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A field trial of cross-well seismic with DAS and a high-frequency source

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SUMMARY

Distributed acoustic sensing (DAS) technology is routinely applied at different stages of resource and mines' exploration, development and monitoring. Naturally, deployment of an optical fibre in a borehole is favourable for obtaining high-quality data due to its cost-effectiveness and high-density coverage and provides rapid acquisition of downhole seismic data. Many tasks that require the use of high frequency-source to achieve necessary resolution primarily focused on investigations for mineral exploration and near-surface monitoring. Cross-hole is one of the methods employed for locating small-size mineral bodies and monitoring near-surface changes. Here, we present the results of a cross-hole acquisition using DAS and a high-frequency electric sparker source. The field trial was conducted at the CO2CRC's Otway International Test Centre, Victoria. A sensing fibre optic cable was cemented in a shallow well and a sparker source was deployed in a separate borehole. Data were collected using the DAS Treble+ interrogator (Terra15 Technologies Pty Ltd). High-resolution seismic data, obtained in this project using the high-frequency source demonstrates the applicability of DAS technology for near-surface studies like CO_2 leakage monitoring and mineral exploration.

INTRODUCTION

Distributed acoustic sensing (DAS) technology is commonly utilised for various tasks throughout the different stages of resource and mine exploration, development, and monitoring. Deploying an optical fibre in a borehole is particularly advantageous for collecting high-quality data due to its cost-effectiveness and high-density coverage, enabling rapid acquisition of downhole seismic data. Many tasks that require the application of high-frequency sources for achieving the necessary resolution are primarily focused on mineral exploration and near-surface monitoring. Cross-hole techniques are among the methods used to locate small mineral bodies and monitor near-surface changes.

There are numerous examples of cross-hole techniques used in mineral exploration for delineation of ore bodies with high mineralization (McDowell et al. 2007; Perozzi et al. 2012). The cross-well approach was also successfully employed to monitor CO_2 storage as demonstrated during the CO_2 injection program at the Ketzin site, Germany (Bergmann et al. 2016). Distributed Acoustic Sensing (DAS) technology implemented in borehole seismic configurations is a powerful tool used for CO_2 storage monitoring (Correa et al. 2017). DAS technology is capable of detecting low-frequency signals (as low as 0.1 Hz) such as passive data generated by ocean (Pevzner et al. 2023) and generated by seismic sources such as vibroseis trucks or surface orbital vibrators (over the usual frequency range ~6-150 Hz), which can be utilised to detect small amounts of CO_2 (Yurikov et al. 2022; Isaenkov et al. 2022).

Combining DAS with high-frequency sources offers numerous advantages, but it presents challenges due to some acquisition parameters limiting the resolution, such as the pulse length and the gauge length. Recent advancements in fibre optic interrogators have significantly enhanced their sensitivity to high-frequency signals. Several experiments of DAS borehole seismic involving downhole high-frequency sparker sources have shown promising results (Tertyshnikov at el. 2023; Tertyshnikov and Pevzner 2019; Pevzner et al. 2019). Such a combination of DAS and high-frequency sources (> 1 kHz) offers high-resolution cross-well tomography for outlining mineralization zones (like high-grade massive sulphide bodies or lithium-bearing pegmatites) or detecting and monitoring near-surface presence of CO_2 (leakage-like scenario).

Here, we present and discuss the results of a cross-hole field trial utilising a sparker source and a fibre optic cable cemented in a shallow well during the experiment on shallow release of gaseous CO_2 at the CO2CRC's Otway International Test Centre, Victoria.

EXPERIMENT DESIGN

The experiment was conducted at the CO2CRC's Otway International Test Centre, Victoria. Two shallow wells were used during the field trial (Figure 1). These boreholes were utilised for different purposes: Brumbys-3 for injecting CO_2 (injector well), Brumbys-1 for the seismic source deployment (sparker well). The distance between the Brumbys-1 and Brumbys-3 wellheads is 26.8 m. The Brumbys-3 is a vertical 100 m deep well, with a CO_2 injection interval located at ~77-87 m depth. Brumbys-1 is a 122 m deep deviated well with 11.3° inclination and 26.5° azimuth from the collar. In this study, we are focusing on data, acquired in the injection Brumbys-3 well using a sparker source deployed in the Brumbys-1 well. Both wells are equipped with fibre-optic cable going along their entire length and connected to Treble+ DAS interrogators (Terra15 Technologies Pty Ltd). The seismic source, used throughout the study, is 1.2 kJ an electric high-frequency sparker.

In total, ~17 tons of CO_2 were injected into the formation through the Brumbys-3 borehole. Carbon dioxide was continuously injected into the well over 8 days. In this timeframe, several datasets were acquired, including two baseline datasets before the injection and two post-injection vintages.

