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Semi-continuous electrical resistivity tomography for geological carbon storage monitoring

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Summary

Electrical resistivity tomography can be used as a non-expensive geophysical method for geological carbon monitoring. The spatial and vertical resolution does not enable the use of the method for imaging the whole plume in 3 dimensions but can be used for 1) near-surface monitoring to prove the absence of leakage when the electrodes are deployed on the surface; and 2) for well integrity and sparse CO_2 saturation estimation when the electrodes are installed in a well.

We present in this paper the results of single-well electrical resistivity tomography obtained at the CMC's Newell County Facility (CaMI Field Research Station) which is a pilot-site for geological carbon storage monitoring technologies development. We analyzed and inverted 750 daily surveys during which 49 tonnes of CO_2 were injected. We show that the use of single-well electrical resistivity tomography can be used for well integrity and CO_2 saturation estimation and is a suitable technology for geological carbon storage monitoring, especially applied to early detection.

Carbon Management Canada's Newell County Facility

Carbon Management Canada (CMC) developed and operates a research pilot-site for Geological Carbon Storage (GCS) monitoring technologies development and testing. CO_2 is being injected into the Basal Belly River Sandstone (BBRS, 300 m depth) to simulate a leak from a deep large-scale GCS site. The small and controlled volume of CO2 enables us to develop and test different monitoring technologies, and to determine detection thresholds for gas-phase CO_2 at shallow to intermediate depths (Lawton et al., 2019; Macquet et al., 2022, Kolkman-Quinn et al, 2023).

The site is equipped with a broad range of geophysical and geochemical monitoring tools (fiber optic for Distributed Acoustic and Temperature Sensing, active and passive seismic, gas sampling…). We focus in this study on the borehole electrodes array installed in the observation well #2 (20m SW of the injection well). It consists of 16 electrodes cemented behind the casing, from 250 to 325 mKB. Daily surveys were run between September 2019 and November 2022.

Electrical Resistivity Tomography

Electrical Resistivity Tomography (ERT) is a geophysical method used for near-surface imaging. The main advantage is its sensitivity to the composition of the pore fluids (Archie, 1942), making the method particularly interesting for CO_2 storage monitoring. The injected CO_2 is more resistive than the brine in place, so time-lapse ERT will observe the change in resistivity due to CO_2 injection and accumulation. The resistivity ratio and the fluid saturation can be linked as proposed by Guéguen and Palciauskas (1994):

$$S_{CO_2} = 1 - S_w = 1 - \left(\frac{1}{RI}\right)^{1/n}$$

where R_0 is the baseline resistivity and R is the monitor resistivity, RI is the resistivity index (or resistivity ratio), S_w is the brine saturation, S_{CO_2} is the CO_2 saturation, and n is the saturation exponent.

Raw resistivity ratio

Even if the sensitivity of a measurement is more complex than attributing a depth and a distance to a configuration, looking at the non-inverted data already gives a good first approximation of the resistivity changes happening in the subsurface. Figure 1 shows few dipole-dipole configurations sampling the perforation depth (middle panel) and a shallower interval (top panel). The increase in resistivity in the reservoir is well correlated with the injection history at the site (bottom panel), and we can also notice small decreases in resistivity during long shut-in periods (green rectangles). The resistivity in the shallower interval, still in the reservoir complex, starts to increase at the beginning of 2021.

