Violet Grove CO_2 Injection Project: Monitoring with Timelapse VSP Surveys

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Abstract

At the Violet Grove pilot project, near Drayton Valley, Alberta, CO_2 is being injected into the Cardium Formation in the Pembina Oil Field for enhanced recovery and carbon sequestration purposes. The reservoir is being monitored for changes using simultaneously acquired timelapse multicomponent surface and borehole seismic surveys. The baseline survey was acquired in March 2005 prior to CO_2 injection. The second survey was acquired in December 2005 after eight months of CO_2 injection. The borehole seismic data displays higher bandwidth and increased resolution as compared to the surface seismic data; in particular, the PS-wave borehole seismic data shows significantly better results. Prelimary comparisons between the baseline and monitor borehole seismic surveys show an increase in amplitudes at the reservoir.

Introduction

Many of Western Canada's major oil and gas fields have been depleted through primary production and secondary recovery methods. Injecting CO_2 into a reservoir can enhance oil recovery (EOR) and has the potential benefit of CO_2 sequestration, which reduces greenhouse gas emissions into the atmosphere. The average Canadian produces about 5 tonnes of CO_2 per year, which is about 150 Mt per year for the country (Government of Canada, 2006). Bachu and Shaw (2004) estimate that Western Canada has a practical CO_2 storage capacity of about 3.3 Gt in its oil and gas reservoirs; 450 Mt of this could be from CO_2 injected into hydrocarbon reservoirs for EOR. However, in order to claim a reduction in CO_2 emissions, the injected CO_2 must be monitored to prove that it is being trapped in these reservoirs.

Time-lapse surface seismic or borehole seismic surveys have been used to monitor injected CO_2 successfully in Anadarko's Patrick Draw Field (O'Brien et al., 2004), Encana's Weyburn Field (Li, 2003), and the Utsira Sand project in the North Sea (Skov et al., 2002). At Violet Grove, the injected CO_2 is being monitored using sparse multicomponent surface seismic lines coupled with a borehole seismic array. Together, these provide lateral coverage of the survey area as well as high resolution images near the observation well.

Background

The Violet Grove site, near Drayton Valley, Alberta was selected for a CO_2 EOR and storage study in conjunction with PennWest Petroleum and the Government of Alberta. The reservoir is located in the Cardium Formation in the Pembina Field. The dominant fracture direction in the reservoir is northeast-southwest. It is expected that the CO_2 will preferentially flow in those directions.

