Experiences in Deep Downhole Digital Micro-seismic Monitoring near 3 km at the PTRC Aquistore CO_2 Sequestration Project

Chris G Nixon, Douglas R Schmitt, and Randolf S. Kofman, University of Alberta
Don White, Geological Survey of Canada
Anna Stork and Michael Kendall, University of Bristol
Kyle Worth, Petroleum Technology Research Centre

Summary

The Aquistore project near Estevan, Saskatchewan, seeks to develop methodologies for the permanent sequestration of CO_2 stripped out of the exhaust of the Boundary Dam coal-fired electrical generation plant. The project includes extensive monitoring both at the surface and from an observation borehole; and here we describe a borehole seismic system capable of making long-term continuous seismic recording that was tested as part of these efforts. The system is deployed at greater than 2900 meters depth at temperatures of 115°C for long term continuous microseismic monitoring. The seismic records are digitized downhole, vastly reducing issues of noise that can accumulate with analog systems deployed on a long wireline.To our knowledge digital recording under such conditions has not been previously described. The surface components include an uninterruptible power supply with 24 hour capacity, large redundant hard-drive data storage, and the ability to remotely monitor the system health via the internet. Nearly 12 weeks of continuous records were obtained throughout this initial feasibility assessment, during which CO_2 was injected in to the reservoir at ~3200 m depth. Seismic 'noise' levels are extremely low at this depth, allowing for detection of regional mine blasts, orientation shots, and even low-frequency teleseisms; these arrivals confirmed that the system was operational. No clear microseismic arrivals have yet been detected during the initial injection.

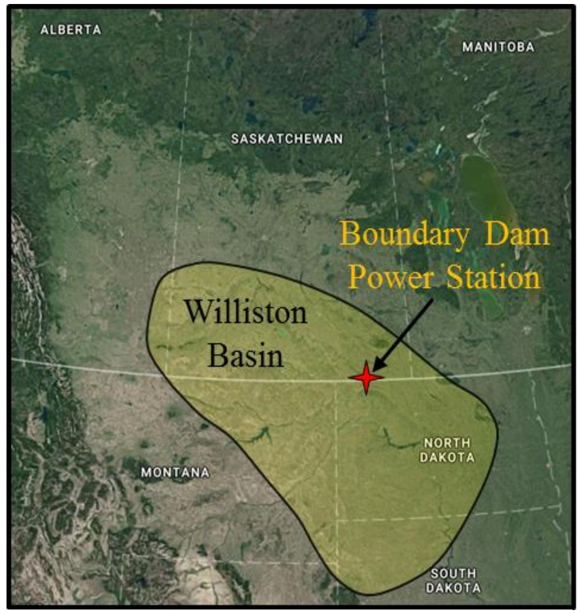


Figure 1. Project location near SK/ND border. Carbon Dioxide is scrubbed from Boundary Dam coal power plant near Estevan, Sk

Introduction

Aquistore, managed by the Petroleum Technology Research Centre, is Canada's first dedicated CO_2 storage project, and is an integral component of SaskPower's Boundary Dam Integrated Carbon Capture and Storage (CCS) Demonstration project - the world's first fully integrated CCS demonstration project from a coal-fired power plant (Global Carbon Capture and Storage Institute & Petroleum Technology Research Center, 2015). Most existing CCS projects are associated with enhanced oil recovery operations. The Aquistore project is located near the SaskPower Boundary Dam generation station south of Estevan, Saskatchewan. CO_2 captured from the power plant is injected into saline aquifers within the basal sands of the Deadwood Formation at depths below 3150 m in the Williston basin (figure 1). This geological interval is an excellent candidate for CCS due to the prevalence and volume of this deep saline aquifer having adequate porosity and permeability, in addition to the existence of numerous overlying low permeability sealing formations (White et al, 2016).

Here, we primarily outline the technical aspects related to the deep seismic monitoring system developed for the Aquistore projects and describe some of the seismic observations obtained so far. The monitoring was carried out for relatively long time periods with the instrumentation subject to extreme temperature and pressure conditions; as we are unaware of any other deployments with digital technology in such environments, our experiences will be of interest to others considering similar recording.