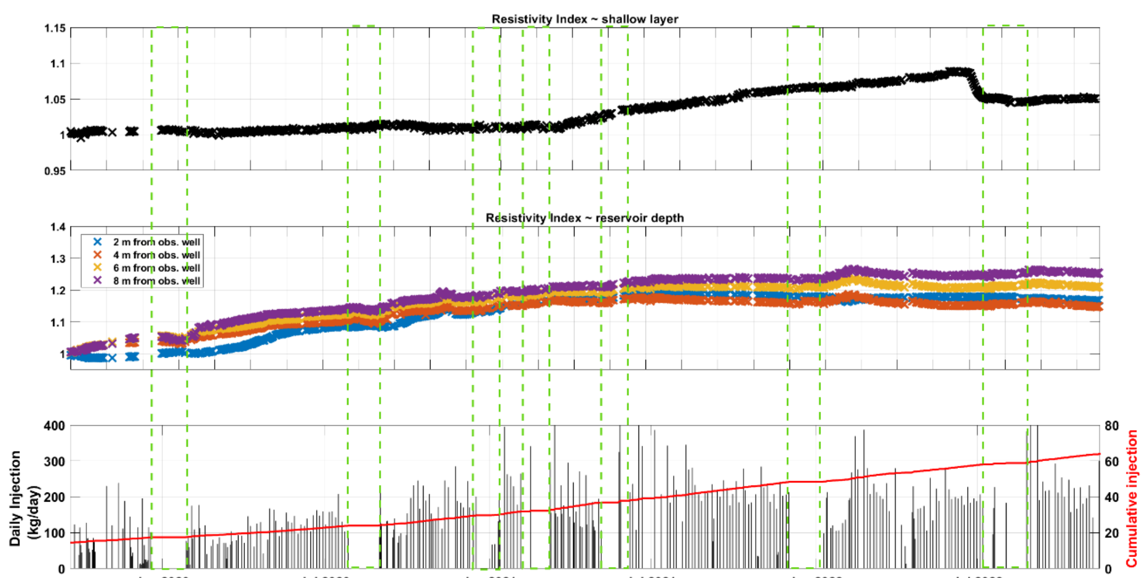

*FIG.1: Summary of raw data analysis. **Bottom:** injection history at the CaMI.FRS. Black bars are daily injections, the red curve is cumulative injection. Green rectangles are extensive shut-in periods. **Middle:** Resistivity ratio for 4 configurations sampling the perforated zone. **Top:** Resistivity ratio for a shallow layer in the reservoir complex.*

Inversion

We use resIPy open sources code (Blanchy et al., 2020) to independently invert the 750 surveys. The starting model is a homogeneous 7 Ω.m model, which is the average of the resistivity well log.

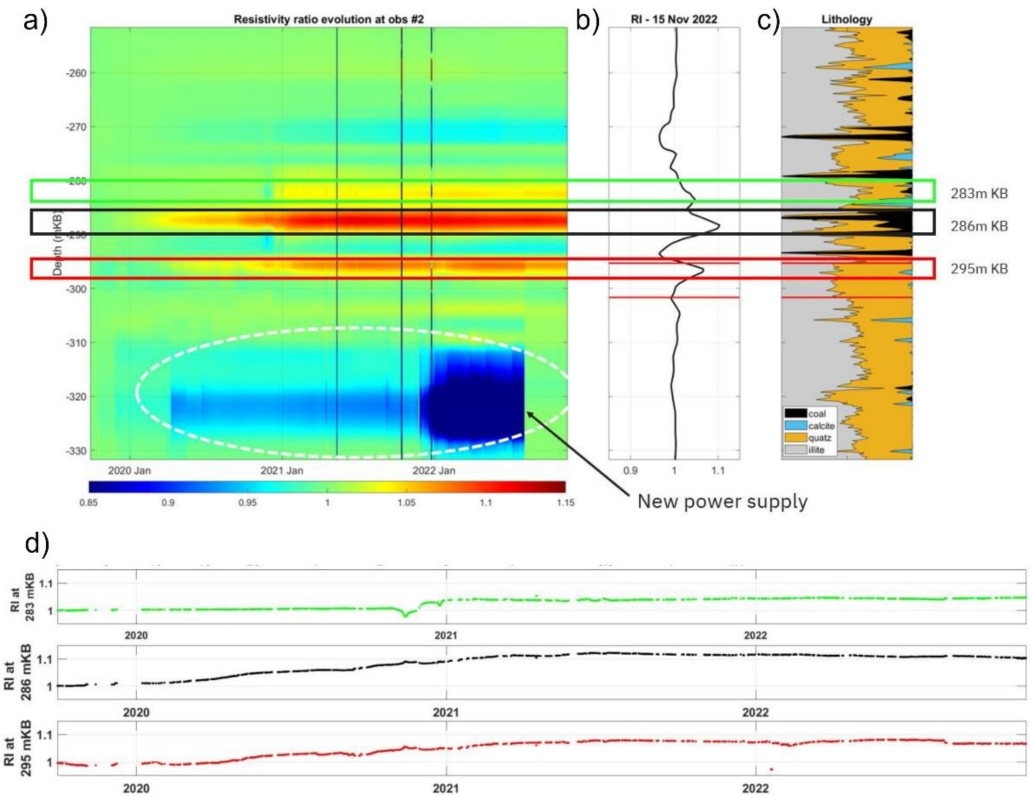

FIG.2: a) Inverted resistivity ratio evolution along the observation well (750 daily surveys). White dashed circle is an interface due to a faulty configuration. b) Resistivity ratio of the last survey of this study (November 15, 2022). c) Lithology from ELAN (Elemental Log Analysis). d) Temporal resistivity ratio evolution for the 3 zones of resistivity increase highlighted with green, black, and red rectangles.

Figure 2 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.

Conclusions

The use of single-well ERT at the CaMI Newel County Facility demonstrates the efficiency of the method to detect very small volumes of injected CO_2. Having only one equipped well prevents us to have a good lateral resolution, but the vertical resolution at the observation well is enough to observe 3 zones of increase in resistivity. The mechanisms leading to those increases in resistivity still have to be understood: CO_2 accumulation with possible methane interaction.

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