3D structural effects in the 3C-2D Stolberg seismic profiles

Han-xing Lu, Gary F. Margrave, and Robert R. Stewart

ABSTRACT

A 3C-2D seismic survey was conducted in the western Canadian foothills in 1991 by Shell Canada Ltd. As an experiment for processing 3C structural data at CREWES, the data were reprocessed using the commercial package, ProMAX. It was found that in these 3C-2D seismic survey lines, the same structures could be seen in both radial (P-SV) and transverse (P-SH) components of the migrated-stack sections. In this case, this is probably due to 3D structural effects (the energy comes out of the plane of the 2D line), or possibly due to the anisotropy of the media.

INTRODUCTION

The complex structural geology in the western Canadian foothills is dominated by a series of thrust faults, complex folds, and steeply dipping beds. Most seismic data from structurally complex areas have three-dimensional effects, such as energy from out of the plane that contains the line. The wide variations in elevation suggest massive structures that are three-dimensional and produce additional out-of-plane noise that is difficult to identify and eliminate in a 2D line. Vertical geophones record only the vertical component of the wave field; when large structures with high angles are involved, the reflected compressional wave will have strong horizontal components. The results of this 3C-2D seismic data demonstrate this effect. Structurally induced events can be correctly incorporated only with 3-D acquisition and processing. Ultimately, it may be necessary to conduct 3C-3D seismic survey in geologically complex areas in spite of the high costs involved.

RESULTS

The 3C-2D seismic survey was conducted in 1991 at Stolberg, Alberta in the western Canadian foothills area by Shell Canada Ltd. We obtained shot gathers of P-P, P-S components. Some undocumented pre-processing has been done by Shell; furthermore, it appears that some of original data tapes are missing. Nevertheless, the three components were edited to have the same geometry (same FFID, and the same channels in the same FFID). After editing, there were 227 shots with shot spacing of 50m. The geophone group interval was 25m and every shot had 240 receivers. The line was essentially straight except for the western end (about 10 shots), so it was treated as a normal 2D seismic line.

The shot gather of the vertical, radial, and transverse components are shown in Figures 1a, b, and c. The seismic data are very noisy. From Figure 1d, a portion of a radial shot gather, we can observe some traces with unexpected polarities. In this figure all the offsets are negative. Although the first arrivals should have the same polarity, they do not; for example, the polarity is reversed for some of the channels between offsets -320m and -420m. This implies that there may still be some orientation problems. The three-component orientation test was performed to investigate the separation of the three components. Unfortunately, a record of how the

three geophones were planted is unavailable. The maximum power method was used for this test. The results were not satisfactory. So it was assumed that the data are already separated into vertical, radial and transverse components. From previous experience we know the maximum power method is successful for VSP 3C data and Ocean Bottom Cable 3C data, but not for first arrivals on land 3C seismic data (Guevara & Stewart, 2000).

The vertical component was processed by conventional methods, except for static corrections. Residual static corrections were estimated and applied iteratively. As mentioned, source and receiver elevations change very rapidly along this line (Figure 1), (Rajasekaran & McMechen, 1995). The normal refraction static corrections were applied to the data (using Hampson-Russell Gli3D software to calculate the refraction static corrections), without good results. This is because the geology does not fit the refraction statics model. Therefore only the elevation static corrections were applied to the data. The steps used for residual static corrections were as follows:

Step1: The horizon in the target zone was picked at the basement on the assumption that the basement is flat; the cross-correlation static corrections were applied to the data, and the stack section generated;

Step2: With the stacked section of step 1 as an external model, the external correlation static corrections were created for second residual static corrections.

