Interpretation of baseline surface seismic data at the Violet Grove CO_2 injection site, Alberta

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ABSTRACT

Time-lapse seismic technology has been implemented in the Penn West pilot project, in west-central Alberta, Canada, to monitor the CO_2 storage in the Cardium Formation. A multi-component 3D surface seismic baseline survey was acquired in March 2003. An interpretation using both PP and PS seismic data has been made. Four horizons of Ardley, Cardium, Blackstone, and Viking Formations have been picked. At well 102/7-11-48-9, the top of Cardium Sand correlates to a weak peak at approximately 1043 ms and 1690 ms in the PP and PS survey, respectively; the top of the Blackstone Formation correlates to a strong trough at 1060 ms and 1714 ms in the PP and PS survey, respectively; There exists a small amplitude anomaly in the Cardium event around the observation well and the injection pad in the PP data. V_p/V_s values were calculated from the compression and shear sonic logs: The good reservoir of the Cardium Formation has a low V_p/V_s value (1.6-1.8); the shale above and below the Cardium Formation has a relatively high V_p/V_s value (1.8-2.0). The average V_p/V_s between Ardley and Viking horizons is approximately 2.0.

INTRODUCTION

The time-lapse seismic technique has been applied successfully to monitor the movement of fluid, pressure fronts, and water-oil contact during hydrocarbon production (e.g. Meyer, 2001; Gouveia, 2004). Some case studies on monitoring CO_2 storage in geological formations by time-lapse seismic also have been described in recent years (Davis, 2003; Raef, 2004). In Canada, an innovative CO_2 monitoring strategy has been implemented in the Penn West pilot in Alberta, which involved a multi-component 3D surface seismic program integrated with active and passive monitoring using geophones permanently cemented into an observation well (Lawton, 2005).

The pilot site is located at the Pembina Oil Field, operated by Penn West Petroleum, 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 bounded by black shales of the Blackstone Formation below and the Wapiabi Formation above. It consists of two lithostratigraphic units: the lower Pembina River Member (an upwardly coarsening sequence, from shale through sandstone to conglomerate), and the upper Cardium Zone Member (a black shale and siltstone interval with pebbly stringers). The total thickness of the Cardium Formation at the site is approximately 20 m. The formation pressure and temperature are 19 MPa and 50 ˚C, respectively. The produced oil in this area is approximately 40 API (Nielsen, 1984). There are 15 wells in the 3D survey area in total. Well 100/7-11-48-9 was chosen as the observation well.

The baseline surface seismic data was shot in March 2005 using a 2 kg dynamite charge. It consists of two parallel, multi-component 2D lines, 400 m apart and oriented east west, and one orthogonal multi-component 2D north-south line of 3 km length, respectively. Two additional short north-south receiver lines were also included (Figure 1). During acquisition, all lines were live with a receiver interval of 20 m, and a source interval of 40 m. Veritas DGC of Calgary processed the 2D lines as individual lines and also as a sparse 3D volume, which covers the injection pad. Pre-stack Kirchhoff migration datasets of vertical, radial and transverse components were delivered. Only the filtered/scaled noise attenuated PP and PS 3D data were interpreted here.

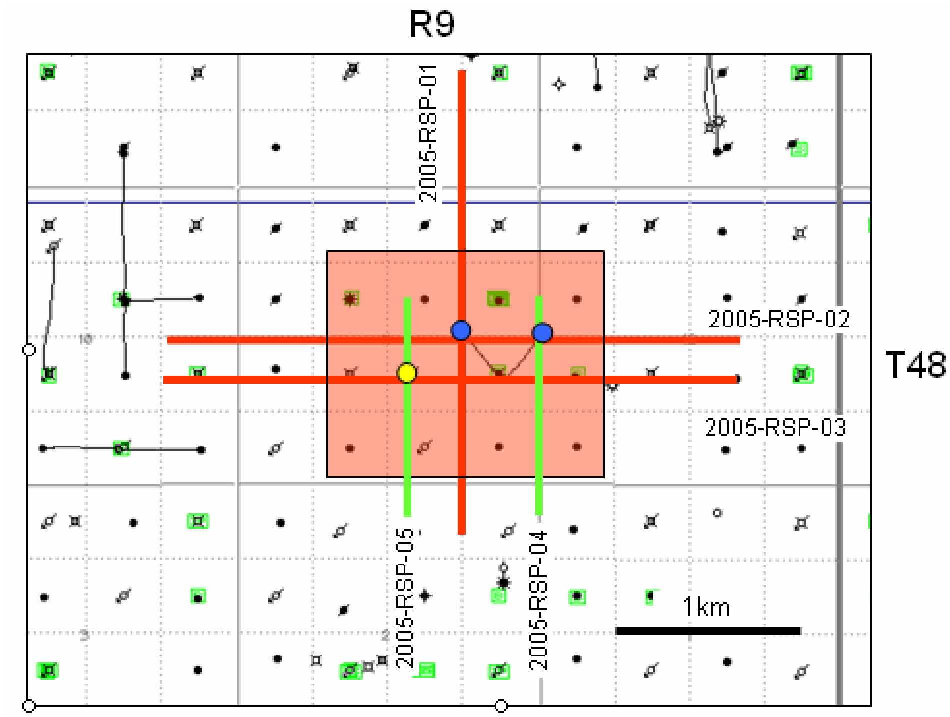

FIG. 1. Map showing the Penn West CO_2 injection site. Multi-component seismic lines are shown in red, receivers-only lines are shown in green. The 3D survey is shown by a semi-transparent red rectangle. The observation (VSP) well location is shown by a yellow circle, and the CO_2 injection well locations are shown by blue circles.

INTERPRETATION

Synthetic seismogram and PP-PS correlation

A dipole sonic log was available from well 102/7-11-48-9, which penetrated the top of the Blackstone Formation. The PP and PS wavelets extracted from the seismic data at the well location were used to generate the PP and PS synthetic seismograms. The top of the Cardium sand correlates to a weak peak at approximately 1043 ms and 1690 ms in the PP and PS survey, respectively; the top of Blackstone Formation correlates to a strong trough at 1060 ms and 1714 ms in the PP and PS survey, respectively (Figure 2). In order to correlate the PP and PS data well, the strong peak at 360 ms and 685 ms in PP and PS data, respectively, which correlates to a depth of approximately 440m at the well, was picked. This reflection is from the Ardley Coal Zone. Figure 3 shows the un-stretched, un-squeezed PP seismic and synthetic seismogram and the squeezed PS seismic and synthetic seismogram used to correlate the PP and PS datasets.

