Focused monitoring of CO_2 injection using time-lapse Vertical Seismic Profile (VSP)

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Summary

The CMC CaMI-Newell Field Research Station, operated by Carbon Management Canada (CMC) in Alberta, Canada, serves as an experimental CO_2 injection site aimed at advancing monitoring technologies. SpotLight utilizes time-lapse Vertical Seismic Profile (VSP) data acquired at the Newell Field Research Station for focused monitoring at 6 specific subsurface spots. CMC's modeling suggests CO_2-induced variations in elastic parameters, with increased saturation leading to amplitude reductions. VSP processing isolates reflectivity wavefields and ensures data cross-equalization for time-lapse analysis. Results are interpreted to determine the presence of CO_2. Interpretation reveals CO_2 detection at 2 out of 6 spots, which aligns with CMC's interpretations of plume migration from walkaway VSP images.

Introduction

Carbon Capture and Storage (CCS) plays a crucial role in addressing climate change resulting from the rising levels of greenhouse gas emissions. The Containment and Monitoring Institute (CaMI) of Carbon Management Canada (CMC) operates the CMC CaMI-Newell Field Research Station, located in Newell County, Alberta, Canada, which serves as a pilot-scale research CCS site aimed at evaluating CO_2 detection thresholds for various geophysical monitoring technologies. These evaluations are conducted under conditions simulating real CO_2 leakage by injecting small amounts of CO_2 at around 300 m depth, in the Basal Belly River Sandstone Formation (BBRS) (Macquet et al., 2019). Using time-lapse Vertical Seismic Profile (VSP) data acquired at the Newell Field Research Station at different calendar times and in parallel with CO_2 injection, SpotLight performed focused monitoring on specific spots chosen by CMC to monitor the CO_2 propagation from the injection well. This monitoring method is a light, non-invasive, active seismic method, focused on a spot (Al Khatib et al., 2021). It has been exclusively used with surface seismic, which makes this project the first of its kind using VSP. It opens the possibility of using a single permanent VSP source location near a CO_2 injection point as a monitoring method.

VSP acquisition and processing

Borehole seismic methods used are the VSP, offset VSP (OVSP), and the walkaway. The walkaway is a series of OVSPs, with the surface source situated at several locations corresponding to successively increasing offsets with respect to the borehole (Mari and Vergniault, 2018). Three lines of walkaway VSP (Lines 7,13, and 15) were acquired as base and monitors (Figure 1). Lines 7, 13, and 15 baselines were acquired in July 2017, May 2017, and August 2019 respectively. Monitors 1 and 2 were acquired respectively in the same period of the year, March 2021 and March 2022 (Kolkman-Quinn et al., 2023).

The targeted monitoring spot must be linked to the source and receiver positions. Traditionally, it is done via demigration (Al Khatib et al., 2021), which is a ray-tracing-based process used to find the source and receiver locations associated with reflections at the spot, in other words, the source-receiver couples that contribute to the spot illumination. In the current project, the VSPs that illuminate, or whose reflection points are closest to, the targeted spots must be identified among the VSPs of the walkaway lines. As the geology of the subsurface is horizontal, computation was simplified: reflection points associated with the walkaway source-receiver couples were determined geometrically. The selected VSPs will likely be affected by formation properties change due to CO_2 reaching the spots. Figure 1 illustrates a spot at the top of the injection reservoir, positioned either in proximity or precisely at the same location as the reflection points of the upgoing VSP waves.

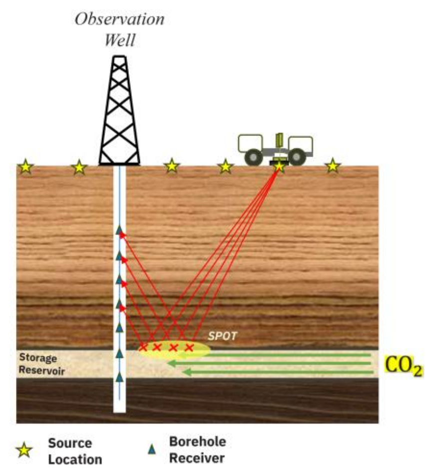

Figure 1: Illustration highlighting the spot at the top of the injection reservoir, coinciding with or near the reflection points of upgoing VSP waves.

For a selected offset VSP, after traces are edited by removing dead traces, a conventional processing sequence is applied. It includes picking of first arrival times, calculation of time-depth relationship, separation of upgoing and downgoing wavefields using singular value decomposition (SVD) filter, flattening of the downgoing P-wave, flattening of the upgoing P-wave by NMO correction, deconvolution of flattened upgoing P-waves by downgoing P-waves, and the generation of the VSP stacked trace. A normal stack is used instead of a corridor stack method due to the absence of observed multiples within the interval of interest. The deconvolution compensates for the source variations, receivers coupling, and seasonal near-surface effects. The compensation is essential to cross-equalize base monitor data prior to time-lapse analysis.

Time-lapse analysis and interpretation

The time-lapse analysis is performed on the selected VSPs after the processing. The results are interpreted on all spots by whether the CO_2 is detected or not and compared at the end with CMC VSP walkaway time-lapse results. The time-lapse analysis is done following a few steps on VSP stacked traces. A correction is applied using the overburden horizons as a reference, which are presumably not affected by CO_2. In the end, an amplitude difference is computed using the signal envelope. CO_2 detection is described as manifesting through a small reduction in seismic amplitudes, resulting in a negative anomaly at the reservoir, while the absence of detection is characterized by no amplitude variation and an anomaly close to zero. An example is shown in Figure 2, corresponding to a spot where CO_2 detection occurred. Interpretation of all results between base and monitors for each spot showed detection of CO_2 at 2 spots out of 6, and no detection was observed in the 4 other spots. These results were compared with CMC walkaway VSP time-lapse analysis and match with their interpreted results.

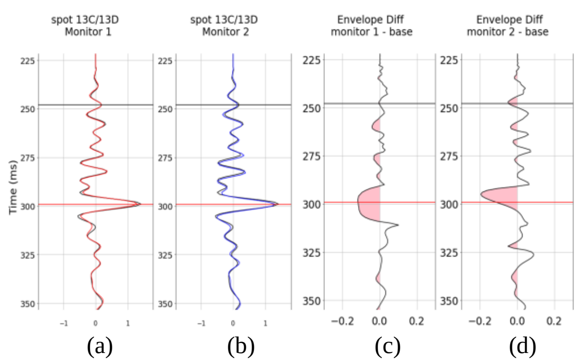

Figure 2: Time-lapse analysis on stacked VSP traces, N°13141, related to spot 13C, and their base-monitor envelope amplitude differences. a) Stacked traces of base and monitor 1. b) Stacked traces of base and monitor 2. c) Envelope amplitude difference of monitor 1 - base. d) Envelope amplitude difference of monitor 2 – base.

Conclusions

A processing and focused monitoring analysis for data recorded with a light seismic spread of single offset VSP type was presented. The CO_2 detection at located spots can be extended over an area if the seismic survey is done on several Offset VSP lines, referred as walkaway lines. In focused monitoring using surface seismic data, an optimum selection step is required to identify the best trace for the monitoring. While in VSP acquisition, the offset VSPs are geometrically selected based on the location of the monitoring spot. The field example shows the possibility of using single offset VSP for focused monitoring in a borehole environment. The results matched CMC's interpretation of the plume migration from walkaway VSP images.

Acknowledgments

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