New approaches to seismic monitoring at the Brooks Field Research Station

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ABSTRACT

The Containment and Monitoring Institute (CaMI) Field Research Station (FRS) is being developed by CMC Research Institutes, Inc. (CMC) and the University of Calgary in Newell County, Alberta. The goal of this research station is to develop and calibrate various technologies for monitoring fluid injection and cap rock behaviour at depths of 300 m and 500 m below surface. Seismic monitoring is advancing rapidly with time-lapse or 4D seismic surveys, but these are expensive and the time interval between repeated, conventional seismic surveys may temporally alias the geological changes taking place in the reservoir. There is now a move towards not only permanent receiver arrays, but also permanent seismic sources. These may operate continuously, or with a rapid repeat time which may enable trigger events to be detected in the subsurface. Some of these technologies include fibre optic distributed acoustic sensing (DAS) and fixed seismic sources. Plans are in place to install some of these systems at the FRS.

INTRODUCTION

The FRS is located approximately 20 km southwest of Brooks, Alberta, on ¾ section of land owned by Cenovus energy and leased to CMC for a period of 10 years. The project has an emphasis on CO_2 detection thresholds at these relatively shallow depths, but is also focussed on understanding and monitoring understanding shallow gas (CO_2 and CH_4) migration, particularly fugitive gas emissions. The specific objectives being assessed at the FRS are sensitivity of monitoring systems for early detection of loss of conformance and in mapping temporal changes in cap rock that may lead to loss of containment. Construction has begun on an array of wells, sensing stations, and surface facilities that will be monitoring fluid injection and cap rock behaviour. CREWES has a key role in the seismic monitoring program at the FRS and CREWES researchers have been able to undertake research on data already collected at the site (e.g. Isaac and Lawton, this volume). The next phase of the seismic monitoring research program is to install permanent receivers, including geophones and DAS, and also to evaluate the efficacy of a permanent seismic source for seismic monitoring programs over the next 5 years.

Figure 1a shows the geometry of a 3C3D surface seismic survey that was recorded at the FRS in May 2014. The program covered an area of 1 km x 1 km and details of the acquisition were provided by Lawton et al. (2014). A total of 1434 shots were recorded into 1400 3C receivers. Figure 2 shows the processed PP and PS post-stack migrated data volumes, and the interpretation of the data is given by Isaac and Lawton (this volume).

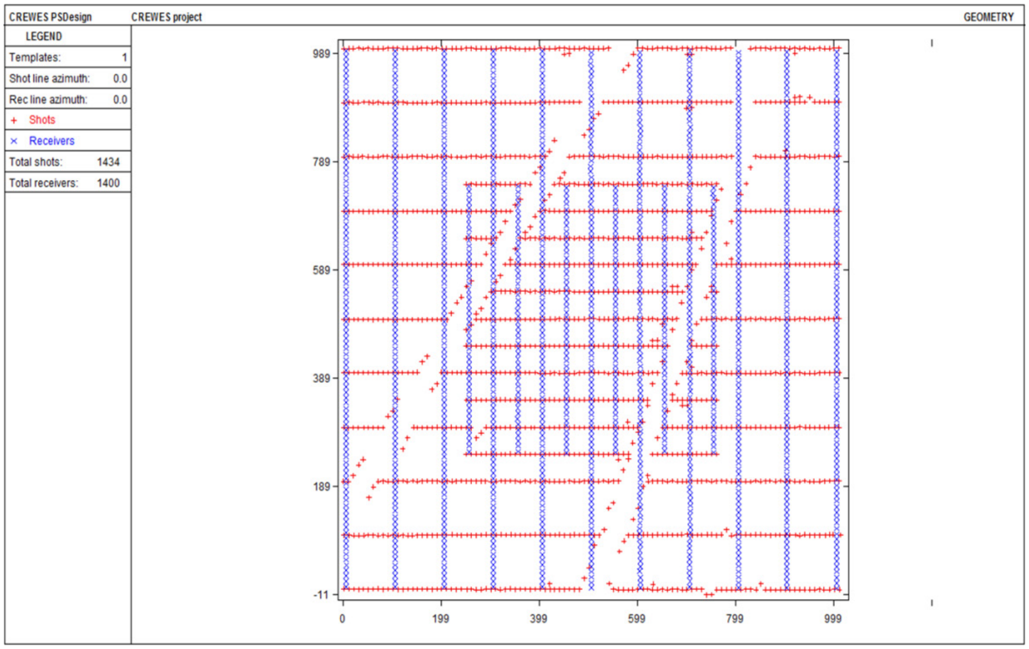

FIG. 1. Acquisition geometry of the CaMI.FRS 3C3D seismic survey.

