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Passive seismic monitoring at a CO2 injection site, Violet Grove, Alberta, Canada

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Introduction

Microseismicity has been observed as a result of fluid injection (Talbei, 1998) and gas injection (Maxwell, 2004). In addition theoretical and laboratory studies of changes in rock properties with CO_2 flooding predict that small changes in seismic attributes should be observable in field seismic surveys (Sinartio, 2002). Passive monitoring and time-lapse seismic surveys have been shown to be effective at mapping the CO_2 injection plume at the Sleipner CO_2 storage site in Norway(Arts, 2002) and at the Weyburn CO_2 injection project in southeastern Saskatchewan (White, 2004). At both of these sites, P-wave amplitude and traveltime anomalies have identified the distribution of CO_2 in the reservoir.

At the Penn West CO_2 injection site in Alberta, Canada, an innovative seismic program has been implemented to monitor CO_2 injection/storage in an oil reservoir. The approach taken involves passive monitoring of CO_2 injection augmented by periodic, sparse, 4D, multicomponent surface seismic programs. Both passive and active seismic use the same set of geophones permanently cemented into an observation well. Active seismic surveys include a number of surface seismic geophones providing 3D subsurface coverage of the pilot site. Two active seismic surveys have been completed to date: one in March 2005 and one in December 2005. Passive seismic monitoring of the site has been underway since March of 2005.

Sensors

The sensor array is comprised of eight 3-component geophone sondes manufactured by Terrascience Systems Ltd. These sondes are installed on cables with 40m between each sonde. Two sets of sondes are interleaved to produce a nominal interval of 20m between geophone levels. In addition to the sondes, two down-hole sampling ports and three pressure-temperature gauges were installed in the same well.

Sensors were installed into the borehole over a period of several days. Installation was a challenge, due to the quantity and variety of cables and sampling tubes which had to be installed. Because the sensors were mounted on 9.1 m long segments of production tubing, great attention had to be given to positioning the sensors to avoid placement over tubing joints. In some cases, short lengths of tubing were inserted to prevent coincident placement of sensors and tubing joins. Centralizers were fitted over joins and the 12 cables and tubes were carefully threaded around the gaps in the centralizers (Figure 1). To keep sensors away from the borehole annulus, shark-fin shaped diverters were installed above and below sensors to ensure that sensors had the required clearance. Cables and tubes were strapped to the tubing at regular intervals using wire and plastic ties. Cables were run perfectly parallel to each other, since crossed cable reduce the available clearance. At the completion of the installation, the lower portion of the borehole was filled with cement and the top (above the sensors) was filled with brine.

Seismic recorder

A “TMA Unit”, produced by Terrascience Systems Ltd. is used to digitize and capture any passive seismicity. The supplied AutoTAR software performs event detection using an STA/LTA algorithm. To date, many event files have been generated, but very few event files show data with seismic-related activity. During acquisition of active monitoring surveys, the down-hole sondes are connected to the surface seismic recorder (a Sercel 408 XL) so that the borehole sonde signals are exactly time aligned and stored in the same files as the surface geophone signals.

Figure 1. Left to right: geophone sondes, pressure/temperature gauges, downhole fluid sampling ports, a centralizer covering a join tubing.

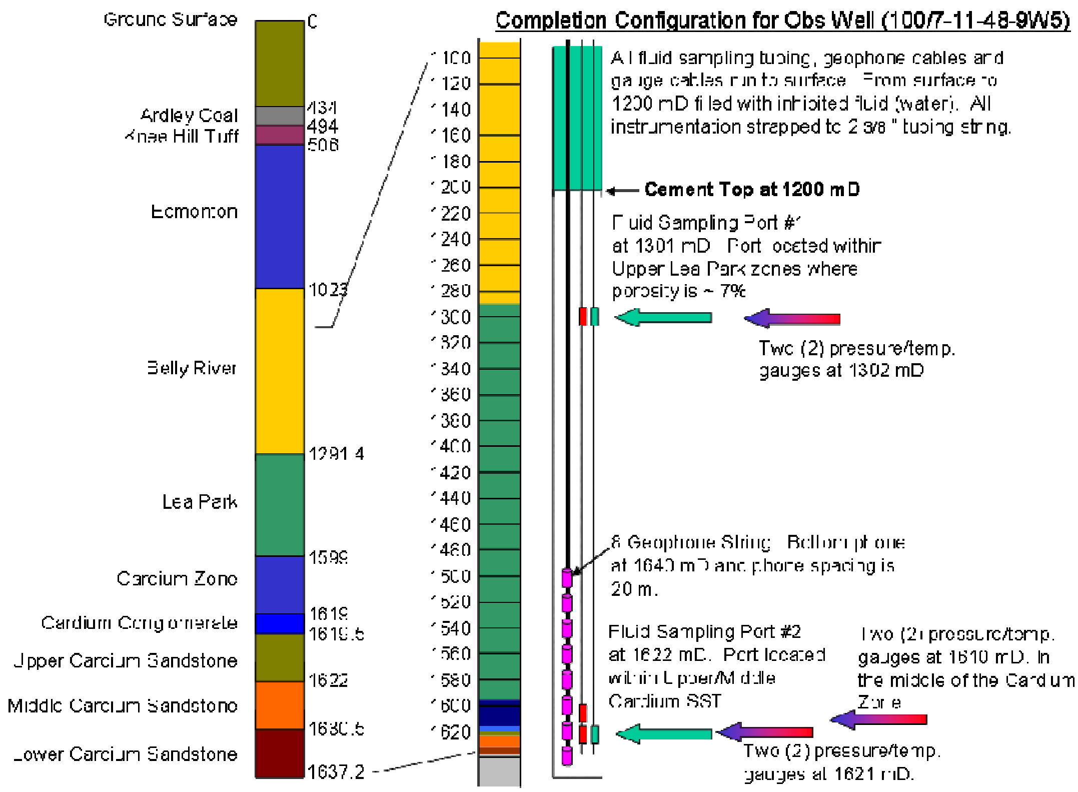

Figure 2. Schematic diagram of the observation well

Figure 3. Detailed installation photographs showing the installation of seismic cables (yellow) alongside stainless steel fluid monitoring lines, and pressure/temperature

instrumentation wires. A total of twelve strands are bound to the side of the production tubing.

Figure 4. Cable and tubing is hand-spooled as the sensors are inserted in the borehole.

Discussion

To date, passive seismic monitoring shows little measurable activity around the reservoir with the TMA Unit instrumentation. Work is ongoing to confirm the sensitivity of the monitoring system and explain the apparent lack of seismicity induced by the CO_2 flood.

The down-hole geophone array has proven very useful in two active seismic experiments, providing VSP coverage about the borehole. This shows that the geophone array is largely functional one year after its installation.

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