Seismic Survey Design for Monitoring CO_2 Storage: Integrated Multicomponent Surface and Borehole Seismic Surveys, Penn West Pilot, Alberta, Canada

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Introduction

Timelapse seismic surveys are now being used at a number of sites to monitor CO_2 storage in geological formations [e.g. Skov et al., 2002; White et al., 2004]. In order to properly map the movement of the CO_2 plume in the injection reservoir and to track possible leakage paths, three-dimensional (3D) seismic surveys are required. However, 3D surveys with close line spacing and small shot and receiver intervals are expensive, and surface seismic data may have insufficient bandwidth to resolve thin (< 20 m) injection zones. At the Penn West CO_2 injection site in Alberta, Canada, an innovative seismic monitoring strategy has been implemented involving a sparse, multicomponent surface seismic program integrated with active and passive monitoring using geophones permanently cemented into an observation well. The surface seismic program provides 3D subsurface coverage of the pilot site whilst data from the downhole geophones provide high-resolution images around the observation well. The downhole geophone installation will be used for passive monitoring of CO_2 injection between active-source seismic surveys. The Penn West baseline survey was completed in March 2005 and the first monitor survey is scheduled for early 2006.

Location and seismic program

The Penn West pilot is located in the Pembina Oil Field in west-central Alberta, Canada, with CO_2 injection into the Upper Cretaceous Cardium Formation at a depth of approximately 1650 m below surface. The Cardium Formation is made up of sandstone sheets and a thin conglomerate layer sandwiched between thick black marine shales of the Blackstone Formation (below) and the Wapiabi Formation (above). The total thickness of the Cardium Formation at the site is approximately 20 m.

Surface access at the site is limited due to swamps and tree cover. The surface seismic program is shown in Figure 1 and consists of two parallel, multicomponent 2D lines, 400 m apart and oriented east-west, and one orthogonal multicomponent 2D north-south line, intersecting near the CO_2 injector wells. These three lines were 3 km long in order to yield a good distribution of source-receiver offsets at the injection pad. Two additional short north-south receiver lines were also included (Figure 1). During data acquisition, all lines were live with a receiver interval of 20 m, a source interval of 40 m, and a charge size of 2 kg at a depth

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of 15 m. In addition, 8 three-component geophones were cemented at 20 m intervals into an observation well (located in Figure 1), and all shots of the surface seismic program were recorded into this downhole array. The deepest geophone was located in the reservoir so that the array can be monitored between time-lapse seismic programs.

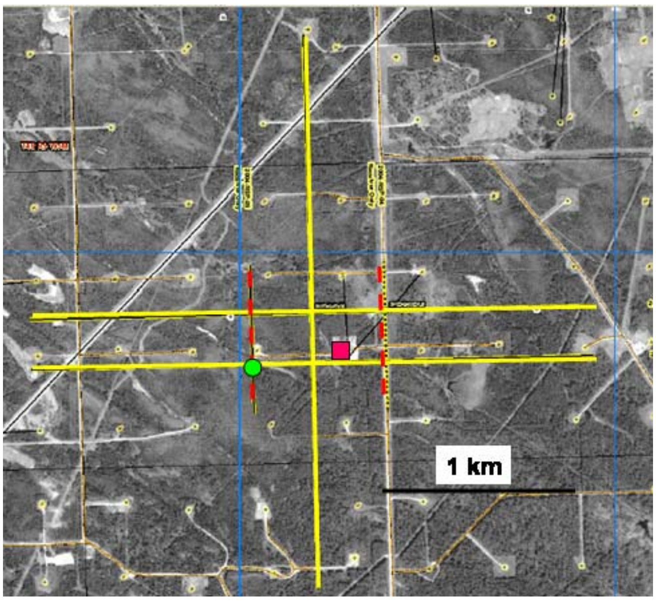

Figure 1. Map showing Penn West CO_2 injection site. Multicomponent seismic lines are shown in yellow, and receivers-only lines are shown in red. The observation (VSP) well is shown by the filled green circle, and the CO_2 injection pad is indicated by the red square.

Baseline surveys

The 2D lines were processed as individual lines and also as a sparse 3D volume which covers the injection pad. Figure 2 shows the P-wave data from the southernmost 2D line into which is spliced the processed vertical seismic profile (VSP) data from the observation well.