The final migrated-stacked section is shown in Figure 2. The interval velocities were converted from the picked stacking velocities. Then the interval velocities were tested for migration through reduction by 5%, 8%. The interval velocities used in migration are lower than the interval velocities converted from the stacking velocities because of structure dip effects.
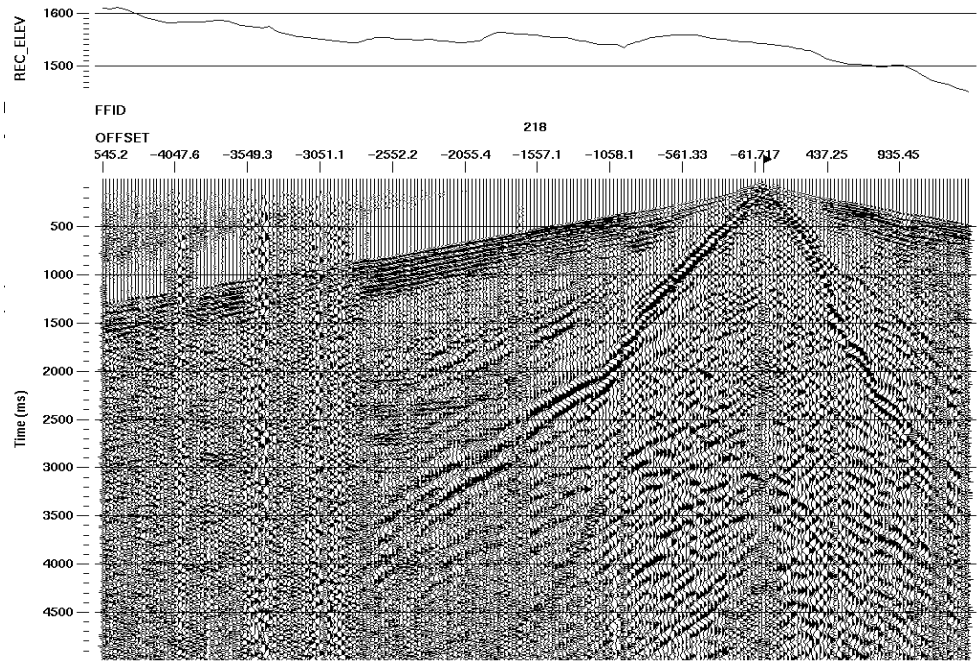
Figure 1a. A single shot gather of the vertical component.
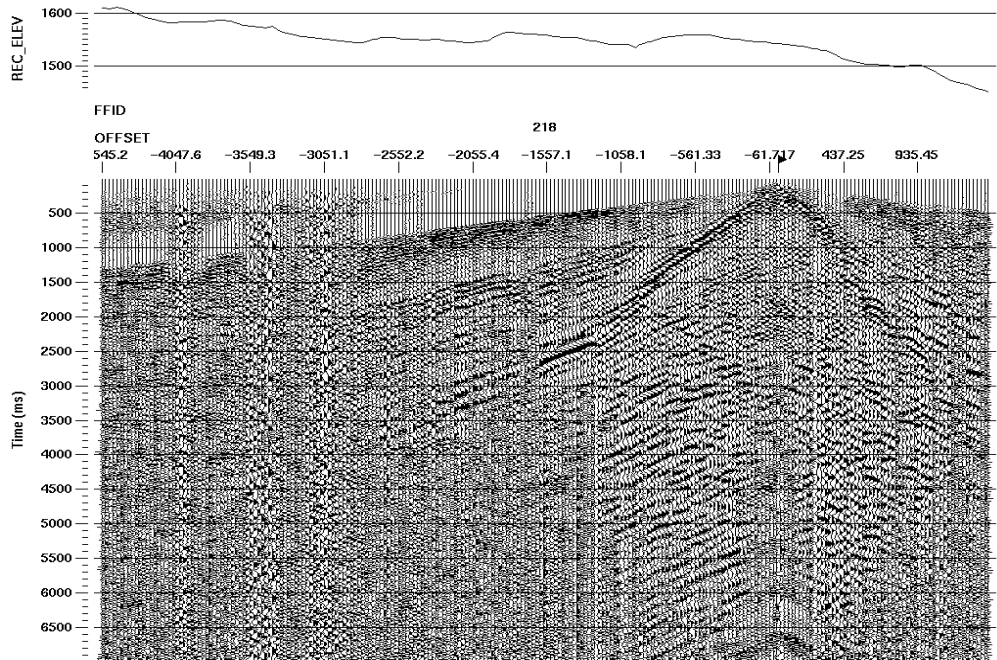