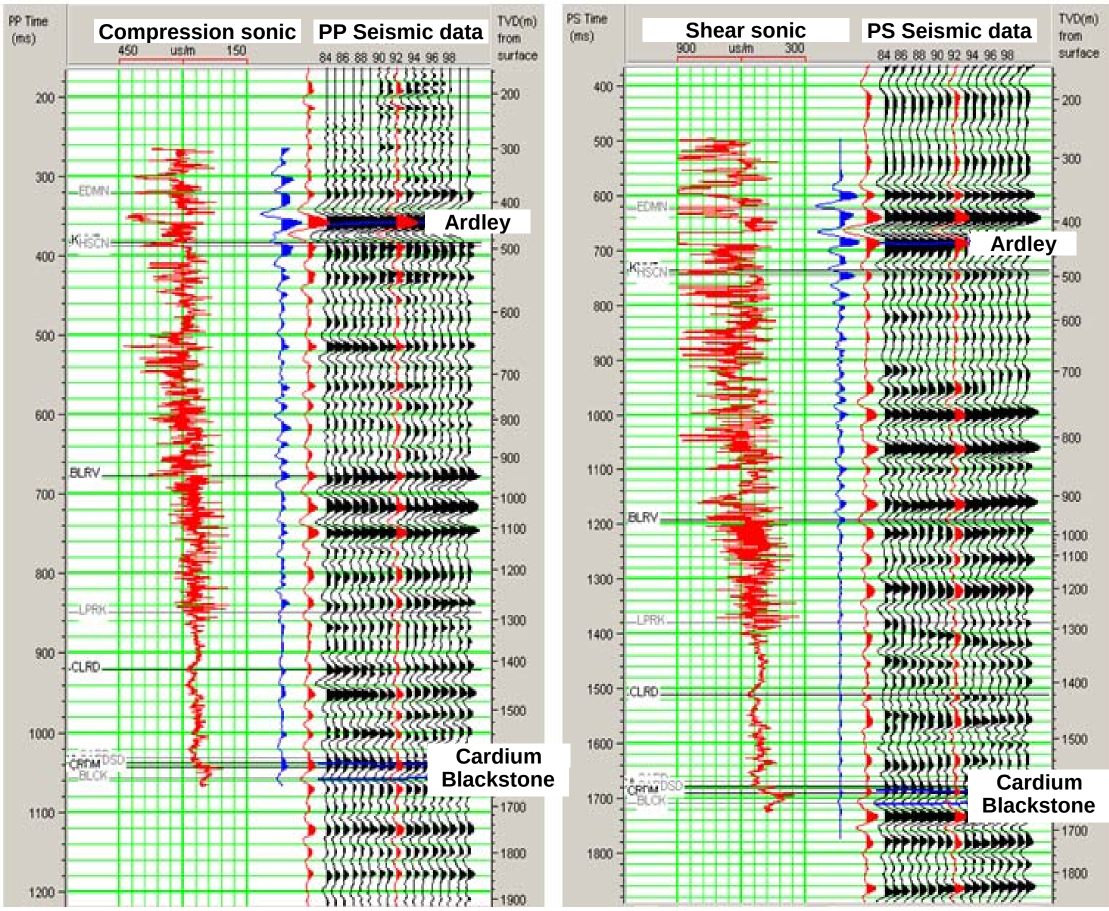

FIG. 2. PP (left) and PS (right) seismic correlation at well 102/7-11-48-9. The blue trace is synthetic seismogram, the red trace is the seismic trace extracted from the seismic data at the well location.

In order to correlate the deep formations with the seismic events, the digital compression-sonic log of well 102/08-14-48-9W5/0, which penetrated the top of the Banff Formation, was projected into the 3D survey. The synthetic seismogram ties the seismic data very well, and the horizons of Cardium and Blackstone picks defined by the synthetic seismogram of this well match very well with the horizons identified from the observation well. The top of the Viking Formation correlates to a strong peak at 1232 ms in PP data. The top of the Viking Formation also correlates to a strong peak at approximately 1950 ms for PS data, which was defined by comparing the reflection character of the PP and PS data (Figure 4).

PP and PS data interpretation

Four horizons, which correspond to the Ardley Coal Zone, the tops of Cardium, Blackstone, and Viking Formations, were picked, and their time structural maps are shown (Figures 5, 6, 7, and 8). All the maps are very flat in PP and PS data. This means the formations are very flat in this area. On the Cardium and Blackstone structural maps, the central part of the 3D survey is slightly lower than areas near the edges of the survey. A small amplitude anomaly was shown around the observation well and the injection pad on the PP amplitude maps of the Cardium and Blackstone horizons (Figures 9 and 10).

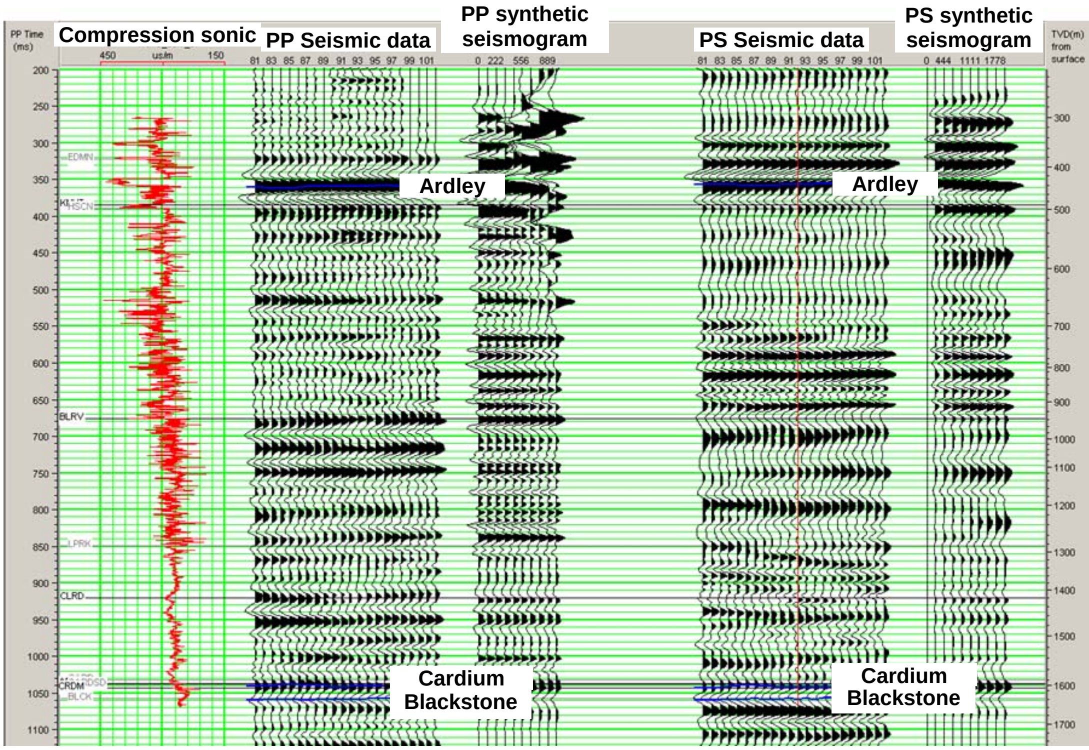

FIG. 3. PP and PS synthetic seismogram at well 102/7-11-48-9.