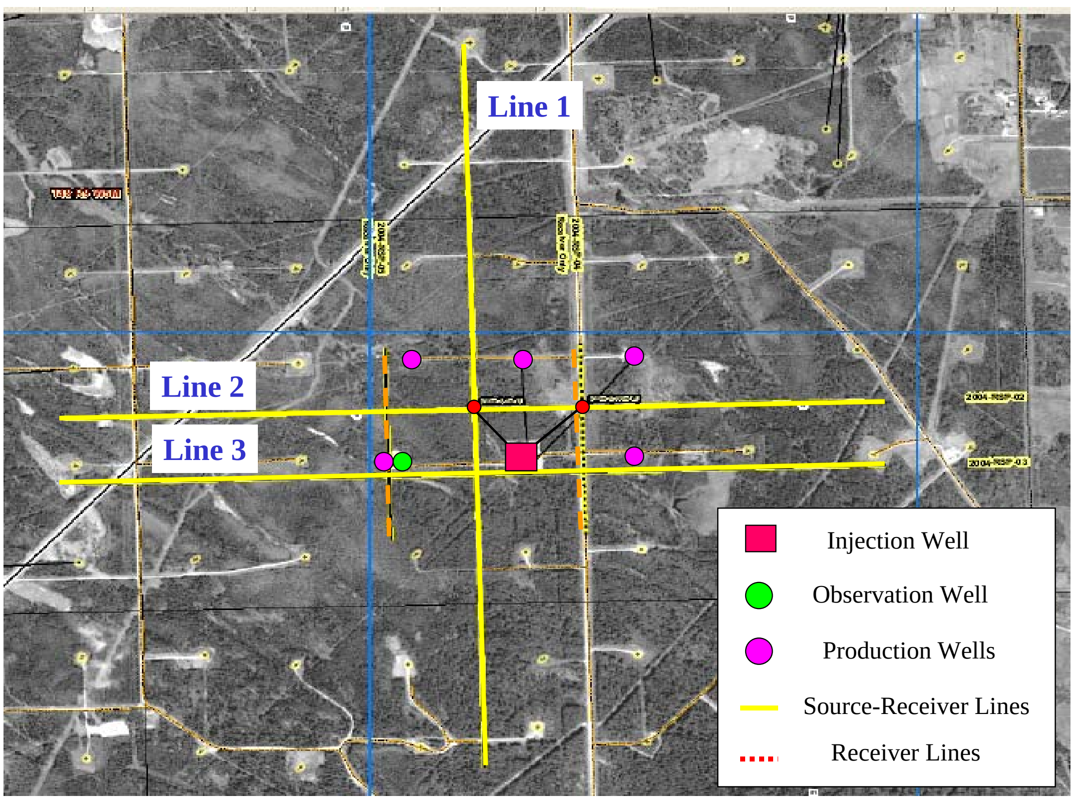

Figure 1. Aerial photo of Violet Grove area with annotated wells and seismic lines.

A permanent 8 level geophone array was cemented into an old production well in February 2005. The array extends from a depth of 1497 to 1640 m with the deepest geophone sitting in the Upper Cardium Formation. The baseline seismic survey was acquired in March 2005 and consisted of two east-west source-receiver lines and one north-south source-receiver line (Fig. 1). The geophone array was live throughout the surface seismic acquisition and recorded three components for each shot. CO_2 injection into the Upper Cardium began after the baseline survey was acquired; approximately 70 tonnes of CO_2 are being injected per day. The first monitor survey was acquired in December 2005. The source locations were repeated with an accuracy of 10 cm in most cases.

VSP processing

To maintain consistency, the baseline and monitor surveys were processed consecutively using the same processing flow (Fig. 2). An anisotropic velocity model was built using a calibrated sonic log from a nearby production well. The anisotropy at the receivers was analyzed using slowness and polarization angles derived from the data (Horne and Leaney, 2000). The average values obtained for epsilon and delta were 0.14 and 0.0075 respectively. These values were used as a starting point when the velocity model was inverted for anisotropy. A least squares vector wavefield separation technique and the anisotropic velocity model were used to separate the data into the following components: down and up P, down and up Sv, and down and up Sh (Leaney, 2002). The upgoing P and Sv wavefields from each survey were migrated with the same anisotropic velocity model and a 1D VTI Kirchhoff migration algorithm.