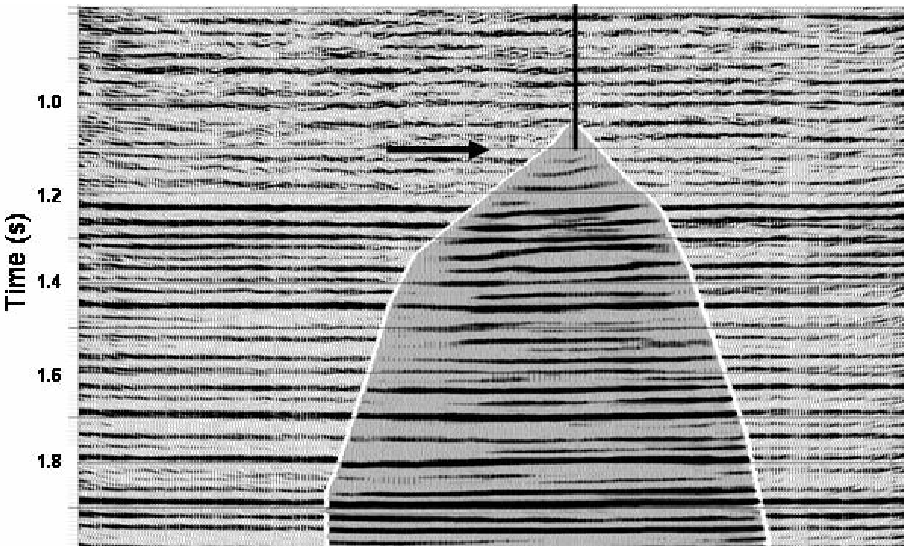

Figure 2. P-wave image across the injection pad. VSP data are spliced into the section. Cardium Formation is shown by the arrow; the observation well is indicated by the vertical line.

Amplitudes of the Cardium reflection are quite low and amplitude anomalies after CO_2 injection should be identifiable in the later monitor surveys. In monitor surveys, the high-amplitude, continuous reflections below 1.2 s should map traveltime anomalies below the reservoir after CO_2 injection. Since the seismic program was recorded with all of the receiver lines live for all shots, 3D imaging of the reservoir zone around the injection pad was possible. An example of data from the 3D volume is shown in Figure 3. Data quality is high and should enable the CO2 injection plume to be mapped from monitor surveys.

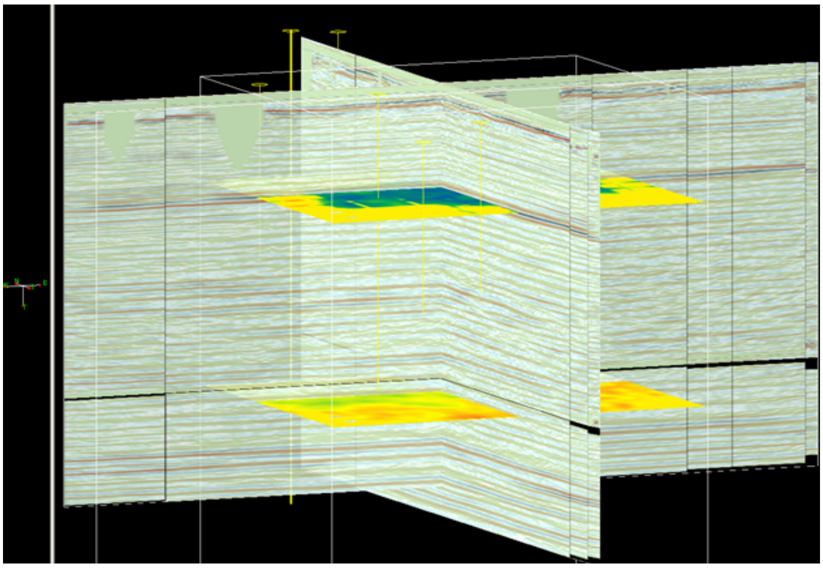

Figure 2. Slices from the P-wave volume imaged across the injection pad. The lower time slice correlates with the Cardium Formation.

Discussion

The baseline surface seismic and vertical seismic profile data have yielded high quality subsurface images of the Penn West CO_2 injection pilot. The sparse surface seismic program integrated with vertical seismic profiles with permanent sensors is a cost-effective and effective approach to time-lapse monitoring.

Acknowledgements

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References

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