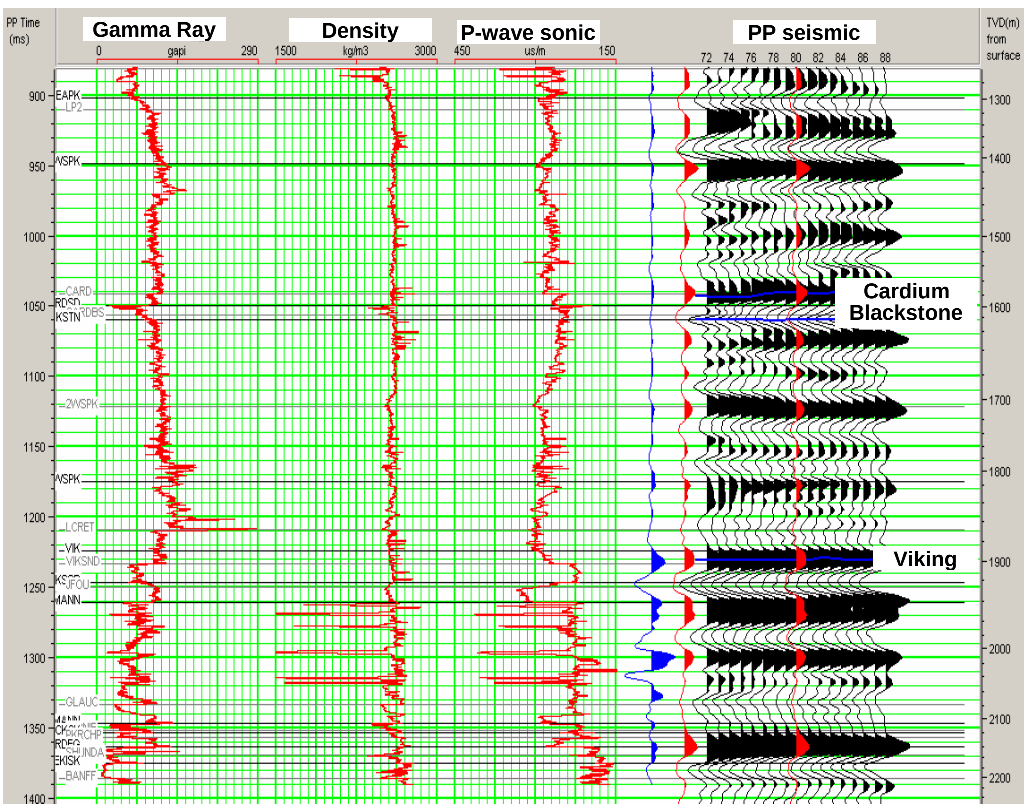

FIG. 4. PP seismic correlation at well 102/08-14-48-9W5/0 and horizon picking. The blue trace is the synthetic seismogram, the red trace is the seismic trace extracted from the seismic data at the well location.

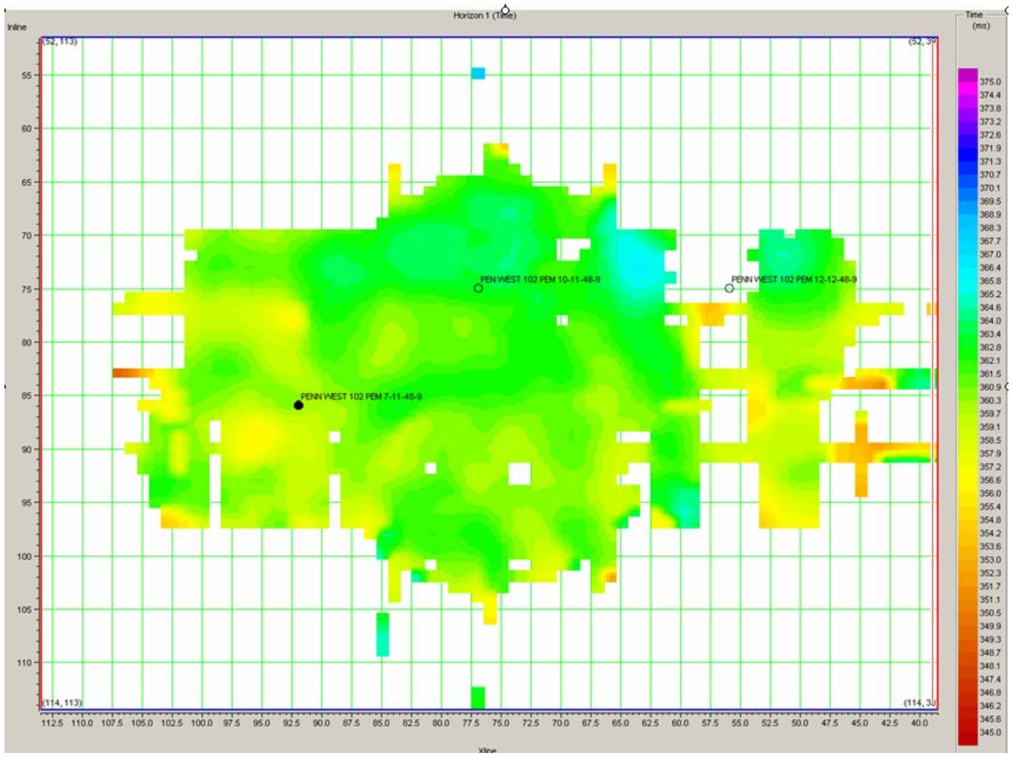

FIG. 5a. PP time structural map of the Ardley horizon. The observation well is shown by a solid circle, the injection wells are shown by open circles; the gaps are due to the absence of data.

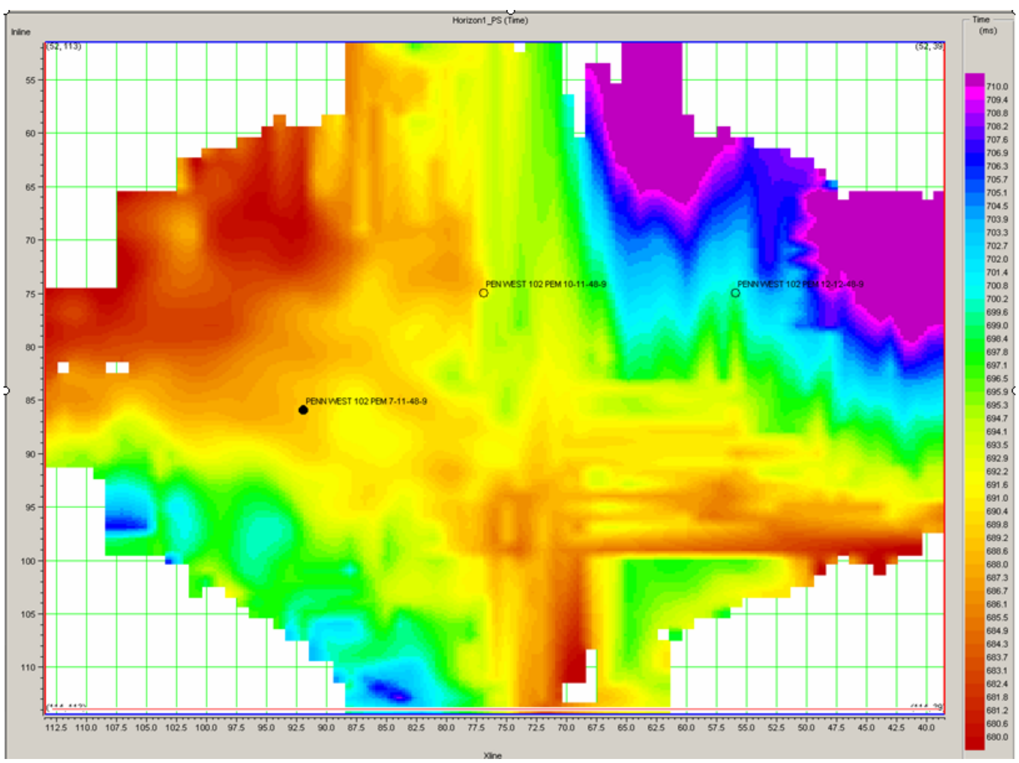

FIG. 5b. PS time structural map of the Ardley horizon. The observation well is shown by a solid circle, the injection wells are shown by open circles.