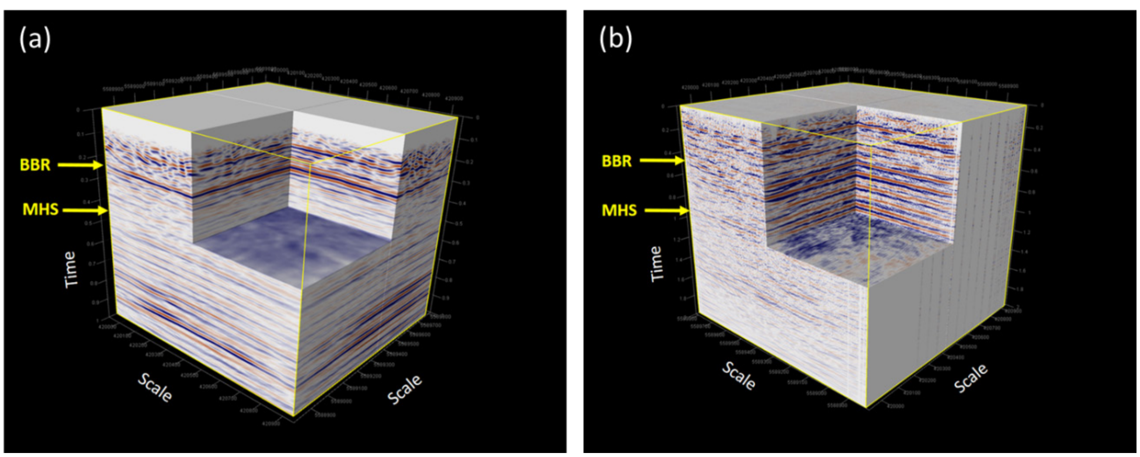

FIG. 2. Processed 3D volumes of: (a) PP data, and (b) PS data.

SEISMIC MONITORING

Distributed Acoustic Sensing

Seismic monitoring programs are designed to image time-lapse or 4D changes in the subsurface, particularly changes in impedance caused by production or injection of fluids. In the latter case, the need by the public as well as regulators to verify secure storage of CO_2 has seen significant research into optimum methods for seismic monitoring (e.g. Daley, et al., 2007; Lawton, 2009; Sodagar and Lawton, 2014). Many of these developments have focussed on improvements in acquisition, processing and interpretation of relatively conventional surface seismic data and vertical seismic profiles (e.g. Lawton, 2009), with the objective of delineating very subtle changes in the seismic response of reservoirs before and after CO_2 injection. More recently, distributed acoustic sensing (DAS) has experienced rapid development for recording VSP data. DAS is based on recording instantaneous strain on an optical fibre using a light source and an interrogator at the top of the well. Seismic waves that are incident on the fibre result in phase delays of light backscattered from imperfections in the fibre. A profile of the backscattered light is built up along the fibre (Parker et al., 2014) and changes in strain can be measured by integrating the light response over intervals of the fibre, to perhaps match the separate of point receivers (geophones) in the conventional well.

An important attribute of optical fibre sensing is that well completions are easier since the fibre is typically housed in ¼" tubular steel on the outside of the well casing for permanent installations. This improves the quality of the cementing operation with less likelihood of microchannels developing along the cement between the casing and the rock formation. The disadvantage of optical fibre is that it is sensitive to longitudinal strain so it will have maximum output for a P-wave parallel to the fibre or an S-wave orthogonal to it, and thus modal separation is difficult.

An example of a comparison between DAS and geophone VSP data from the Aquistore CO2 storage site is shown by Daley et al. (2014); an example from this paper is shown in Figure 3. Similar applications for DAS in recording of VSP data can be found in Mateeva et al. (2013).

