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Multi-disciplinary evidence of migration of CO2 in the storage complex at the CMC Newell County Facility

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Summary

Carbon Management Canada, in collaboration with the University of Calgary, developed and operates a research pilot site for geological carbon storage monitoring testing and development. In this paper, we integrate the results of different disciplines to understand the injection at the site. Geophysical monitoring (electrical resistivity tomography and vertical seismic profile time-lapse), reservoir modeling and pressure/temperature data (gauges, distributed temperature sensing, and static gradient test) show the expected accumulation of CO_2 in the reservoir, as well as migration into a shallower interval of the reservoir complex.

Introduction

Carbon Management Canada (CMC) operates a comprehensive CO_2 storage pilot site, the Newell County Facility (formerly known as the CaMI Field Research Station) in Southern Alberta. This research site is designed for developing and testing monitoring technologies to ensure secure Geological Carbon Storage (GCS) (Lawton et al., 2019; Macquet et al., 2022). At the site, we are simulating a leak from a deep large-scale GCS site by injecting a small volume of CO_2 at 300 m depth. The small and controlled volume enables us to determine detection thresholds for various monitoring technologies and understand how we can use each of them efficiently.

The site hosts a broad range of geophysical and geochemical monitoring tools to track the injected CO_2: active seismic time-lapse (surface 2D, 3D, and vertical seismic profile), passive seismic, electrical resistivity tomography (ERT), distributed acoustic sensing (DAS), distributed temperature sensing (DTS), water and gas samplings, and other innovative technologies.

In this paper, we are describing the results of few technologies (VSP, ERT, DTS, static gradient survey), and showing how the integration of the different methods enables us to understand the injection processes happening at the site.

Monitoring technologies

Figure 1 shows a schematic view of the monitoring technologies used in this study. The observation well #2 hosts permanently installed geophones for VSP time-lapse, and permanent electrodes for ERT monitoring. The injection well hosts pressure and temperature gauges, and the static gradient survey was conducted in this well. The 3 wells have fiber optic cables for DTS measurements.

1. Vertical seismic profile time-lapse

Because of their higher signal-to-noise ratio compared to surface seismic surveys, VSP time-lapse is often used for GCS monitoring (e.g., Harris et al., 2017; Pevzner et al., 2021). At the

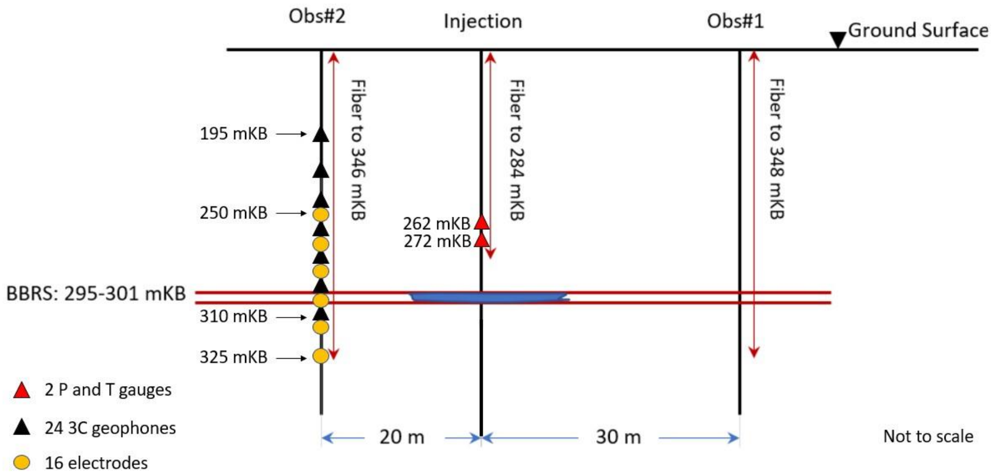

FIG.1: Schematic view of the monitoring technologies installed at the FRS and used in this study.

Newell County Facility, twenty-four geophones permanently installed between 195 and 310 mKB (Fig. 1) enabled us to image the plume in March 2021 after the injection of 32 tonnes of CO_2 in the reservoir (Kolkman-Quinn et al., 2023).