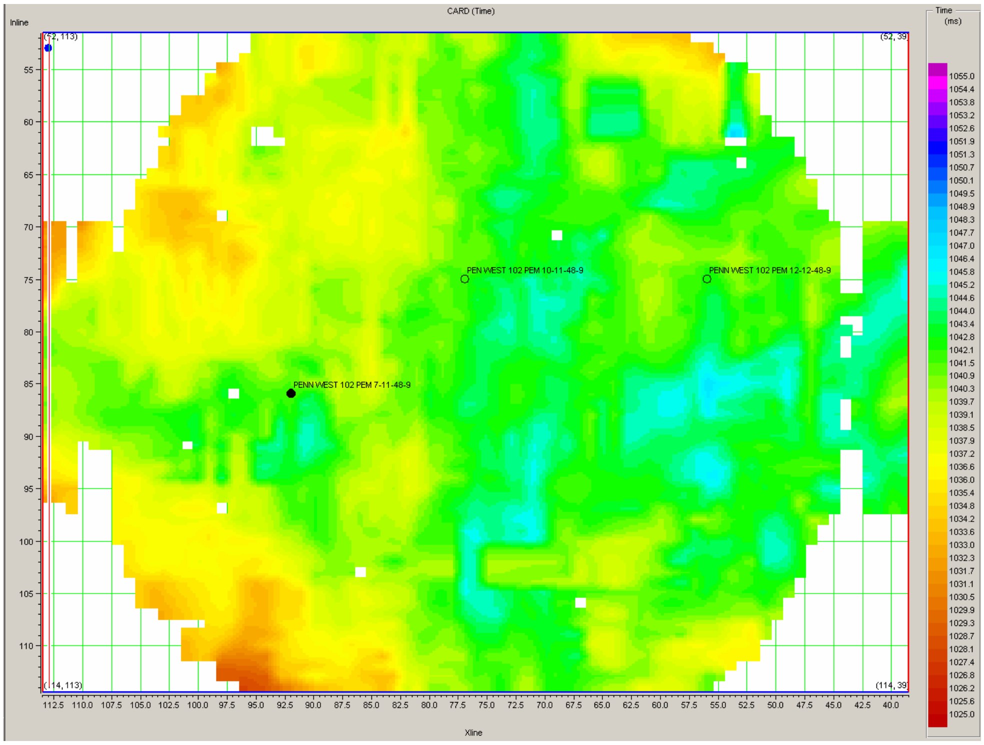

FIG. 6a. PP time structural map of the Cardium horizon. The observation well is shown by a solid circle, the injection wells are shown by open circles.

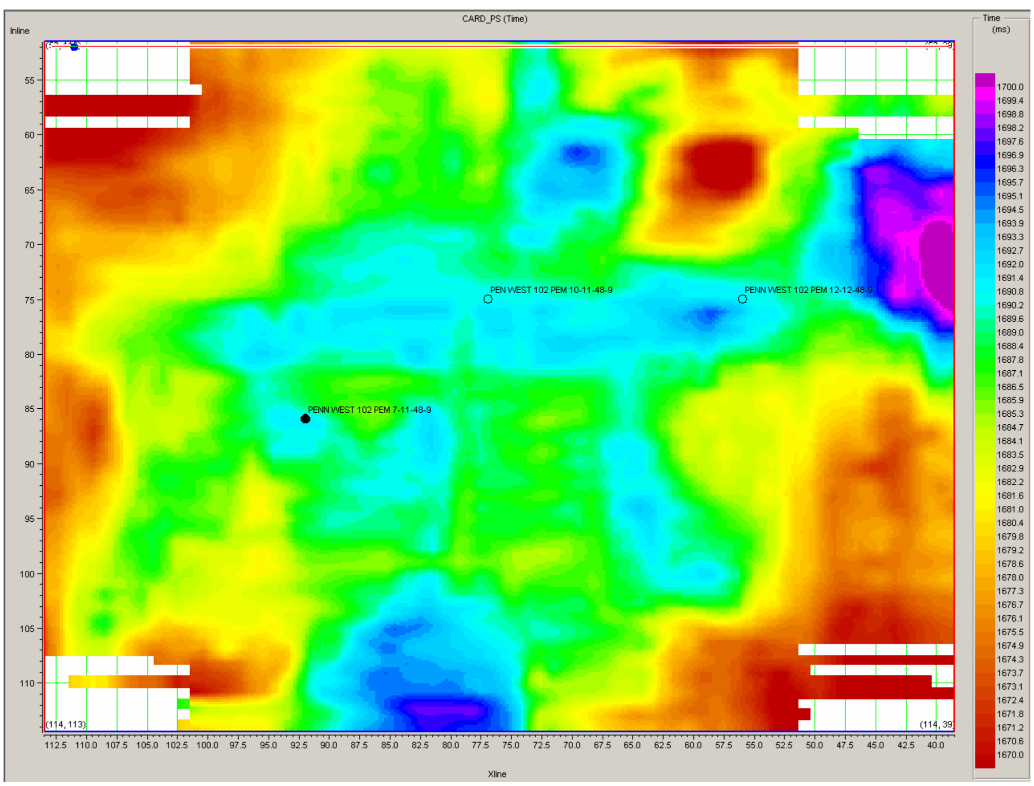

FIG. 6b. PS time structural map of the Cardium horizon. The observation well is shown by a solid circle, the injection wells are shown by open circles.

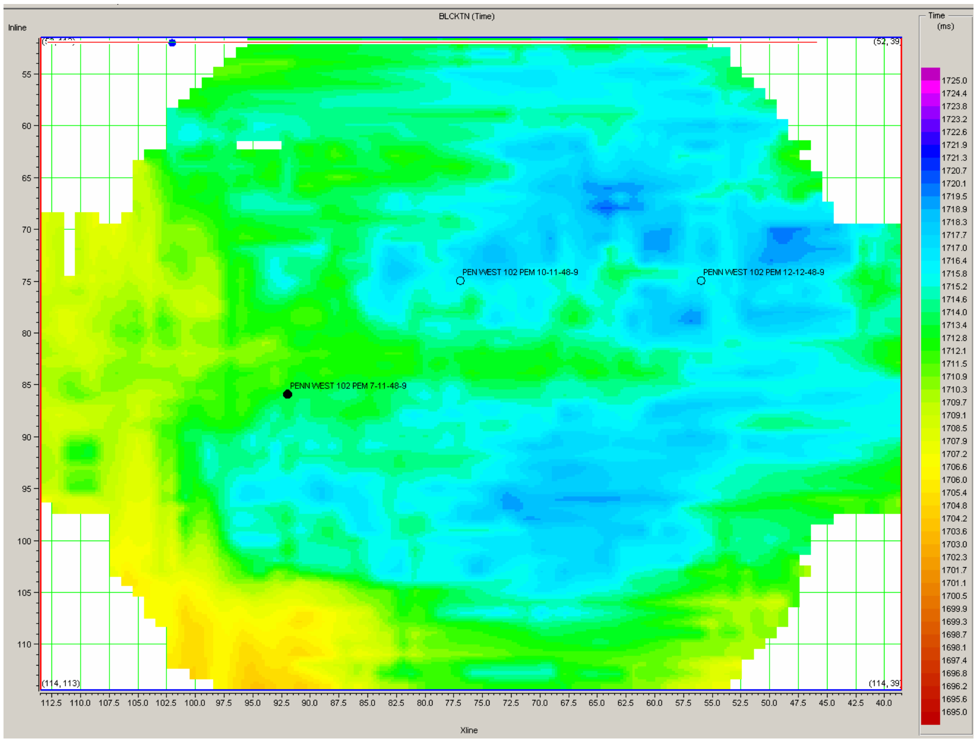

FIG. 7a. PP time structural map of the Blackstone horizon. The observation well is shown by a solid circle, the injection wells are shown by open circles.

