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Geophysical Monitoring of CO_2 Injection – CCS and CO_2-EOR

Results of a baseline magnetometric resistivity survey at the Field Research Station, Alberta

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Introduction

In saline aquifers, the large conductivity contrast between CO_2 and brine makes electrical properties appealing for monitoring CO_2 plume progression. However, field measurements of electrical properties at depth are subject to technical difficulties due to challenges in the installation and maintenance of permanent downhole electrodes. Moreover, electric fields are weak in conductive media, and measurements in saline aquifers can be very noisy (Schmidt-Hattenberger et al., 2011).

With the magnetometric resistivity method (MMR), electrical property contrasts in the ground are obtained from the measure of the magnetic field induced by a galvanic source (Edwards and Nabighian, 1991). Due to the fact that the measurements are done with a magnetic sensor, MMR offers many advantages for monitoring: easier deployment in boreholes (no contact needed) and problems related to electrode installation and corrosion are avoided. Also, the problem of noise in conductive media is reduced because the measured signal is a function of current density and not conductivity.

The Field Research Station (FRS) is an experimental site operated by the Containment and Monitoring Institute of Carbon Management Canada. A controlled CO_2 release experiment is planned a this site for the next 5 years, to test the monitoring capability of various geophysical methods (Lawton and Osadetz, 2014; Lawton, 2016). A preliminary numerical study showed that downhole MMR could be suitable for monitoring a CO_2 plume at the FRS, given adequate noise conditions (Bouchedda and Giroux, 2015).

In this contribution, we present the results of a baseline survey conducted at the FRS. The aim of the survey was to evaluate the noise conditions at the site and determine the optimal data acquisition parameters, in addition to providing baseline data for a monitoring program. To our knowledge, this experiment is the first field application of MMR for CO_2 monitoring.

Survey parameters

The Field Research Station covers an area of 1 km × 1 km located in the county of Newell, Southwest of Brooks, Alberta. The FRS site encompasses Upper Cretaceous clastic reservoir formations. A 3D seismic survey shows that geology at the site is mostly 1D.

The MMR survey was performed June 20th to 23rd 2016. The acquisition equipment was composed of:

- a GGT-30 transmitter powered by a Hatz diesel motor generator (Zonge International, USA);
- a Zonge controller (Zonge International, USA);
- a NordicEM24 controller and receiver from GDD instrumentation Inc. (Canada);
- a MAG43-3D fluxgate borehole probe and preamplifier from Geonics Ltd. (Canada);
- four 1 km 12 AWG wires;
- electrodes made of reinforcing steel bars approximately 1.8 m long.

Two sets of measurements were done using two orthogonal current dipoles (Figure 2). Acquisition parameters are:

- current at dipole 1 consists of 100% duty cycle current at 4 Hz.
- for dipole 2, 50% duty cycle current at 2 Hz repetition was used.
- the GGT-30 transmitter allowed injecting between 25 A and 30 A.
- measurements were carried out in the observation well #2 located approximately 30 m northeast of the injection well, from 100 m down to 325 m depth (fiberglass casing is in place within the measurement interval).
- measurements were performed every 2 m near the reservoir (about 300 m deep), but the step size was increased above and below.
- time-series long enough to hold 512 cycles were recorded for dipole 1 and 256 cycles for dipole 2.
- sampling frequency was 12 kHz.

Figure 1 - Field equipment deployed at the FRS.