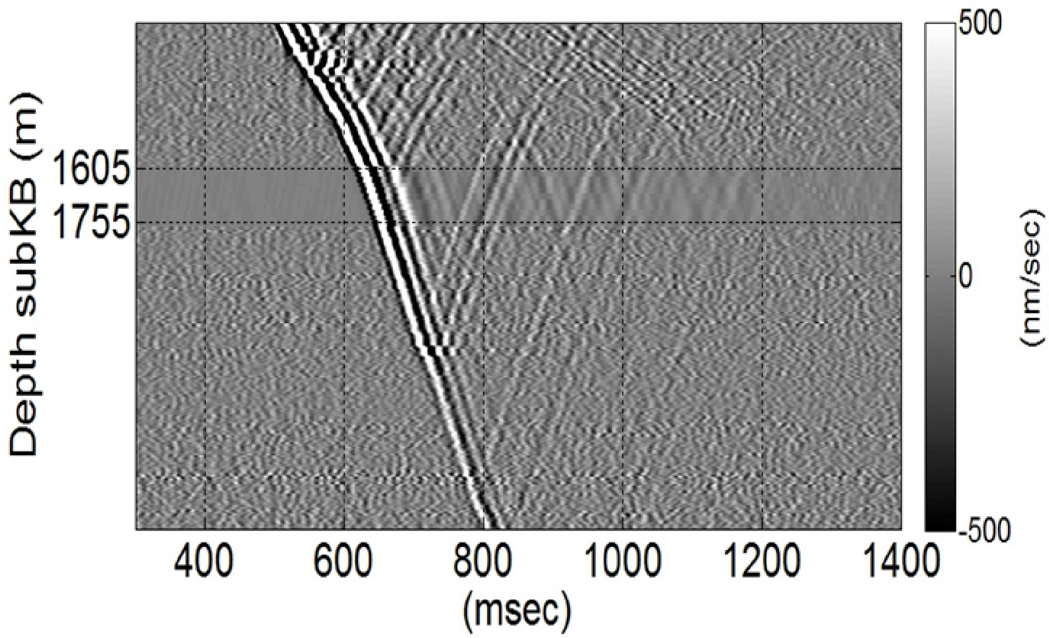

FIG. 3. Comparison of DAS and geophone data from a VSP (from Daley, 2014). The geophone data are shown between depths of 1605 and 1755 m.

The data in Figure 3 shows that DAS data are slightly noisier than geophone data, but phase is very similar between the two datasets. Verliac (2015) undertook a systematic comparison of DAS systems offered by 4 different technology providers. While the recorded data were quite similar, differences in amplitude were noted and some depth inaccuracy was found and attributed to acquisition and processing methodologies.

Experiments have been undertaken recently with surface seismic recording using DAS fibre laid in trenches. Kendall (2014) reported on a study in which trenched DAS data were recorded with surface 3C geophone data and found that the results were comparable but not identical. He attributed the differences mainly to modal contamination in the DAS fibre data.

In order to decrease the directivity of DAS fibre, some experiments have been undertaken recently with the optical fibre wound in a helix on a mandrel, with encouraging results (Daley, personal communication).

Continuous sources

An important goal of seismic monitoring is to capture changes in the reservoir when they occur. A worst-case example may be failure of the cap rock in an injection program, such as CO2 storage program or steam injection for steam-assisted gravity drainage (SAGD) in oil sands production. Seismic monitoring is advancing rapidly with time-lapse or 4D seismic surveys, but these are expensive and the time interval between repeated, conventional seismic surveys may temporally alias the geological changes taking place in the reservoir. Thus, we need more rapid monitoring surveys that would be able to capture trigger events that might require immediate mitigation to the injection or production operation. Microseismic monitoring is being used successfully for real-time monitoring of hydraulic fracturing, but these programs are generally limited to capturing events that are proximal to the injection well.

In programs such as CO2 storage, steam injection or waste water disposal, frequent or continuous reflection seismic surveys could be used advantageously to monitor rapid response to changes in the reservoir. A good example of continuous seismic monitoring of a SAGD operation is given by Forgues et al. (2006), using a SeisMovieTM method. The continuous source in this case was a 1 kW piezoelectric transducer.

Larger, permanent fixed sources have also been developed. The ACROSSTM source, developed by JOGMEC, is shown in Figure 4.

FIG. 4. ACROSS permanent seismic source (after Kurosawa and Kato, 2015)

The ACROSS source is an eccentric mass that rotates about an axis at highly controlled frequencies and is highly repeatable (Kurosawa and Kato, 2015). It was originally developed to monitor fault slip on subduction faults in Japan. ACROSS sources have been installed in Japan, at the Aqusitore CO2 storage project in Saskatchewan, and in Saudi Arabia.

A smaller-scale eccentric mass source has been developed by scientists that the Lawrence Berkeley National Laboratory in California (Barry Freifeld, personal communication). This source is a modified from a concrete shaker. This source has been installed at the Otway CCS research center in Australia, and is shown in Figure 5. It has a 0 – 80 Hz spin-up and spin-down each over a 1 minute time period. Peak force is 10 t.

FIG. 5. LBNL permanent seismic source. Image courtesy of Barry Freifeld (LBNL), Curtin University and the Australian CO2CRC.

Planned installations at the CaMI.FRS

The monitoring plan layout of CaMI.FRS is shown in Figure 6. The first well was drilled in March, 2015 and will be completed as a CO2 injector well by the end of 2015. Injection will be up to 1000 t/yr into the Basal Belly River Formation at a depth of 300 m below the ground surface. The development of the full geostatic model of the site is detailed by Dongas and Lawton (this volume), with some time-lapse seismic modelling results presented by Nowroozi and Lawton (this volume). As shown in Figure 6, electrical resistivity cables and optical fibre will be trenched in across the site at a nominal depth of 1 m. A permanent 10 x 10 buried geophone array will also be

In the upcoming winter season, we plan to drill two observation wells at the FRS (shown by the green dots in Figure 6. These are located 20 m southwest of the injector well, and 30 m northeast of the injection well, respectively. These two wells will be completed with fibreglass casing to enable electrical and electromagnetic monitoring techniques to be deploy in addition to surface seismic, cross-well seismic and VSP seismic surveys.