DAS data was recorded using a Terra15 Treble+ interrogator. All data were acquired with a 0.82 m pulse length, a 0.82 m gauge length (post-processing), a 0.82 m channel spacing and a 0.233 ms sampling rate. At the beginning of each survey, a seismic source was deployed at 110 m depth in the Brumbys-1 well, and the source was moved up from this level at one-meter intervals up to the last source point located at 4 m depth from the collar. To increase the signal-to-noise ratio, a repetition of 10 shots per level was performed at each level.

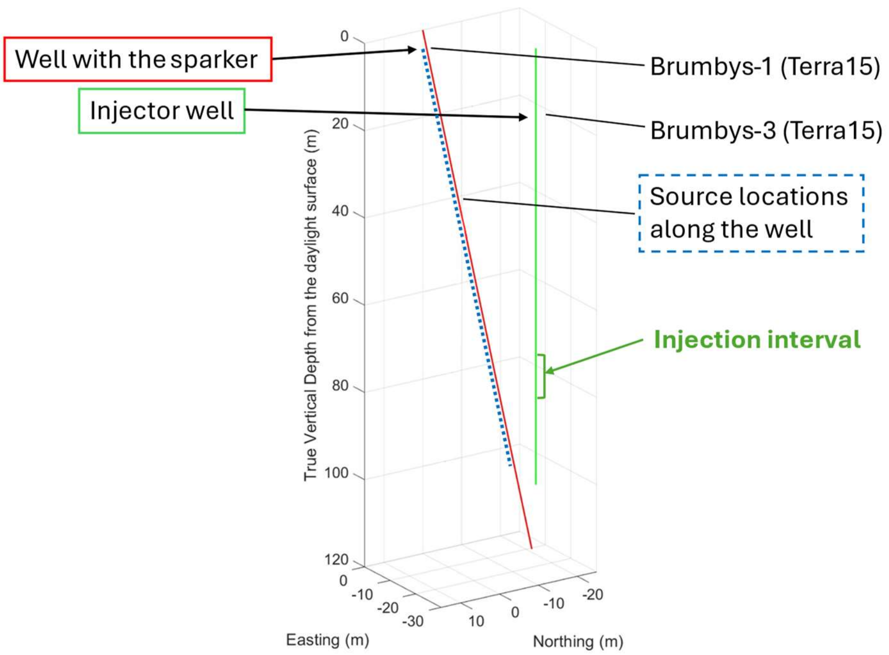

Figure 1. Wells geometry

DATA ANALYSIS

Examples of seismograms acquired in the Brumbys-3 well with a sparker at 100 m depth are shown in Figure 2. Figure 2a shows a baseline gather, obtained a day before the start of the injection. Figure 2b shows the last monitor, obtained two days after the end of the injection. These pictures were obtained by stacking together 10 excitations, that were made to improve the resulting signal-to-noise ratio. Baseline direct wave travel times are shown with the dotted purple line. We observe a direct wave time delay of 1.4 ms right after the indicated CO_2 injection interval. In addition, the direct wave signal inverts polarity at the end of the injection interval. These observations allow us to confirm the detectability of CO_2 in the shallow formation due to a change in the acoustic impedance of the formation caused by the CO2 injection.

The amplitude spectrum of the signal from the last monitor is presented in Figure 3. This plot shows that the peak amplitude of the signal acquired with the Treble+ interrogator unit in Brumbys-3 well at the source depth corresponds to signal's high frequencies (500-1000 Hz).

CONCLUSIONS

The field experiment demonstrates the acquisition of high-quality data using a combination of a high-frequency low-power source with DAS in a cross-well configuration setup. The distributed sensing array's high-density spatial channel sampling and the interrogator's high sensitivity at a small gauge length (0.82 m) ensured proper wavefield sampling generated by the high-frequency (~1 kHz) source. Such an approach in cross-hole allows rapid and effective recording of seismic data suitable for the inversion of high-resolution tomographic images. This configuration of cross-well acquisition becomes favourable in many tasks for the location and imaging of relatively small objects and changes in the subsurface, like high mineral concentration or near-surface CO_2 leakage monitoring.