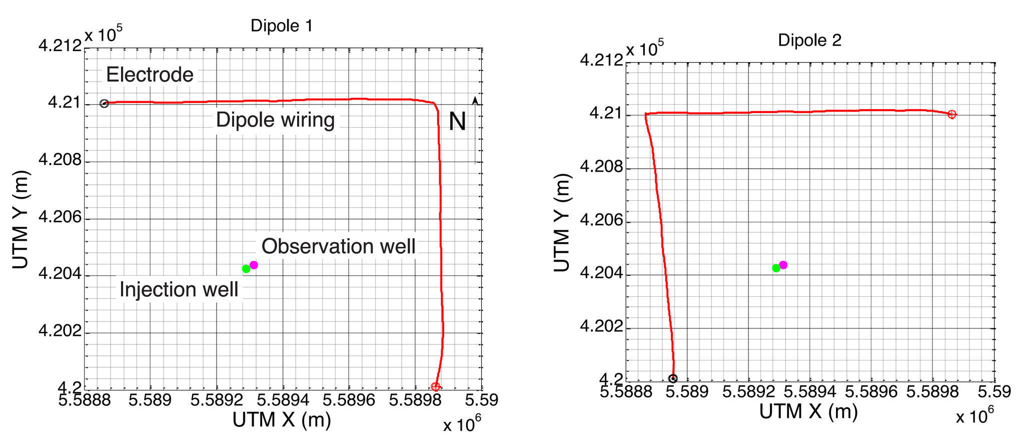

Figure 2 - Location of injection dipoles.

Survey results

A four-step processing sequence was applied to the data before interpretation. Detrending was first achieved by eliminating low frequency noise created by natural variations of the terrestrial magnetic field. The signal was then stacked to eliminate 60 Hz noise and to reduce the variance of the high frequency noise. Figure 3 shows the time series measured at dipole 2 after stacking. Third, the *x* and *y* components of the signal were derotated using the primary field and orthogonal Procrustes rotation analysis as described by Key and Lockwood (2010). Finally, the primary magnetic field caused by the dipole wires was calculated analytically knowing wire and receiver positions, and subtracted from the measurements.

MMR magnetic field data after processing are shown in Figure 4. Theoretically, the B_z field for a layered earth is zero (Acosta and Worthington, 1983). However, a linear trend can be observed in this component. This trend is attributed to inaccuracies in the observation well position and the effect of metallic pipelines and well casings that are far from the receiver (see Figure 5). Indeed, metallic pipelines create a long wavelength anomaly that appears as linear trends. This effect should be removed in time-lapse measurements by taking the difference between the baseline measurements and the measurements after CO_2 injection. On the contrary, the horizontal components show a few local anomalies that can be explained by layering effect or variation of resistivity with depth.

A series of measurements were done at a depth of 320 m with the transmitter off to evaluate the noise level at the site (Figure 6). Time series segments were stacked to evaluate the noise level for conditions comparable to the processed data. The values of noise level after stacking are low, with 2 pT and 6 pT for dipole 1 and dipole 2 respectively.