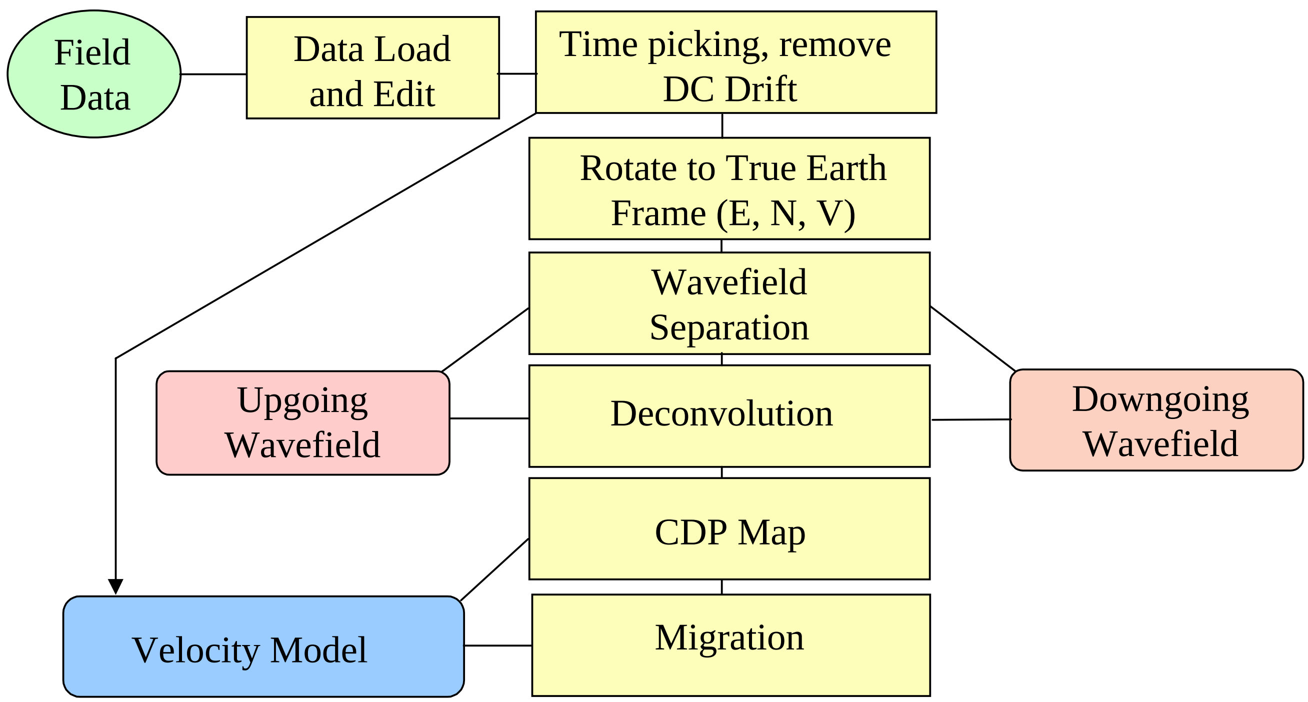

Figure 2. VSP processing flow used for the baseline and monitor surveys.

Figures 3 and 4 show the comparison between the surface and borehole seismic data for the east-west line that runs closest to the monitor well (Line 3). Figure 3 displays the tie between the P-wave surface and borehole seismic data, and Figure 4 shows the comparison between the Sv-wave surface and borehole seismic data. While both of the VSP images show increased vertical and lateral resolution, the Sv-wave VSP data provides a substantially better image of the subsurface than the Sv-wave surface seismic data. Both of the migrated VSPs clearly image the Cardium Formation for a radius of about 100 m around the observation well.

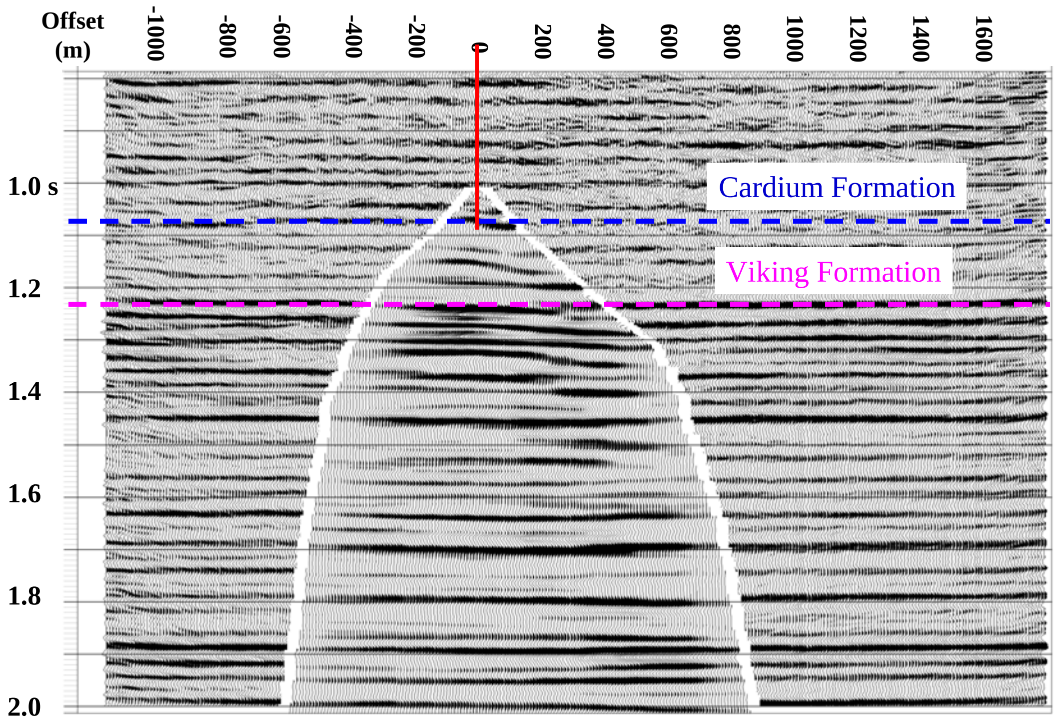

Figure 3. Comparison of the baseline P-wave surface and borehole seismic data for Line 3.