Downhole System

We have constructed a system for long term seismic monitoring purposes in boreholes to depths of nearly 3 km (figure 2). The system centres on a string of 5 Sercel Slimwave™ 3-component sondes to provide the data acquisition capability. The tool string consists of 5 individual triaxial sondes at 15 m spacing for a total geophone tool string length of 60 m. Extended digital recording at 2800 m depth was possible due to maximum operating temperature and pressure of 135°C and 100 MPa, respectively, although we operated at a slightly lower temperature of 115°C. Geophone data is digitized downhole at 0.5 ms/sample and sent via 4 conductor 3/16" wireline to the surface electronics package. 750 Gb of seismic data was aquired over 3 individual deployments between May 27th and December 2nd, 2015. Buried dynamite shots were used during each deployment to orient the horizontal geophones. Using a combination of Vista Seismic Processing and Matlab, seismic events were manually selected for further analysis, and differentiated from water borne tube waves by moveout. The data set is currently being subjected to further tests to compare efficacy of visual vs algorithmic event selection.

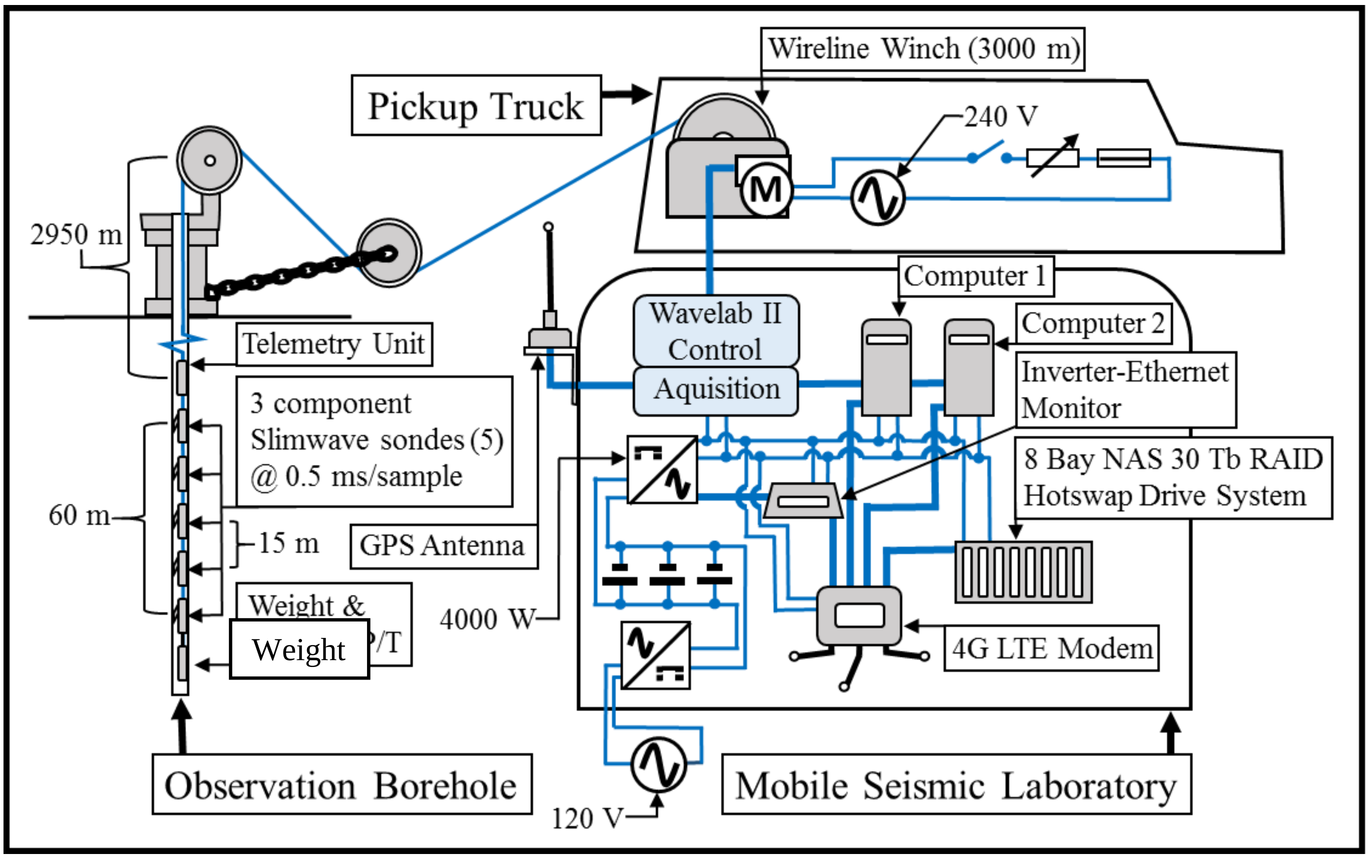


Figure 2. Microseismic Monitoring, Technical Layout. System depicted in deployed configuration. Battery backup ensures uninterrupted monitoring. Precise timing provided by GPS antenna. NAS drive system ensures no data lost. Remote computer operation and data retrieval possible through cellular uplink.