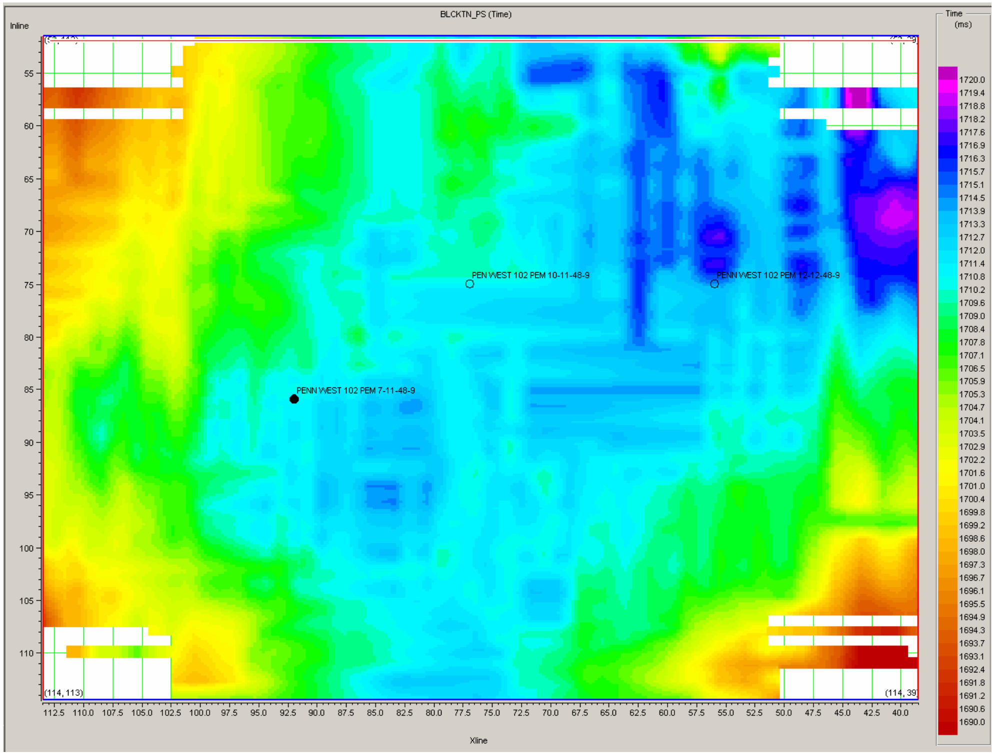

FIG. 7b. PS time structural map of the Blackstone horizon. The observation well is shown by a solid circle, the injection wells are shown by open circles.

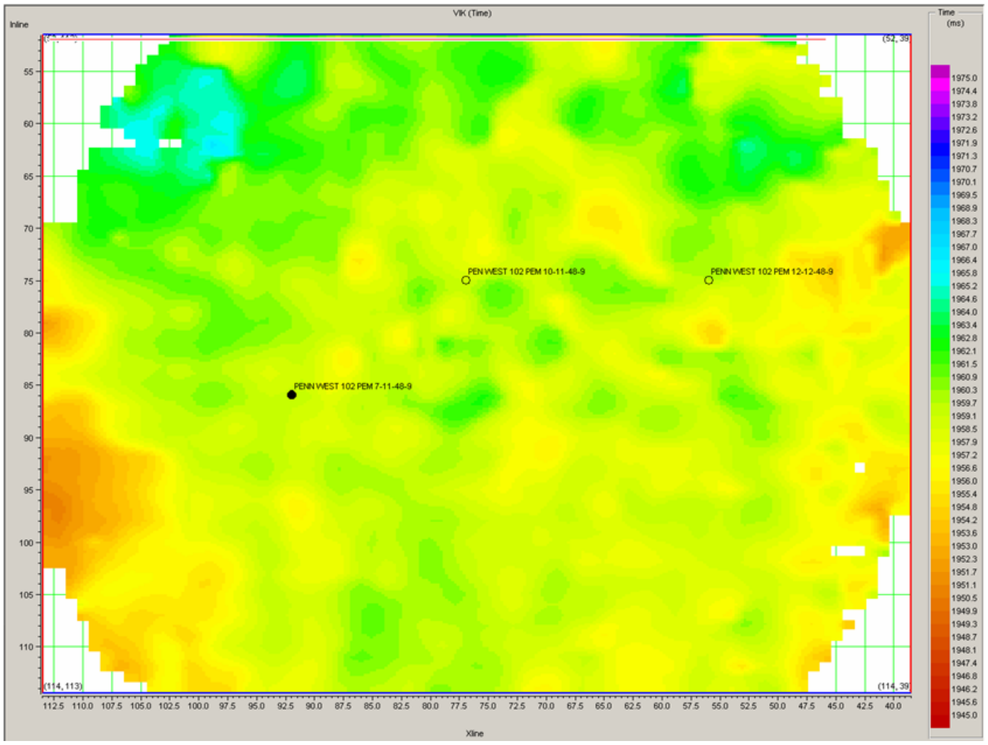

FIG. 8a. PP time structural map of the Viking horizon. The observation well is shown by a solid circle, the injection wells are shown by open circles.

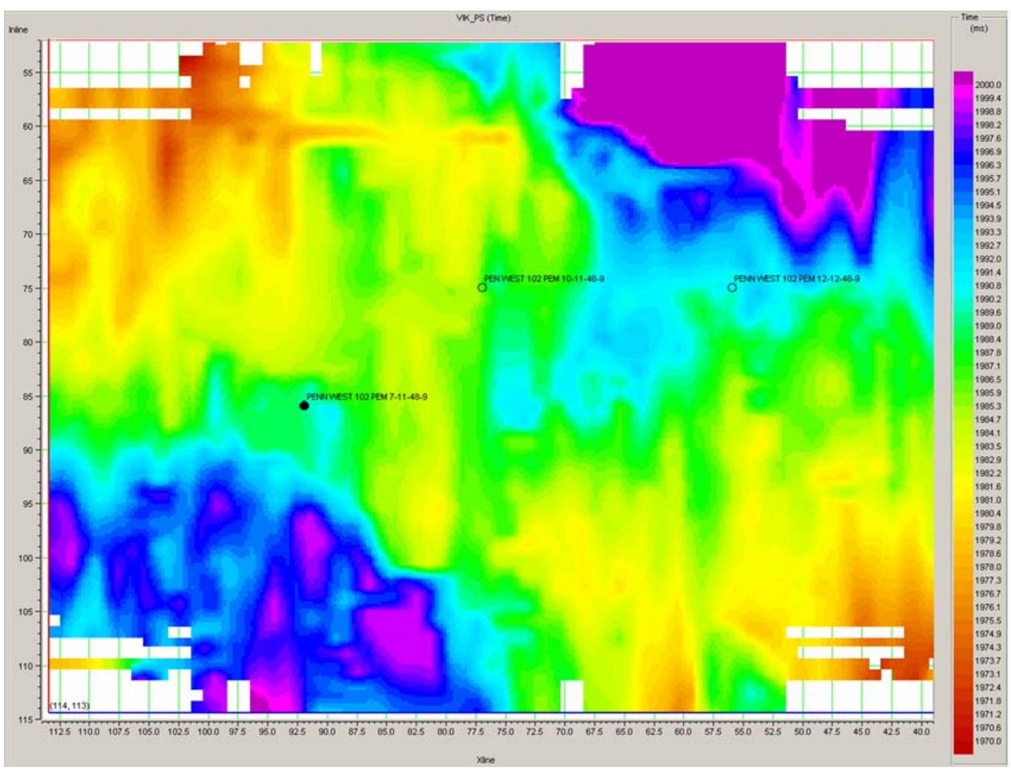

FIG. 8b. PS time structural map of the Viking horizon. The observation well is shown by a solid circle, the injection wells are shown by open circles.