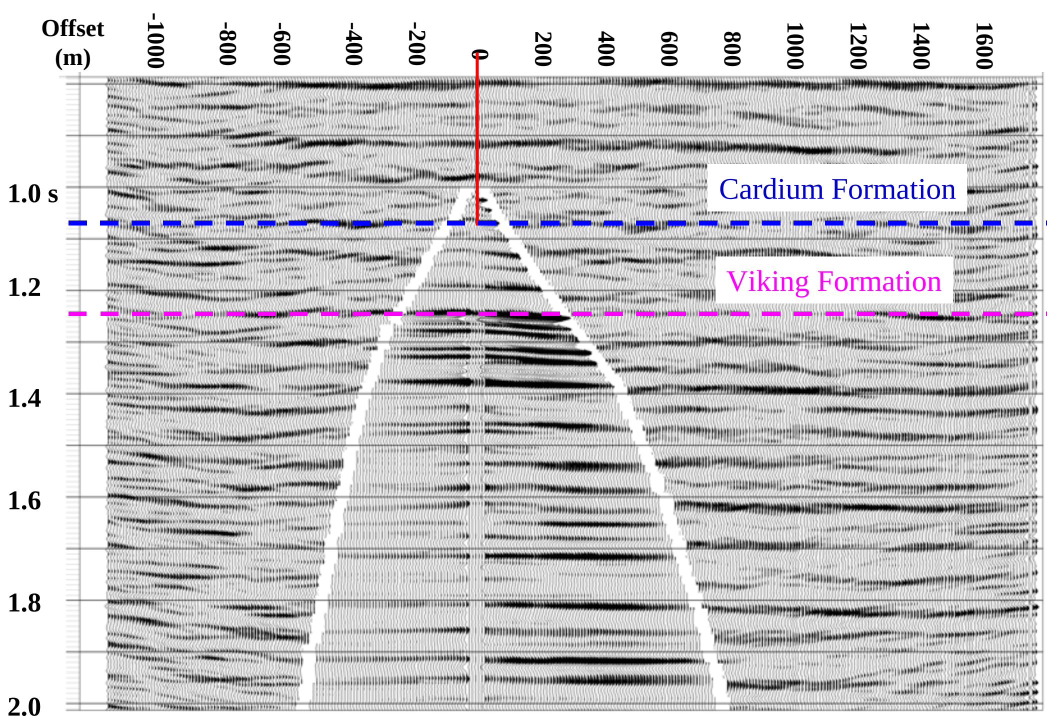

Figure 4. Comparison of the baseline Sv-wave surface and borehole seismic data for Line 3.

Comparison of the baseline and monitor survey results

At this time, the CO_2 has not broken through to the production well adjacent to the monitor well. Based on the dominant fracture direction in the reservoir, changes related to the CO_2 injection should initially appear on the east-west line north of the monitor well (Line 2) or the north-south line (Line 1). Line 2 was selected for the initial timelapse analysis as it runs above both of the CO_2 injectors (Fig. 1).