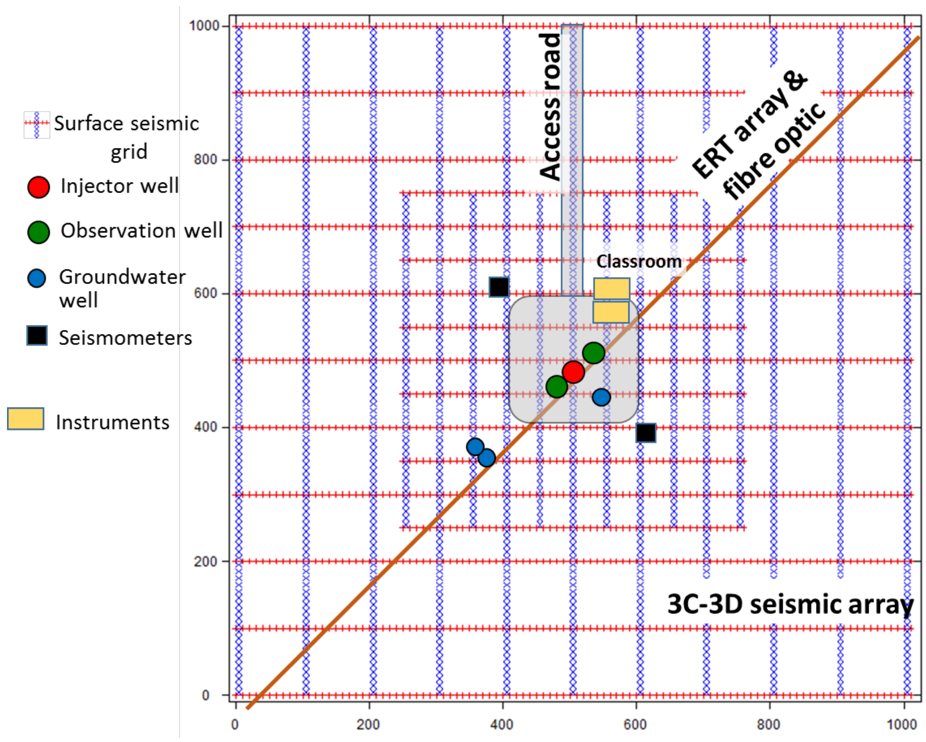

FIG. 6. Layout of Phase 1 of the FRS monitoring research program

The monitoring wells will encompass the following instrumentation:

Observation well #1

- Integrated fibre optic cable capable of distributed heat pulse testing as well as distributed temperature sensing (DTS) and distributed acoustic sensing (DAS).
- Stainless steel U-tube for sampling reservoir fluids from the Basal Belly River Formation. This will be completed with a pressure gauge at the injection zone.
- Above zone pressure gauge to monitor fluid pressure in an aquifer in the Upper Foremost Formation immediately above the McKay coal zone.

Observation well #2

- Integrated fibre optic cable capable of distributed heat pulse testing as well as distributed temperature sensing (DTS) and distributed acoustic sensing (DAS).
- Experimental, helical wound DAS fibre to increase DAS performance for vertical seismic profiles (VSP) and walkaway seismic programs.

- Electrical Resistivity cable with electrodes mounted on the casing.
- A 20-level geophone array, with nodes at 5 m spacing, for VSP acquisition and microseismic monitoring during injection.

The observation well completion and monitoring instrumentation has been designed in collaboration with LBNL scientists. The helical-wound optical fibre in Observation well #2 will possibly be one of the first times anywhere this has technology has been installed on the outside of well casing.

Depending on funding, we would also like to install a permanent rotary seismic source at the FRS. The location of the source will be determined after field trials to optimize the signal to noise ratio in the time interval of interest.

DISCUSSION AND CONCLUSIONS

High quality baseline multicomponent seismic data has been collected and processed at the CaMI Field Research Station. We have ambitious plans to advance new seismic monitoring technologies at this site. This will included surface and borehole 3C geophone arrays and fibre optic acoustic sensing. New fibre deployment geometries will be tested to improve the directional response of fibre and improved modal separation. Stay tuned!

ACKNOWLEDGEMENTS

We thank CMC Research Institutes, Inc (CMC). for access to the seismic data and CREWES sponsors for contributing to this seismic research. We also gratefully acknowledge support from NSERC (Natural Science and Engineering Research Council of Canada) through the grant CRDPJ 461179-13.

The baseline seismic program was recorded by Tesla Exploration under contract to CMCRI. Schlumberger Carbon Services is acknowledged for their role in project management for the field implementation of the Field Research Station.

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