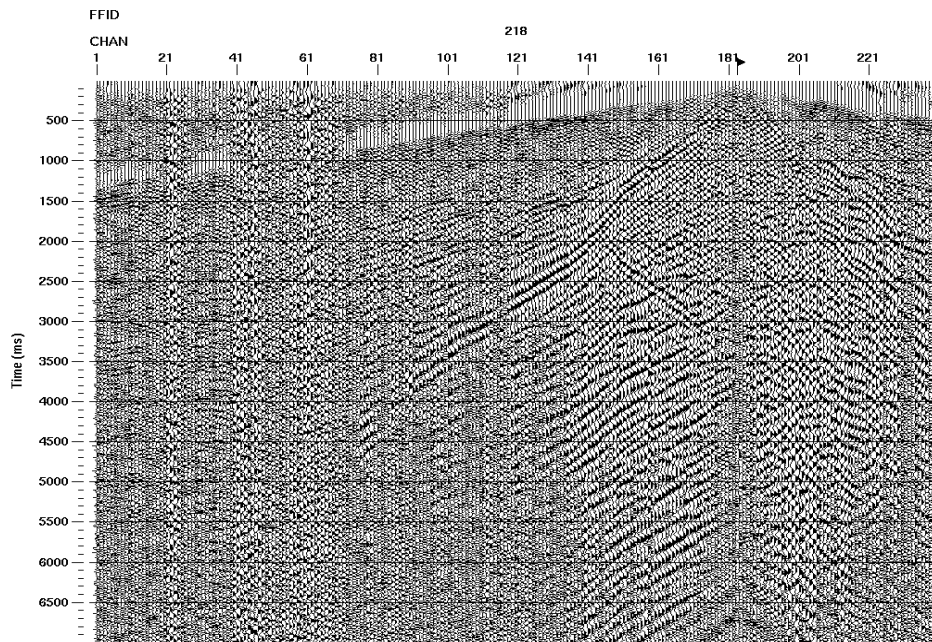Figure 1b. The shot gather of the radial component at the same location as (a).

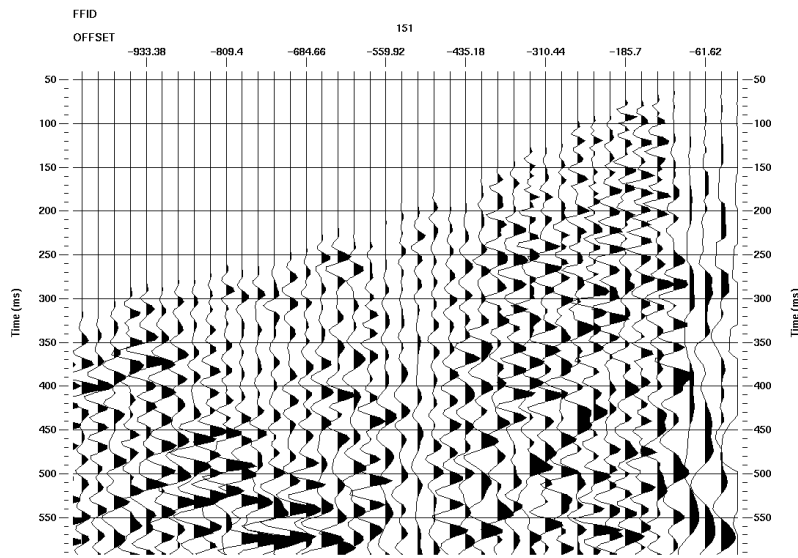Figure 1c. A shot gather of the transverse component.