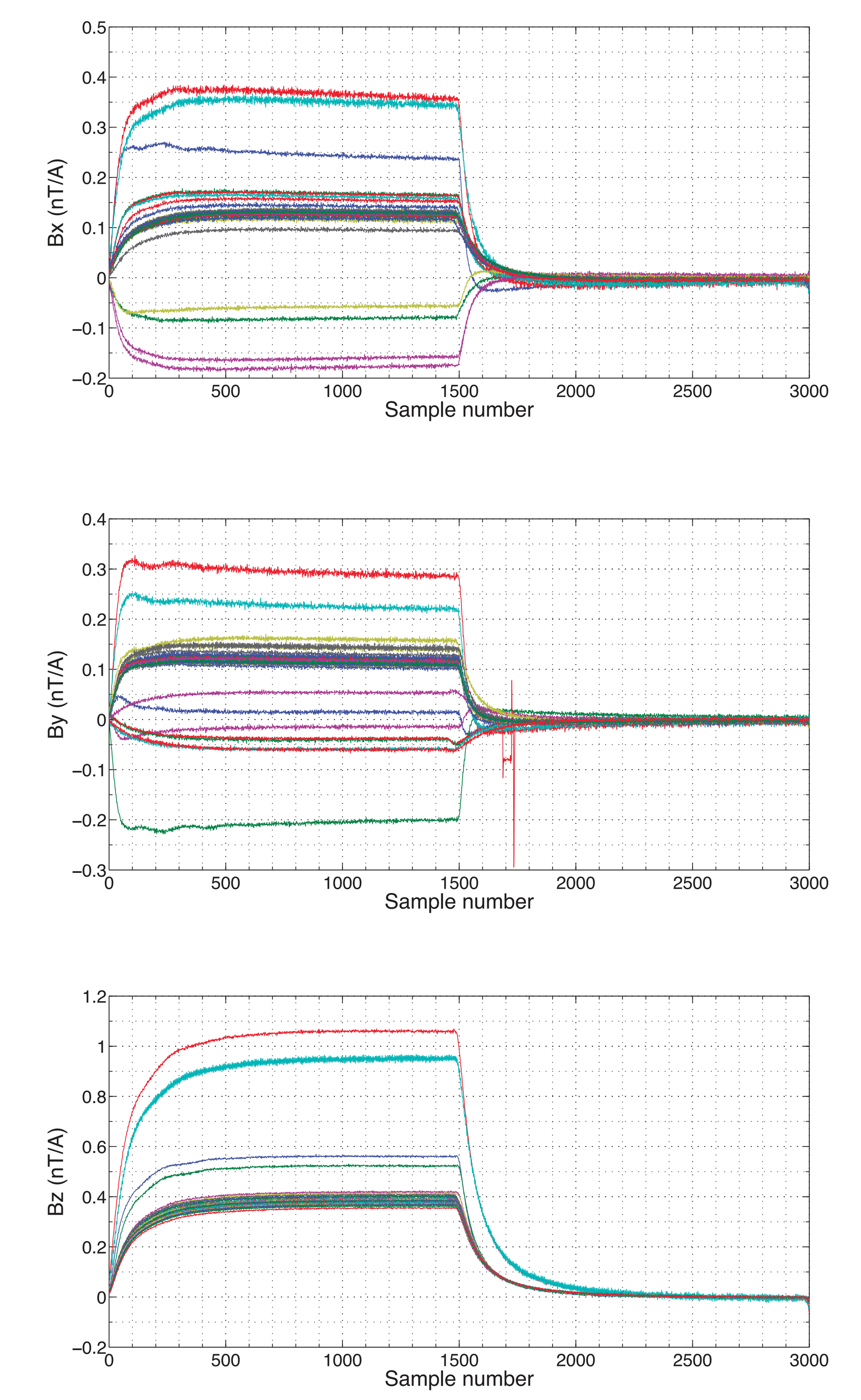

Figure 3 - MMR times series after stacking.