Over the following 12 months, an additional 20 tonnes of CO_2 were added to the reservoir and several new VSPs were acquired. Figure 2 shows the amplitude difference between the 2017 baseline and various monitor VSP surveys. We can see the time-lapse residual corresponding to the accumulation of gas-phase CO_2 in the Basal Belly River sandstone (BBRS) since March 2021,

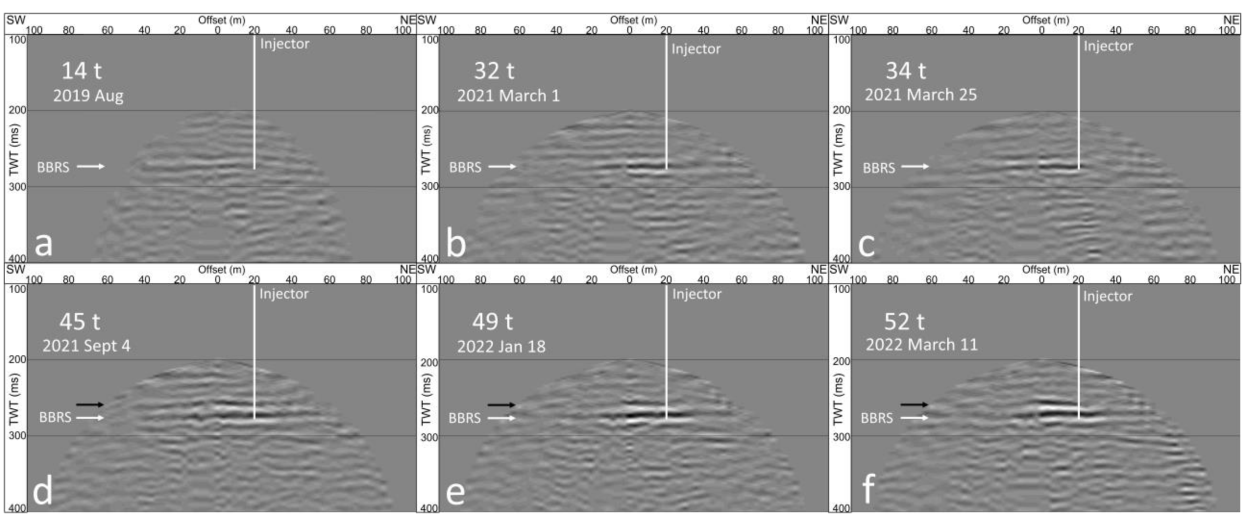

FIG.2: VSP CDP time-lapse sections showing the difference between baseline 2017 May data and monitor data acquired on (a) 2019 August 27 (b) 2021 March 1, (c) 2021 March 25, (d) 2021 September 4, (d) 2022 January 18, and (f) 2022 March 11. The injection well's projected location is indicated by a vertical 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 of the reservoir complex.

and a vertical expansion of the time-lapse anomaly starting to be noticeable in September 2021 (black arrow in figure 2).

2. Semi-continuous electrical resistivity tomography

Observation well #2 hosts 16 permanently installed electrodes from 250 to 325 mKB. 750 daily surveys were run between September 2019 and November 2022 and were independently inverted to obtain the resistivity profiles along the observation well. Figure 3 shows the evolution of the resistivity ratio (monitor resistivity over baseline resistivity) as a function of time. We can observe an increase in resistivity in 3 layers of the reservoir complex. The perforated interval (red rectangle) and a coal layer (black rectangle) show increasing resistivity since the beginning of the ERT monitoring period while a shallower layer (green rectangle) shows increasing resistivity by late 2020.