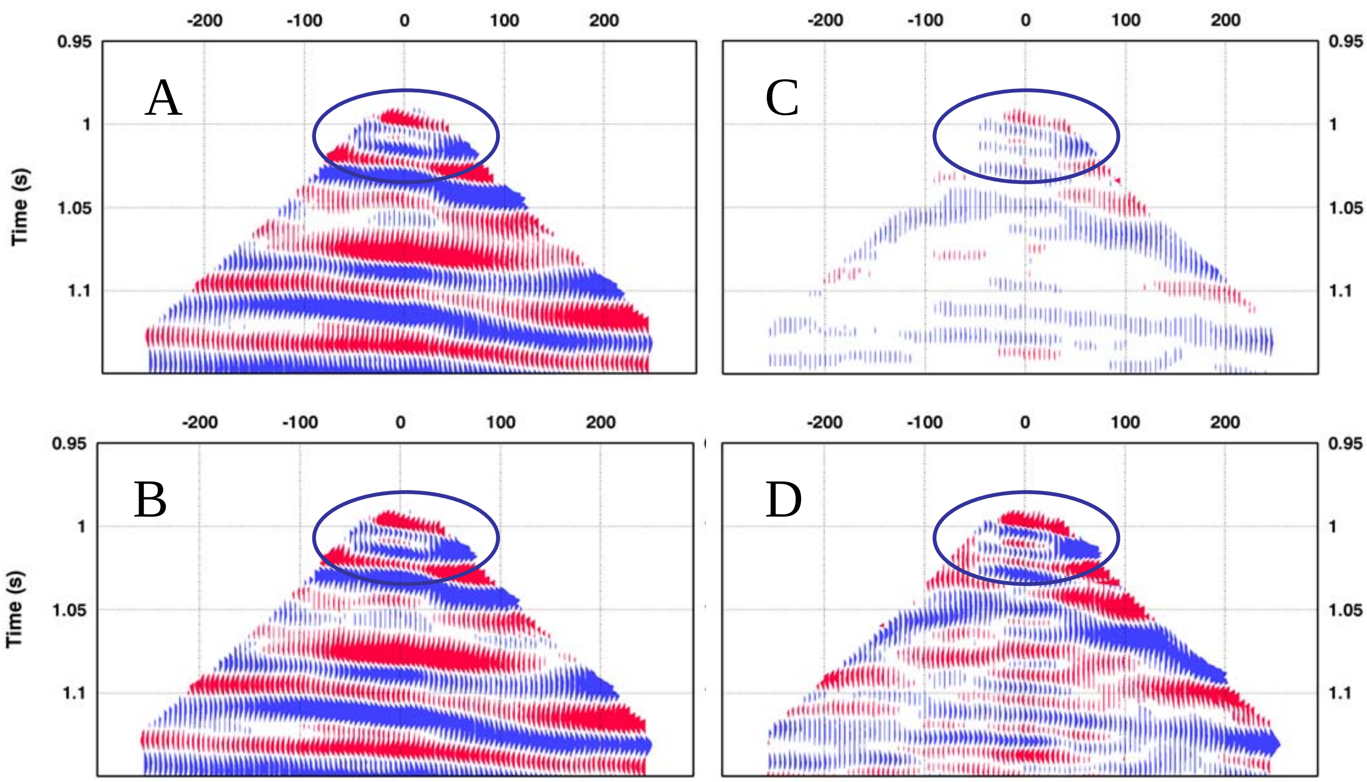

Figure 5. Comparison of the baseline and monitor migrated images from Line 2. The Cardium is located at the top of the image. A is the baseline, B is the monitor, C is the difference between the monitor and the baseline, and D is the difference display with the amplitudes scaled up 4 times.

Figure 5 shows a comparison of the baseline and monitor migrated images from Line 2 as well as the difference between the images (Fig. 5C and 5D). The amplitudes at the Cardium event have doubled in the eight months since the baseline survey; this suggests that the CO_2 flood has progressed about 335 m southwest of the injector towards the monitor well. Future work includes modeling the changing response of the reservoir as the CO_2 is injected using the Biot-Gassman relationship. Differences seen below about 1.1 s are due to differences in the frequency content of the surveys. However, this is a preliminary result, and it has not yet been correlated to the surface seismic results.

Conclusions

The VSP data from the baseline surveys image the reservoir for a radius of 100 m around the monitor well and have increased bandwidth and resolution compared with the surface seismic data as can be seen in Figures 3 and 4. In the case of the Sv-wave data, the borehole data provides significantly better results than the surface seismic data.

Preliminary results from the timelapse analysis show an increase of 30 to 60% in the reservoir reflectivity amplitudes in the eight months between the baseline and monitor surveys. This indicates that the CO_2 flood has progressed southwest of the injector probably along the dominant fracture trend in the area.

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