Figure 1d. A portion of a shot gather of the radial component, from the first break. Several unexpected polarities are found.
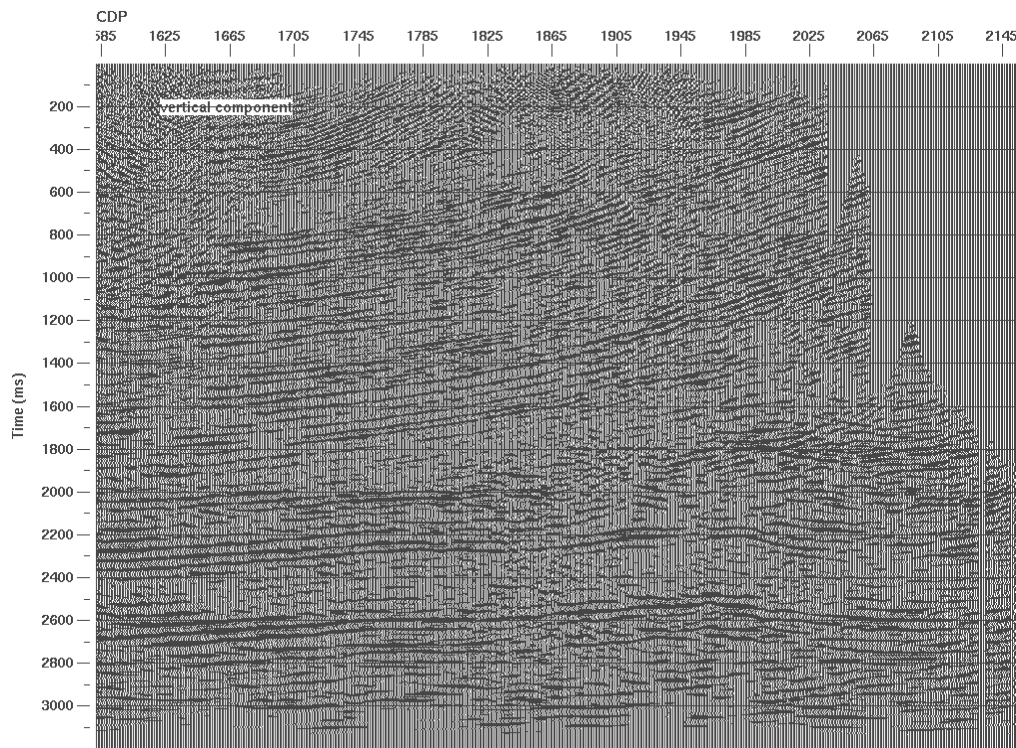
Figure 2. The migrated section for the vertical component.

For the P-SV and P-SH data, a Vp/Vs ratio=2.2 was used for asymptotic binning (Harrison, 1992). For the P-SV data, the most difficult thing was the receiver static corrections in the common receiver stack section; it was hard to pick even one horizon for structural data (Figure 3a), so the conventional hand receiver static correction method failed.

Statics for the radial component

The source static corrections for the vertical component and the receiver static corrections multiplied by 2.0 were applied to the radial component. If the structure is flat, the horizon on the common receiver stacked section of the radial component can usually be picked. Flattening the event picked by hand, the hand statics were estimated for the radial component. The receiver stack section in Figure 3b represents the result obtained after hand static corrections were applied. The result is not perfect (Figure 3b), but after residual static corrections are applied this should not be a problem.

After cross-correlation, the residual static corrections were estimated. The same procedure was iterated until maximum static corrections were reduced to 24ms. The migrated stack section for the radial component processed by P-SV processing flow is shown in Figure 4. It seems that there are still some static correction problems; because there are discontinuities on some events in the migrated section. The migration noise can be seen in this section.

In the Stolberg case, it was difficult to pick even one horizon from the common-receiver stacked section (Figure 3a), so another method was tested. A flat basement was assumed, which may be true in the depth domain, but is not necessarily true in the time domain, especially in geologically-complex areas. The correlation gate was set to a large number for the maximum static corrections for the radial component. In this way, the hand statics step was implied. This cross-correlation sometimes produces false results (a very flat structure was obtained, which may not be real). In consequence, when the cross-correlation method is used (especially where a large value for maximum static correction is defined), the final migrated section of vertical component is always used as a reference to ensure that the correct results for the radial component are obtained.
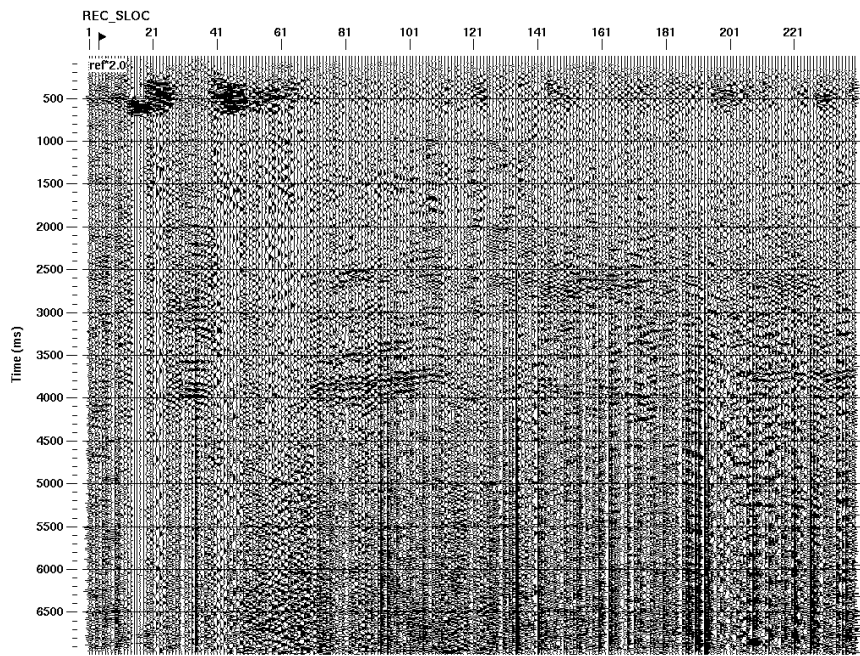