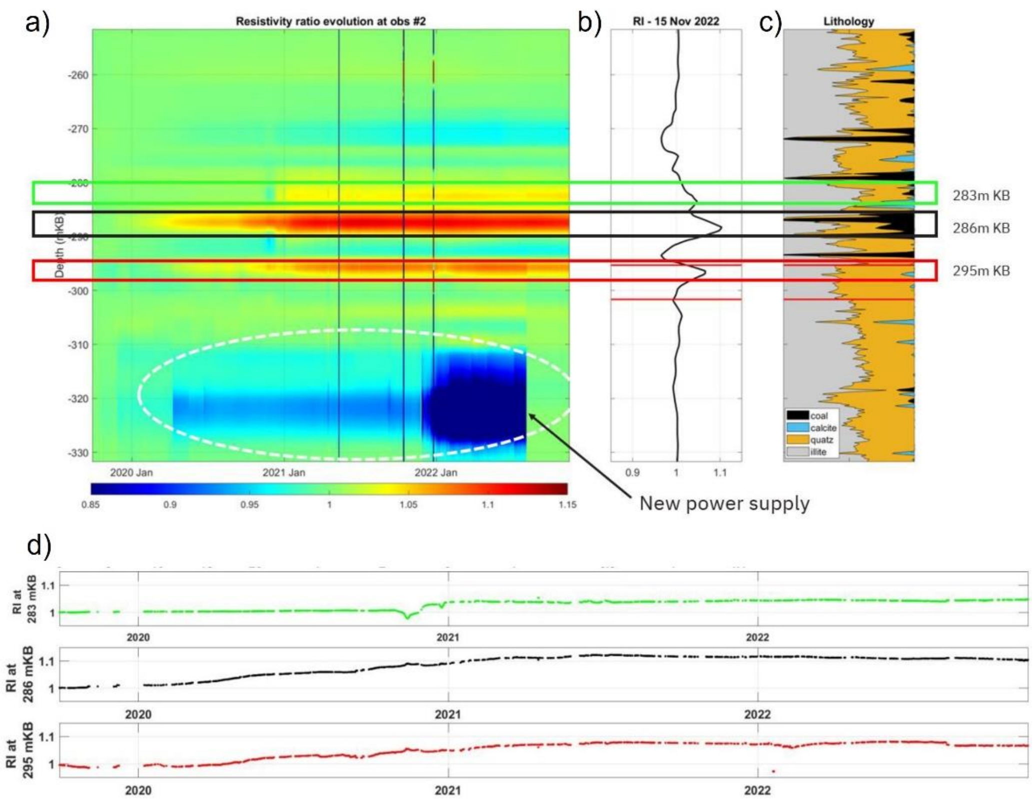

FIG.3: a) Inverted resistivity ratio evolution along the observation well (750 daily surveys). White dashed circle is an interface due to a faulty configuration. b) Resistivity ratio of the last survey of this study (November 15, 2022). c) Lithology from ELAN (Elemental Log Analysis). d) Temporal resistivity ratio evolution for the 3 zones of resistivity increase highlighted with green, black, and red rectangles.

3. Continuous distributed temperature sensing

The DTS method involves inferring temperature from the backscatter of laser light in a fibre optic cable (e.g., Hartog, 2017). CMC's Newell County Facility has DTS fibre installed in all three wells:

on the tubing in the injection well reaching a depth of 284 mKB and cemented behind casing in the observation wells reaching depths of ~346-348 mKB. Here we are only showing results of the injection well DTS data, recorded every 5min since 2018.

Figure 4 shows a low-temperature anomaly occurring at the base of the fiber, with the highest amplitude at 279 mKB. This anomaly started in the fall of 2020 when the maximum allowed bottom-hole pressure was increased from 5 MPa to 6 MPa. The cold anomaly is correlated with the pressure gauge readings: appearing during periods of high-pressure injection and disappearing during low-pressure injection and shut-in periods.

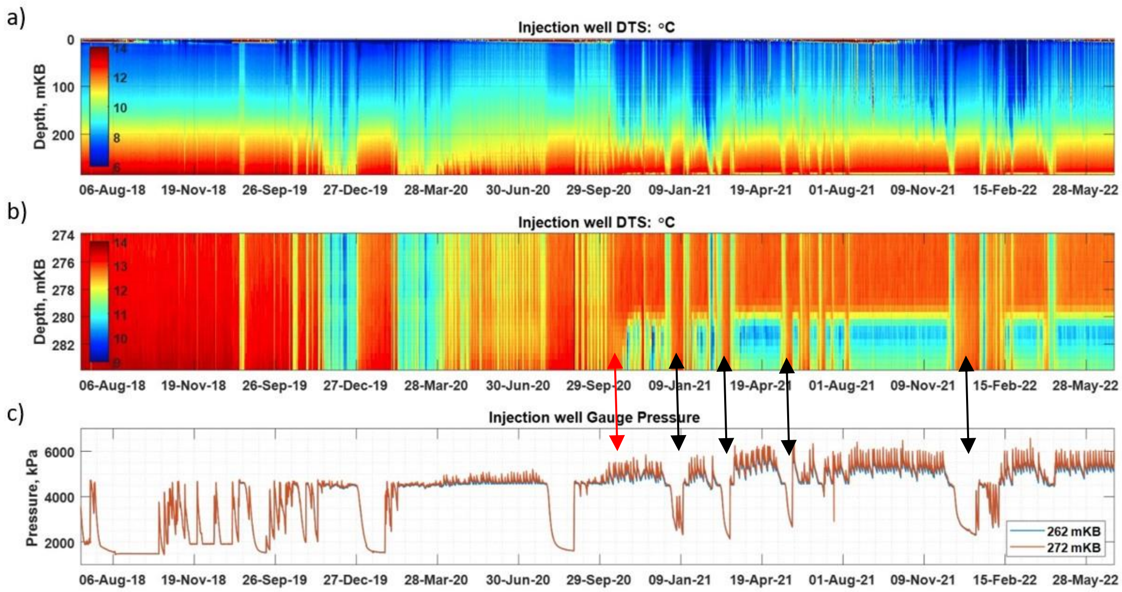

FIG.4: a) Injection well DTS data from 2018-2022 over the full depth of the fiber. b) Injection well DTS data zoomed on the bottom portion of the well. c) Injection well gauge pressure. Red arrow shows the start of the cold anomaly and the start of regular high-pressure injection (October 2020). Black arrows show the correlation between the return to normal temperature as pressure decreases below 5.5 MPa. Modified from Behmanesh et al., 2023.