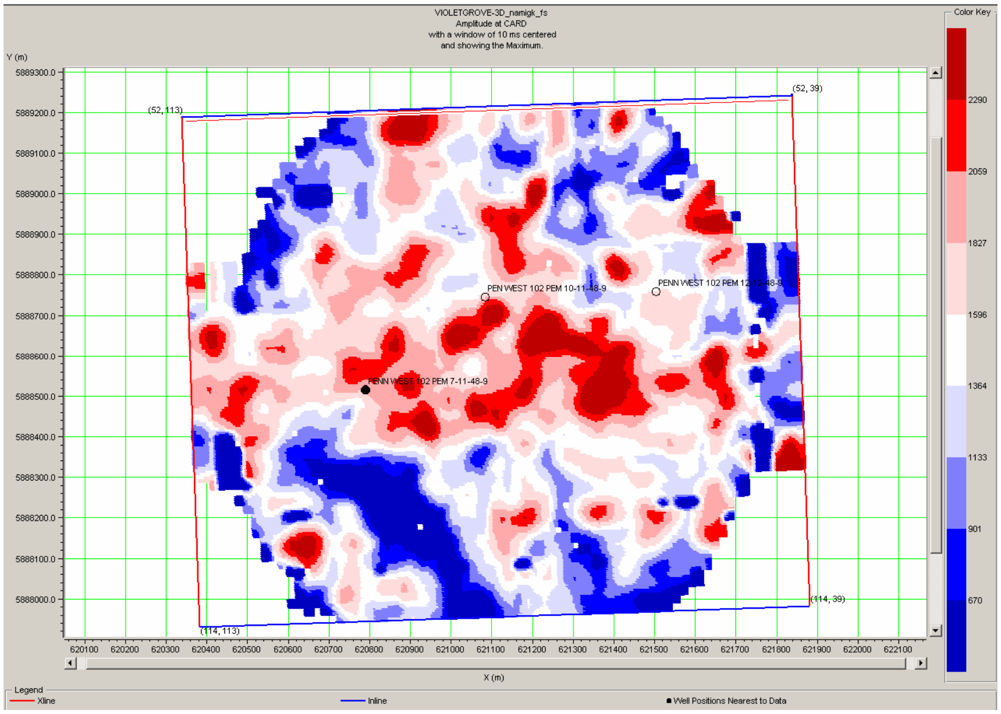

FIG. 9a. Maximum amplitude map of the Cardium horizon in PP data. The observation well is shown by a solid circle, the injection wells are shown by open circles (A 10ms time gate centered at the Cardium horizon was used).

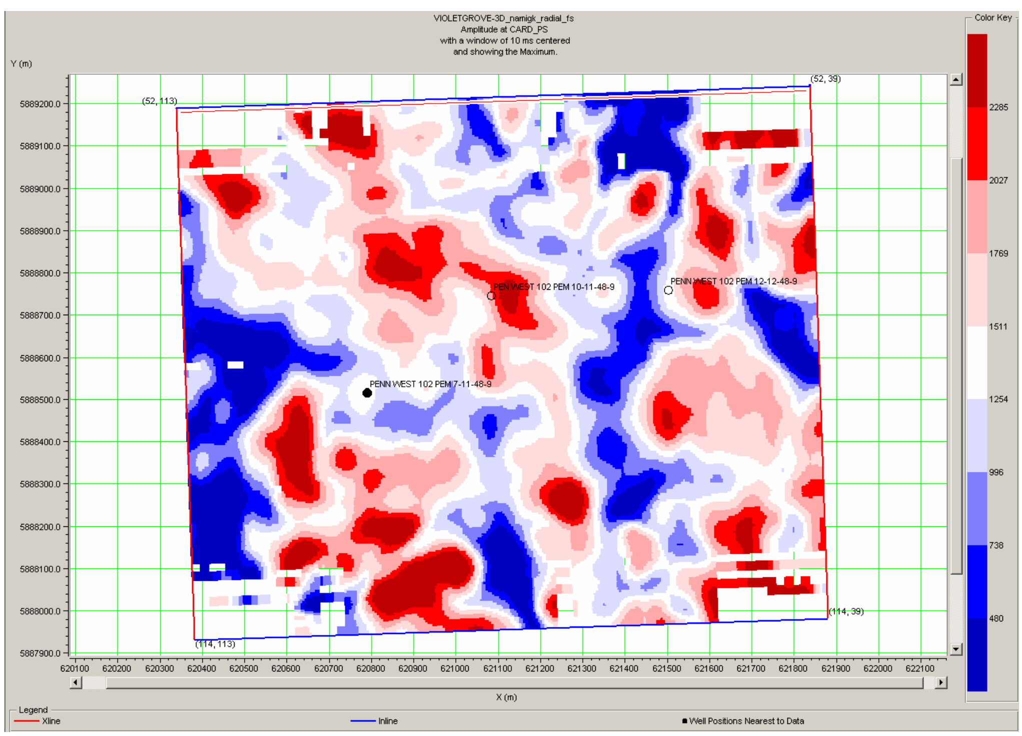

FIG. 9b. Maximum amplitude map of the Cardium horizon in PS data. The observation well is shown by a solid circle, the injection wells are shown by open circles (A 10ms time gate centered at the Cardium horizon was used).

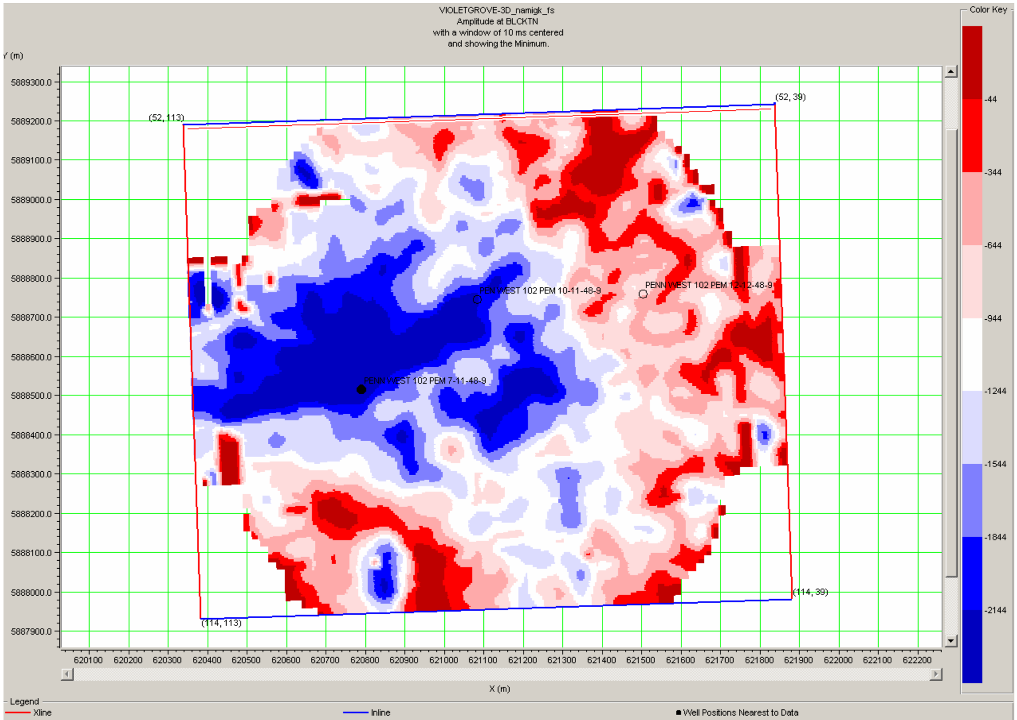

FIG. 10a. Maximum negative amplitude map of the Blackstone horizon in PP data. The observation well is shown by a solid circle, the injection wells are shown by open circles. (A 10ms time gate centered at the Blackstone horizon was used).