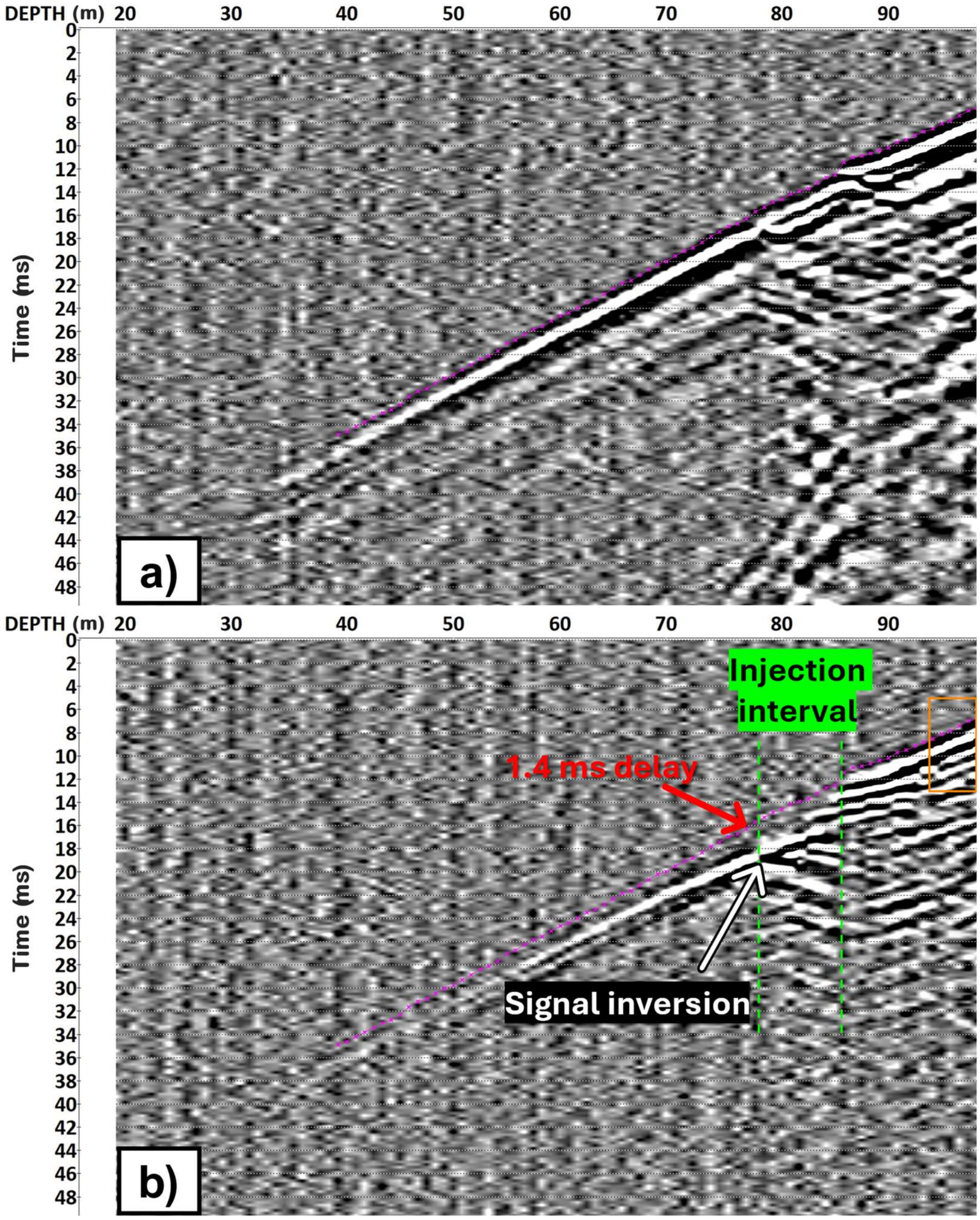

Figure 2. Brumbys-3 (injection well) data: baseline acquired a day before injection (a) and last monitor acquired two days after injection (b) for 100 m depth source position. The purple line shows direct wave travel time for baseline data. The red arrow points first breaks delay after the end of the injection. The orange rectangle shows the signal spectrum estimation area for Figure 3.

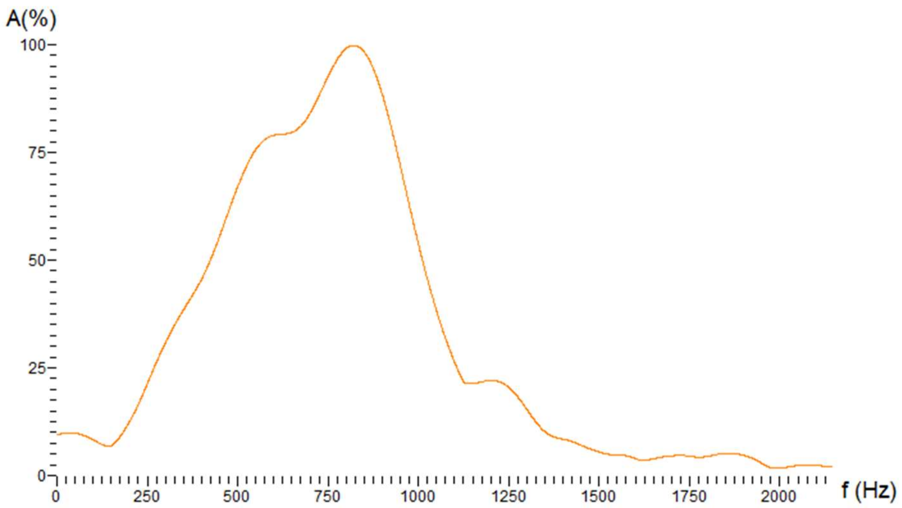

Figure 3. Signal spectrum of the sparker source on the source depth (100 m) in the injection well (Brumbys-1) from the last monitor (post-injection) data

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