4. Static gradient test

In April 2022, a static gradient test was carried out to calibrate the surface and downhole pressure and temperature gauges (located at depths of 262 and 272 mKB) in the injection well (Behmanesh et al., 2023). The test also aimed to gather information about the temperature profile from the fiber termination point down to the depth of the perforations. The static gradient test yielded a more comprehensive account of a cooling occurrence in a coal layer at the injection well. At the bottom of the wellbore, a cooling incident was detected where the temperature recording decreased before it reached the background geothermal gradient again. The bottom-hole pressure was high and CO_2 in liquid-phase was discharging in the reservoir. It is believed that this cooling event occurred due to the migration of injected CO_2 into a shallower part of the reservoir complex, causing a reduction in pressure that resulted in a phase change and evaporation of the liquid CO_2, leading to a drop in its temperature.

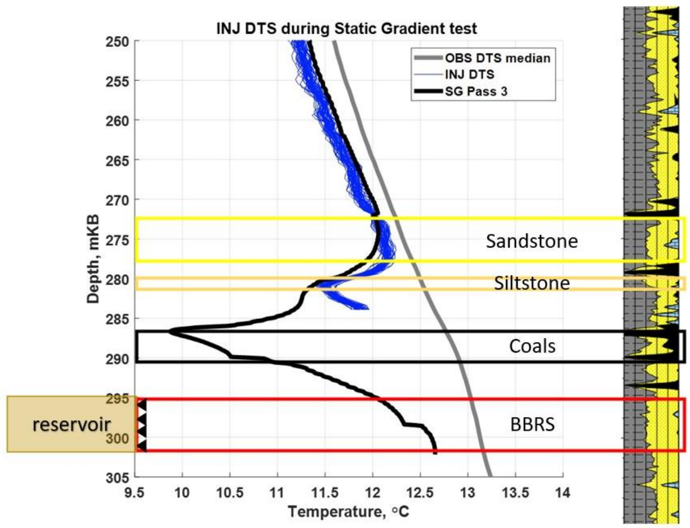

FIG.5: Static gradient measured temperature profile is shown in black. DTS data recorded during the experiment are shown in blue. Unperturbed temperature profile (form observation well DTS) is shown in grey. Modified from Behmanesh et al., 2023.

Discussion

Collectively, observations from four independent datasets (DTS, ERT, VSP, and static gradient test) indicate the development of a CO_2 plume within the perforated BBRS interval along with migration within the storage complex, the latter beginning most likely in late 2020 under a higher-pressure liquid phase injection program.

To summarize:

1. The expected CO_2 accumulation in the perforated BBRS interval (295-301 mKB) can be observed on ERT and VSP results after 10 and 32 tonnes of CO_2 injection, respectively.

2. The ERT showed an increase in resistivity in the coal layer concurrent with the BBRS resistivity increase, which may indicate an increasing saturation of CO_2 or of desorbed methane gas above the perforated sandstone interval since injection began.

3. DTS recorded the consistent occurrence of a cooling event above the BBRS beginning in October 2020. The ERT also detected a shallower resistivity anomaly at 283 mKB by late 2020.

4. VSP monitoring did not clearly detect migration in the shallow interval of the reservoir complex by March 2021, but it was evident by September 2021 and early 2022.

5. The static gradient survey revealed unusually low temperatures in the coal zone situated above the perforated section. At a depth of 286 mKB, the maximum deviation from the geothermal gradient, -3°C, was recorded.

DTS and static gradient test data give observations of the reservoir behavior at the injector, while ERT and VSP data from the nearby observation well provided lateral imaging of the CO_2 away from the injector. The reservoir complex layers involved in the migration and the migration pathway itself are still to be determined.

Conclusion

The CMC Newell County (formerly CaMI.FRS) provides a controlled CO_2 injection and storage field research site, enabling the development and testing of monitoring technologies for subsurface monitoring in a heterogenous storage complex at shallow to intermediate depths. Integration of different disciplines is required to fully understand the complex processes happening in the reservoir. PVT data and expertise, reservoir modeling, and geophysical observations each bring a different piece of information needed to describe the detailed picture of GCS monitoring.

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