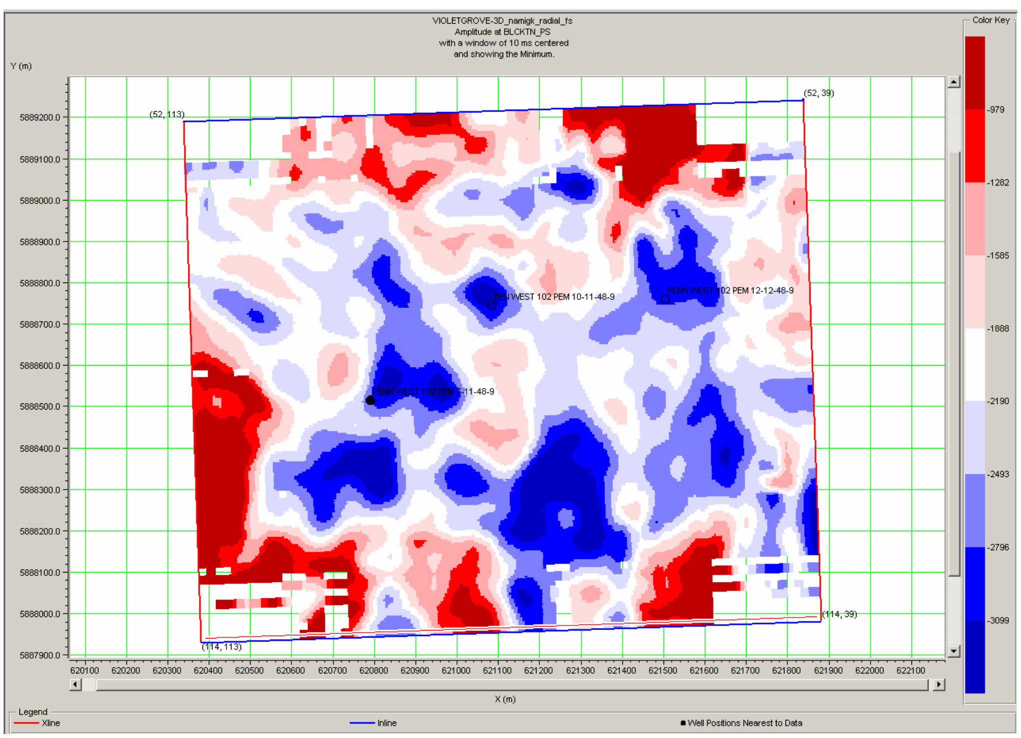

FIG. 10b. Maximum negative amplitude map of the Blackstone horizon in PS data. The observation well is shown by a solid circle, the injection wells are shown by open circles. (A 10ms time gate centered at the Blackstone horizon was used).

Rock properties

The P-wave and S-wave velocities of different lithologies were analyzed by using the sonic logs of well 102/7-11-48-9. The gamma ray values of clean sands range from 33 to 65 API, for P-wave velocities from 4400-4800 m/s and S-wave velocities from 2700-2800 m/s, respectively; the gamma ray values of shales range from approximately 100 to 130 API, with P-wave velocities of 3500-4200 m/s and S-wave velocities of 1700-2500 m/s, respectively. Figure 11 shows a plot of V_p and V_s versus the gamma ray value over the depth interval from 1500 to 1660 m.

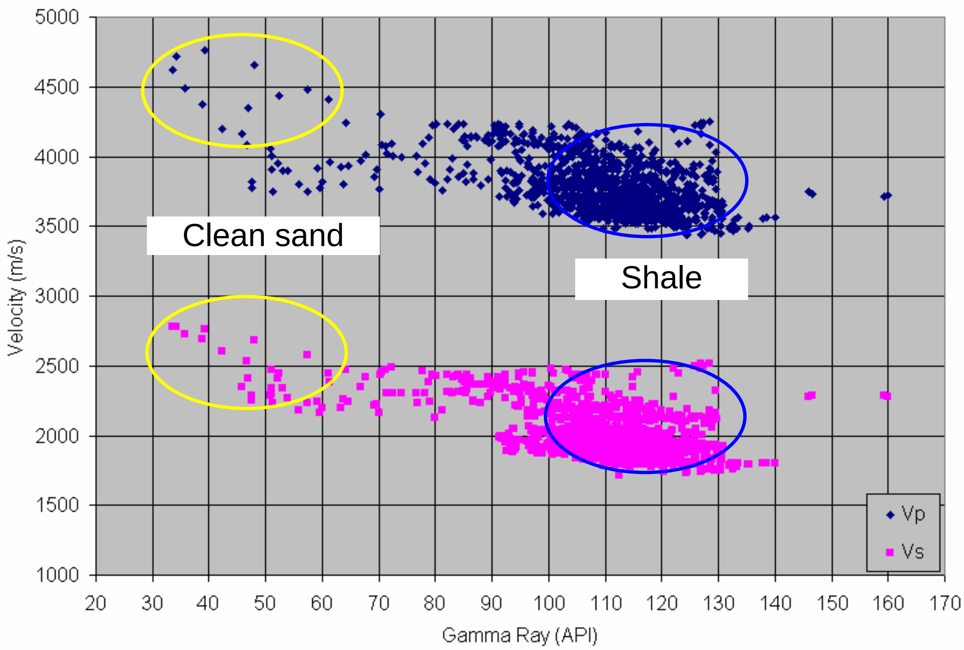

FIG. 11. Cross plot map of Gamma ray value and V_p, V_s over the interval from 1500 to 1660m for well 102/07-11-048-09W5/0.

The V_p/V_s values were also calculated and the cross plot map of measured depth, gamma, and V_p/V_s were shown in Figure 12, and 13. Over the interval from 1500 m to 1665 m, the V_p/V_s value ranges from 1.61 to 2.11. The good reservoir of the Cardium Formation has a low V_p/V_s value (1.6-1.8); the shale above and below the Cardium Formation has a relatively high V_p/V_s value (1.8-2.0).

The average V_p/V_s ratio map was computed from the PP and PS travel times of the interval between Ardley and Viking by using the following equation (Xu, 2004):

$$V_p / V_s = \frac{2 * \Delta T_{ps}}{\Delta T_{pp}} - 1$$

Figure 14 shows an almost constant V_p/V_s ratio of 1.95-2.0, that means the lithology is constant laterally in the 3D survey. This value is similar to that derived from the dipole sonic log (Figure 12).

