen in the field data, the synthetic time-lapse residual in Figure 3b also has an asymmetric appearance, due to the fold and attenuation distribution of the reflection data stacked into CDP bins centered on Observation well # 2, which is offset 20 m from the injector.

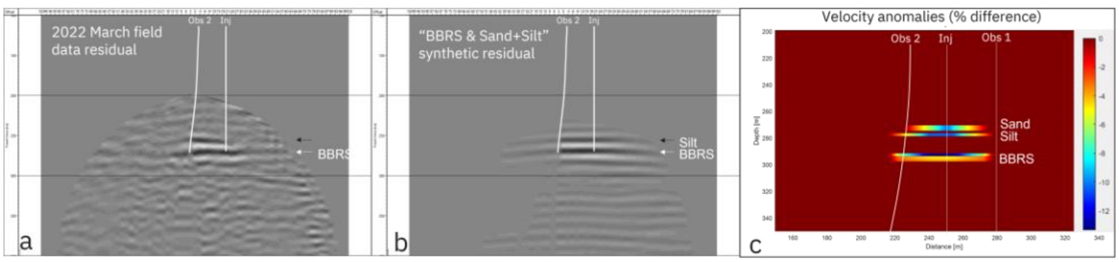

FIG. 3. The best match between the field data time-lapse residual from March 2022 (a) and the acoustic forward model (b) was obtained by modeling velocity anomalies in thin sandstone and siltstone layers above the perforated BBRS interval (c).

Conclusion

The VSP monitoring campaign from 2017 to 2022 has so far demonstrated the initial detection and delineation of a simulated CO_2 leak from injection into the BBRS after 32 t of injection, and detected subsequent migration within the storage complex following additional injection of 13–20 t of CO_2, as seen in Figure 7. These results demonstrate the effectiveness and sensitivity of time-lapse VSPs for both direct reservoir monitoring and above zone monitoring. Integrated with other data types such as temperature and pressure gauges, distributed temperature sensing, and electrical resistivity tomography, vertical seismic profiles can act as a reliable core technology within a CO_2 monitoring program.

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References

Kolkman-Quinn, B., Lawton, D., Macquet, M., 2023, CO_2 leak detection threshold using vertical seismic profiles: International Journal of Greenhouse Gas Control, **123**, 103839

Brie, A., Pampuri, F., Marsala, A.F. & Meazza, O. 1995, Shear sonic interpretation in gas-bearing sands. SPE Annual Technical Conference: Society of Petroleum Engineers, 30595, 701–710.

Macquet, M., Lawton, D., Osadetz, K., Maidment, G., Bertram, M., Hall, K., Kolkman-Quinn, B., Monsegny-Parra, J., Race, F., Savard, G., Wang, Y., 2022, Overview of Carbon Management Canada's pilot-scale CO2 injection site for developing and testing monitoring technologies for carbon capture and storage, and methane detection: CSEG Recorder, **47**, 1

Macquet, M., Lawton, D., Saeedfar, A., Osadetz, K., 2019, A feasibility study for detection thresholds of CO_2 at shallow depths at the CaMI Field Research Station, Newell County, Alberta, Canada: Petroleum Geoscience, **25**, 509-518.