Winch/Wireline

The system utilizes a GeoVista GV570 wireline winch (figure 3). The installed wireline is a ~3,000 m long, 3/16" diameter, 4-conductor (24 awg) cable (Rochester stock type 4-H-181A) capped with a Gearhart-Owen 4-conductor (GO4) cable head. The winch has a Rotapuls CK46 depth encoder to measure cable position and a strain circuit to measure tension on the cable. A 19-pin connector connects to the four conductors in the wireline, the depth encoder, and the strain circuit. A custom fabricated adapter is used to connect the winch to the Sercel WaveLab II Surface Control Interface Panel (SCIP) and the WaveLab Interconnection Box (WIB). The Sercel winch extension cable connects to the SCIP and a 4-conductor shielded cable connects the WIB.

Sheave Assembly

The wireline was fed through a pair of 14” x 3/16” FHE Starlite sheave assemblies. The lower sheave was chained to the base of the well-head and the upper sheave is mounted in a custom-built frame bolted to the top of the well-head. This system was designed specifically for long term monitoring projects and eliminated the need for a rig or crane to be onsite for the duration of monitoring.

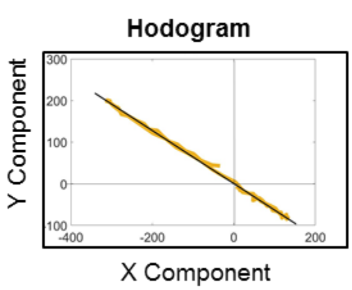
Tool string

The downhole tools used in this project include a SlimWave Gamma Ray Unit (SGRU), SlimWave Highspeed Telemetry Unit (SHTU), and five SlimWave Seismic Acquisition Units (SAU’s). Sercel specifies continuous operation is possible at 135°C (150°C brief exposure) and 1,000 bars (14.5 kpsi). The temperature at the Aquistore recording depth (typically ~2,850 m) was ~115°C. The system is capable of data transfer rates of slightly over 3 Mb/s. The sampling intervals are restricted to ¼ ms, ½ ms, 1 ms, 2 ms and 4 ms. The head on the downhole side of the cable is designed with a fishing profile and four weak points designed to fail once a threshold force is reached. To allow the SJC to work with the GO4 cable head a custom cross-over was designed and built. An optional SlimWave Weight Unit (SWU) is available for the bottom SAU.

Data Acquisition

The WaveLab II surface acquisition panel consists of: 1) The Surface Control Interface Panel (SCIP) is the junction box where standard fitting electronics are interfaced (ie USB). 2) The WaveLab Interconnection Box (WIB) is an interface allowing the field gear to connect to the SCIP. 3) The Surface Control Power Panel (SCPP) is a constant current supply that powers both the downhole tools and the SCIP. A GPS receiver was used to provide precise timing for the Aquistore survey. Tool control and data acquisition were performed with two laptops, a network switch, an 8-bay Network-attached storage (NAS) device and an external USB hard drive. Each laptop is equipped with GBridge software, giving remote access to the entire system through the on-site internet

Orientation shots (buried dynamite) were clearly recorded, with a signal to noise ratio (SNR) on the order of 10^4. Hodograms were very linear, nearly negating the need for least squares fitting for horizontal component orientation. Using the rotation angles from hodogram analysis, it was possible to reduce the remaining orthogonal axis nearly to noise levels after orientation of the signal traces. Confidence of the tool orientation with this method is very high (see figure 3).



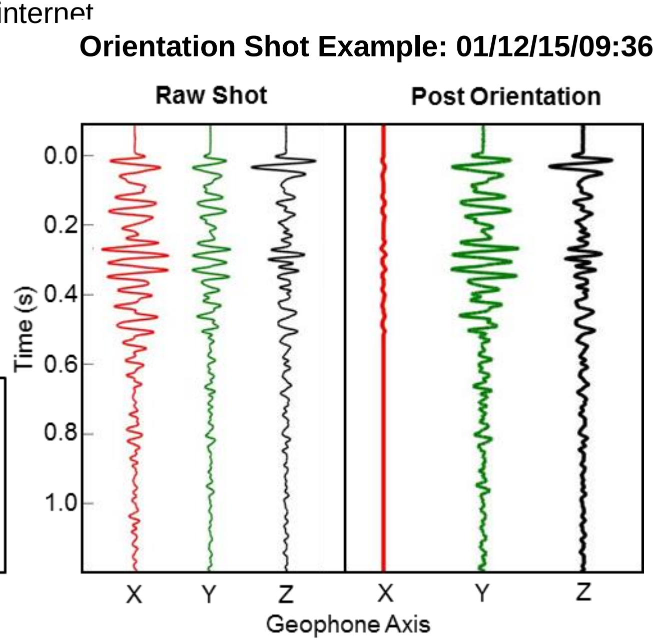


Figure 3. Example Orientation shot. Raw Shot shows data prior to rotation from resulting hodogram analysis. Post orientation has optimized maximum signal in Y vs minimum signal in X. Hodogram: Yellow shows cross-plotted horizontal traces with least squares linear fit in black.