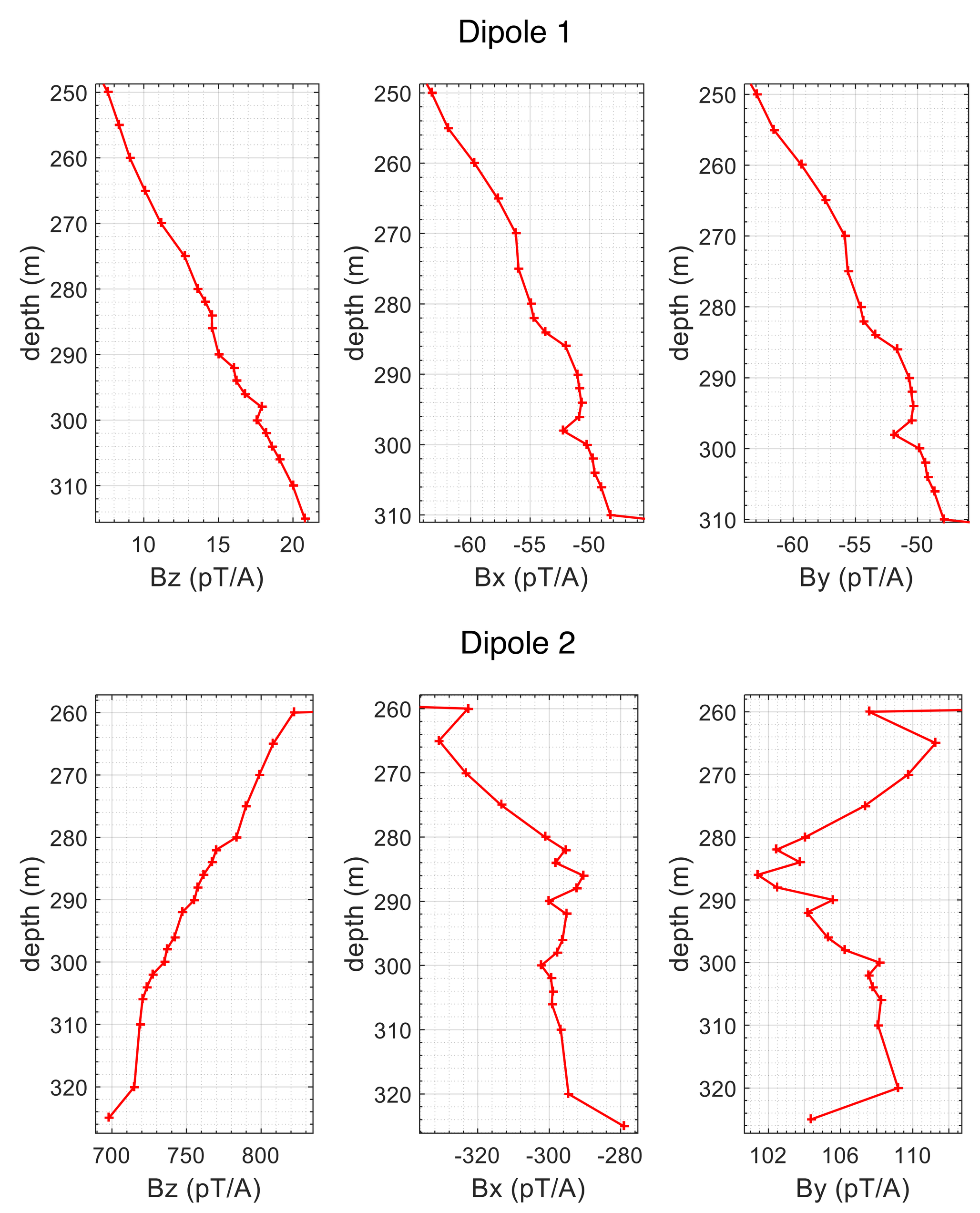

Figure 4 - MMR data after processing.

Conclusion

Downhole MMR measurements were performed at the Field Research Station in Alberta to evaluate the suitability of the method to monitor injected CO_2 movements under real conditions. Low contact impedance at the source electrodes allowed injecting high current (25 A to 30 A), yielding low signal- to-noise ratio. Baseline data of high quality were thus obtained using the two orthogonal source dipoles.

Basic modeling indicate that a 5 m thick disc of radius larger than 15 m, centered at the injection well and with a resistivity 10 times higher than the host rocks, produces an anomaly larger than 10 pT, which would be detectable given conditions comparable to the baseline survey. In order to better assess the amplitude of the MMR anomalies, CO_2 flow modeling will be used to estimate its spatial distribution and to model more realistic changes in resistivity. This exercice will allow evaluating the resolving power of MMR data inversion. The contribution of MMR data in joint inversion schemes (especially MMR-ERT) will also be assessed.

Nevertheless, questions remain relative to time-lapse repeatability conditions and true amplitude of the anomalies that will be generated by the injected CO_2, which will be answered by a repeat survey that will be conducted after start of injection.