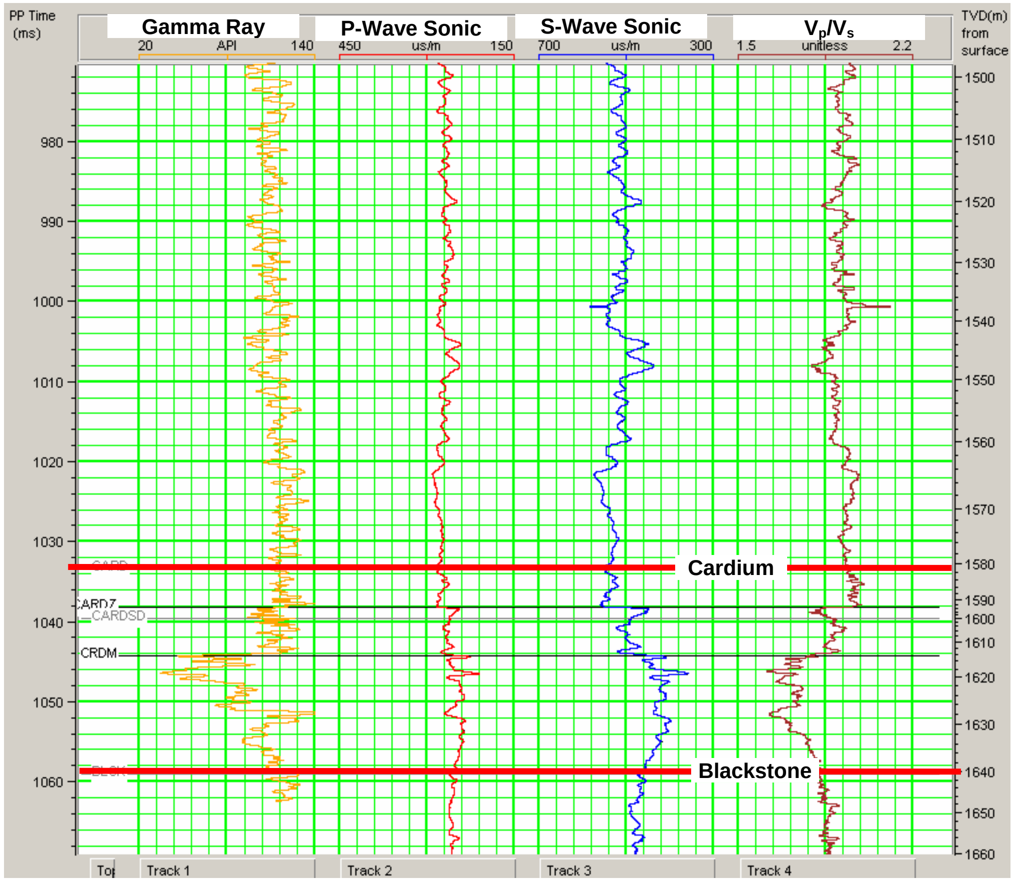

FIG. 12. Logs from well 102/7-11-48-9.

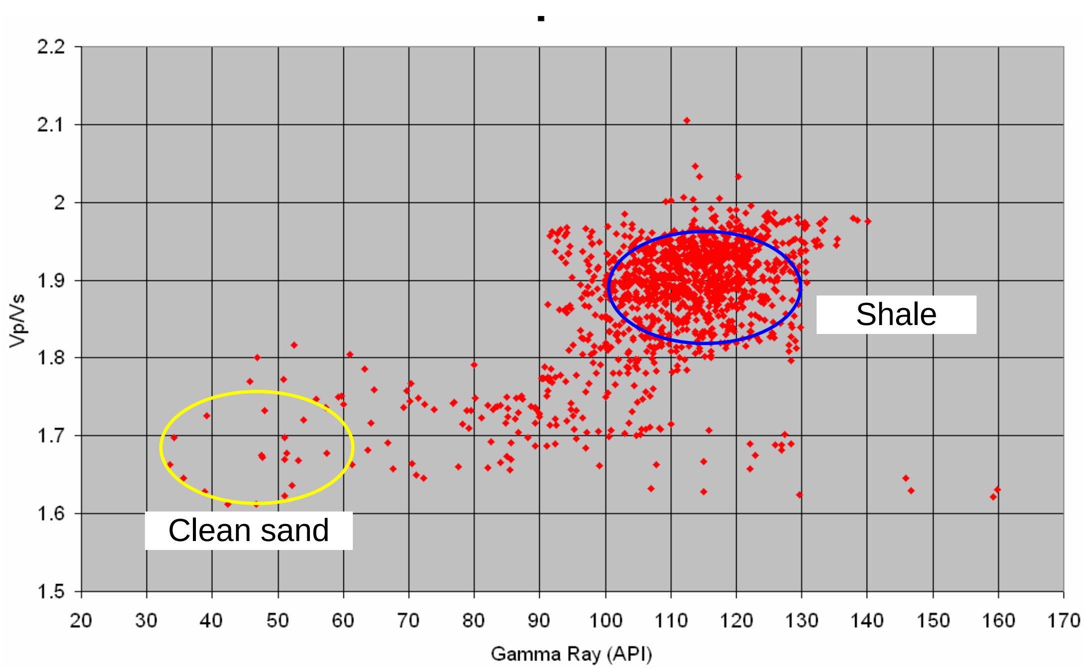

FIG. 13. Cross plot map of gamma ray versus V_p/V_s over the interval from 1500 to 1660 m of well 102/7-11-48-9.

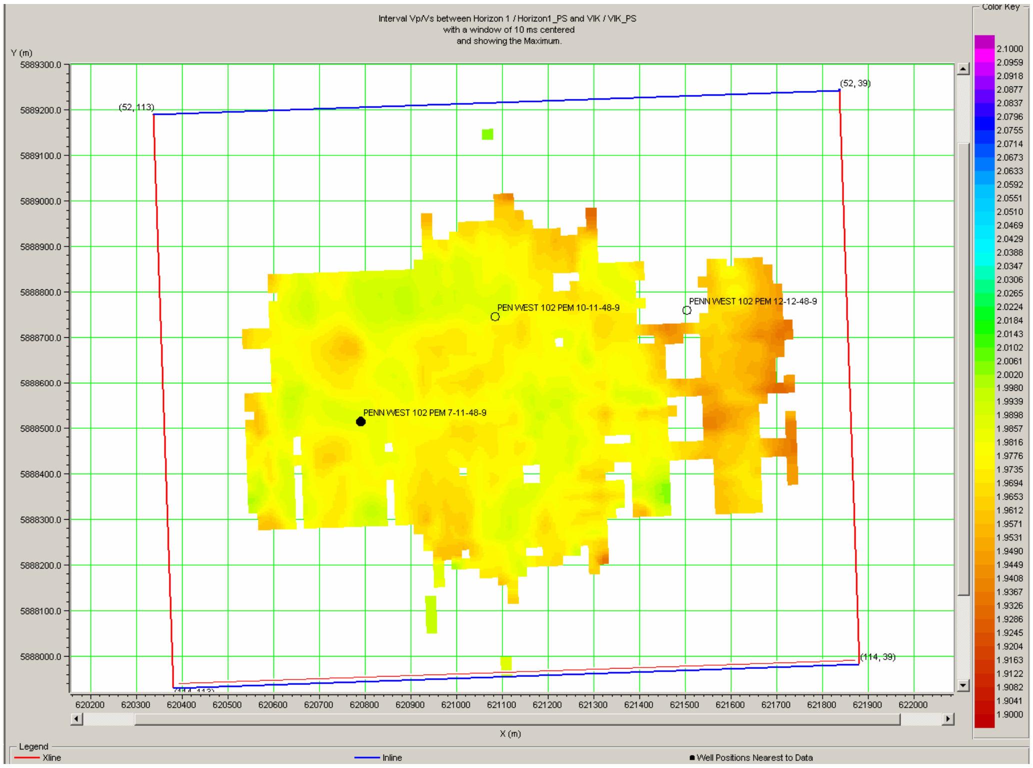

FIG. 14. Average V_p/V_s map between Ardley and Viking horizons. The gaps in the map are due to the absence of data.

CONCLUSIONS

Four horizons (Ardley, Cardium, Blackstone, and Viking) were picked. At the location of well 102/07-11-48-9W5/0, the top of Cardium sand correlates to a weak peak at approximately 1043 ms and 1690 ms in the PP and PS survey, respectively; the top of the Blackstone Formation correlates to a strong trough at 1060 ms and 1714 ms in the PP and PS survey, respectively; There exists a small amplitude anomaly in the Cardium reservoir around the observation well and the injection pad in the PP data. V_p/V_s values were calculated from the compression and shear sonic logs: The good reservoir of the Cardium Formation has a low V_p/V_s value (1.6-1.8); the pure shale above and below the Cardium Formation has a relatively high V_p/V_s value (1.8-2.0). The average V_p/V_s between Ardley and Viking horizons is approximately 2.0.

FUTURE WORK

In the near future, some CO_2 detection methods such as acoustic impedance inversion, AVO etc. will be tested on the baseline data in preparation for analysis of monitor survey data. In early 2006, the first monitor survey will be shot and processed. After that, the monitor survey will be interpreted and compared with the baseline survey.

ACKNOWLEDGEMENTS

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