Example

With a geologically calm environment and high resolution digital recording equipment, the data collected in this project is of very high quality, and more sophisticated data analysis is currently underway. Although the CO_2 was injected only 400 m away from the recording instruments, we did not detect any clear microseismic events. That the instruments were functioning, however, is not in doubt as regional mine blasts and even teleseisms were obtained. An example of a mine blast (Figure 4) shows a seismic event with a high apparent upward moveout of 12000 m/s across the downhole array.

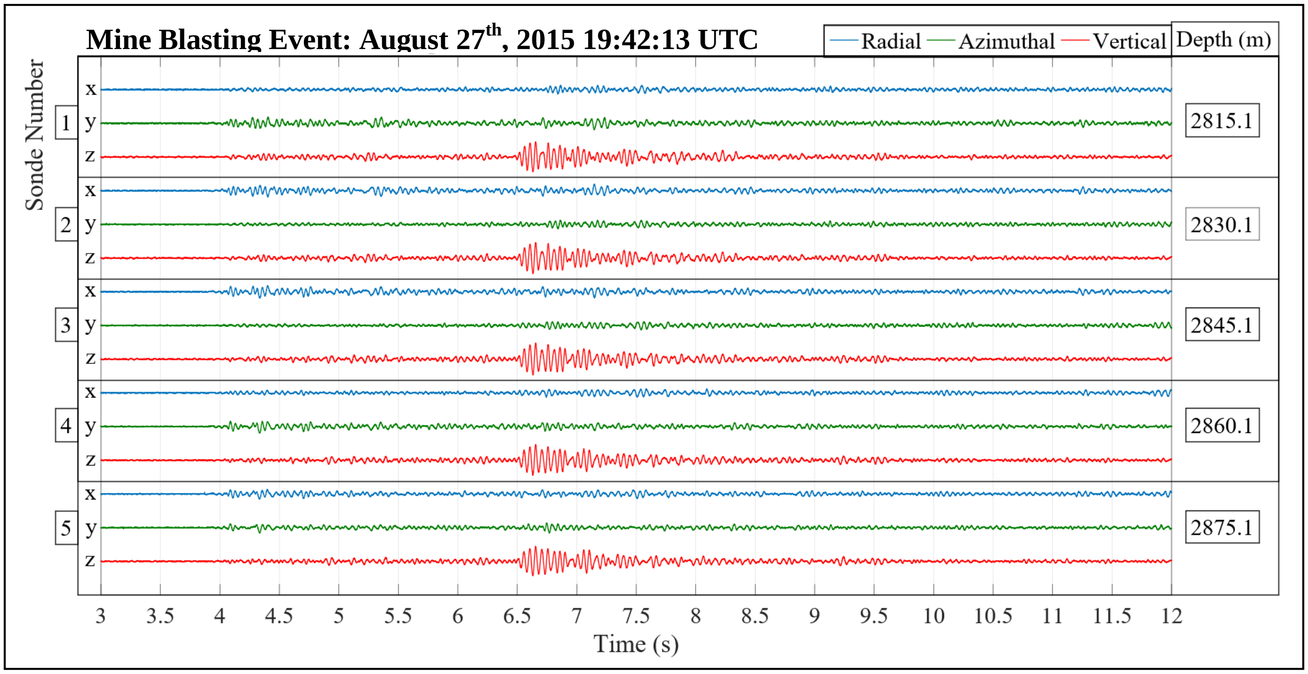


Figure 4. P-wave apparent moveout (upward): 12000 m/s. S-wave apparent moveout (upward): 8600 m/s. S-wave appears strongly only on vertical component. Associated with local mine blasting event.

Conclusions

An overall lack of microseismic events is encouraging for the future of CCS in the Williston basin, although more research is needed before it can be declared a success. Although not without difficulties, the system discussed here performed well in the harsh conditions below 2800 m. Implementation of this system has pushed the limits of what is possible for downhole seismic data acquisition and can access an improved level of microseismic precision. Continued analysis and integration with surface monitoring data may further elucidate the efficacy of CCS with great environmental and economic benefits due to the rapidly growing urgency of climate change.

Acknowledgements

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