Figure 3a. Few events can be seen in the receiver stack section. The source static corrections for vertical component and the receiver static corrections multiplied by 2.0 were applied to the radial component.
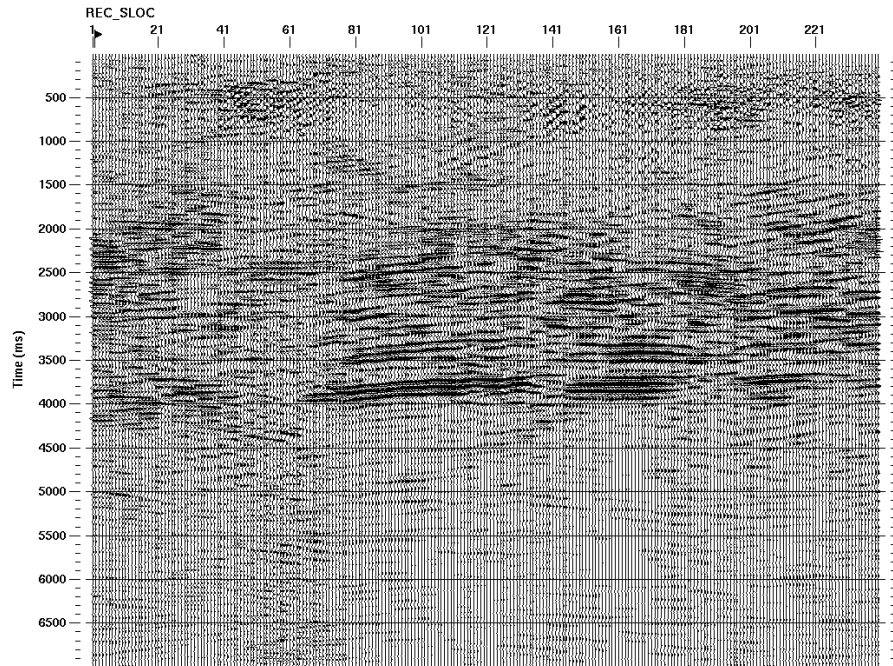
Figure 3b. The receiver stack section after applying receiver hand static corrections to receivers.
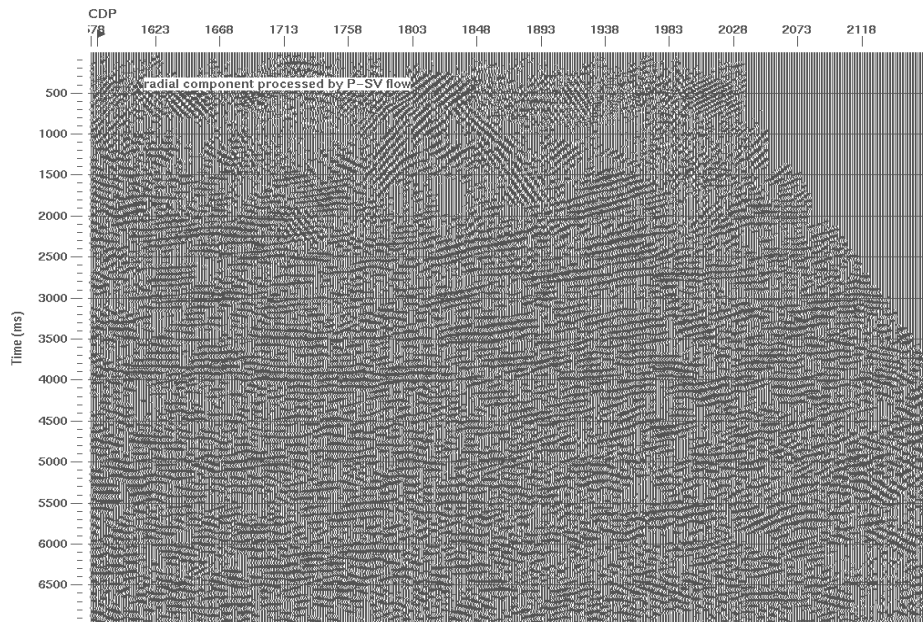