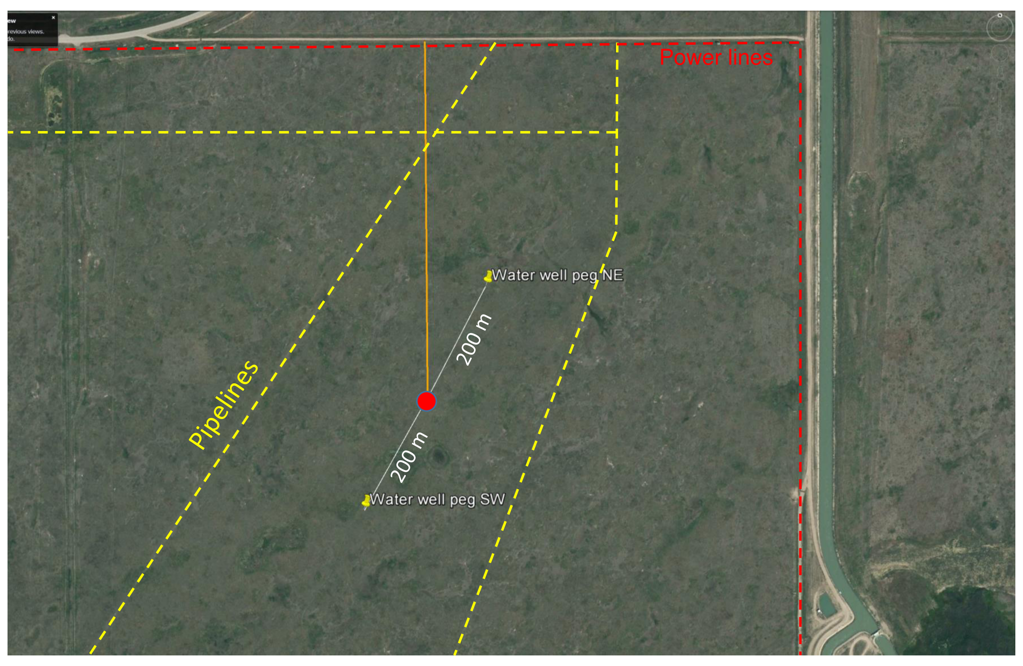

Figure 5 - Aerial photo showing the location of pipelines and power lines at the FRS.

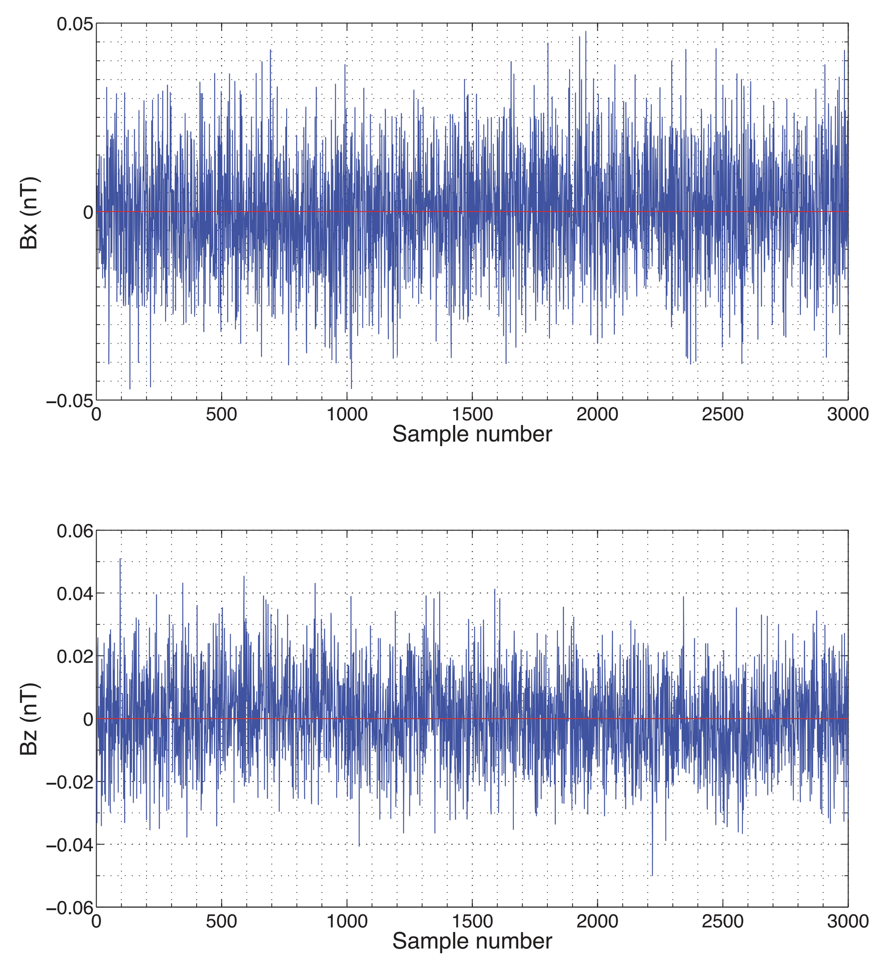

Figure 6 - Raw tiem series segments showing the noise level.

Acknowledgements

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