Figure 4. The migrated stack-section for the radial component (conventional processing for radial component).

As mentioned above, when the residual static corrections for the radial component were calculated the basement was assumed to be flat. This may be true in the depth domain, but not in the time domain. An alternative method to calculate the residual static correction for the radial component is to project the structure (in the zone of

interest) from the vertical component to the brute stack section of the radial component (Figure 5). This means that the event A in the vertical component should be multiplied by a constant value, which is calculated from the Vp/Vs ratio. In Figure 5 it is assumed that Vp/Vs=2.0, and this event in the radial component may then be picked and a gate can be specified. A cross-correlation was applied to calculate the residual static corrections for the radial component. Stacking velocity analysis and residual static correction were applied iteratively. This approach avoids the assumption of a flat basement and is consistent with the vertical component at the correct position.

This idea was tested on the radial component of the Stolberg data set. Some difficulties were experienced in determining the difference of the total static corrections between P-P and P-SV components, which made it difficult to project the event in the vertical component to the correct position of the radial component.

The receiver static corrections present the most difficult problem in pre-processing the structural seismic data in the structurally complex area. To avoid this step, the most powerful tool is pre-stack depth migration with topography.
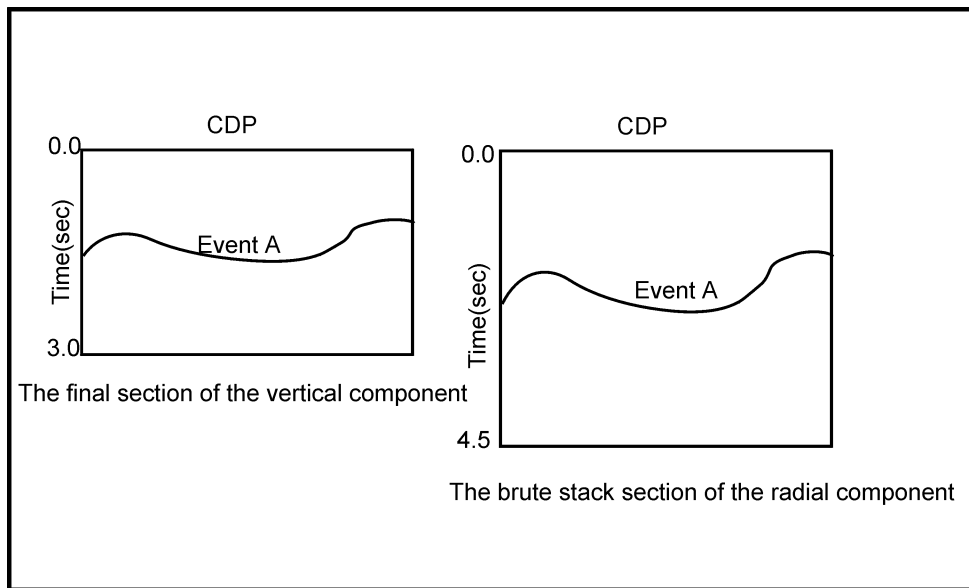

Figure 5. Event A of the vertical component is projected to the brute stack section of the radial component. In this case a value of 2.0 was assumed for Vp/Vs ratio.

The P-SH data were processed using the P-SV (radial component) flow. The results are shown in Figure 6. A very similar structure appears in both the transverse component and the radial components, which may be due to anisotropy. More likely, it indicates out-of-the plane reflections. As mentioned above, the 3C orientation is suspect. Attempts to re-orientate using geometrical rotation were not successful. However, it does not seem likely that mis-orientation could produce such a large effect. Birefringence analysis at this point is meaningless. The most likely explanation is that the horizontal geophones recorded energy from out-of-plane.
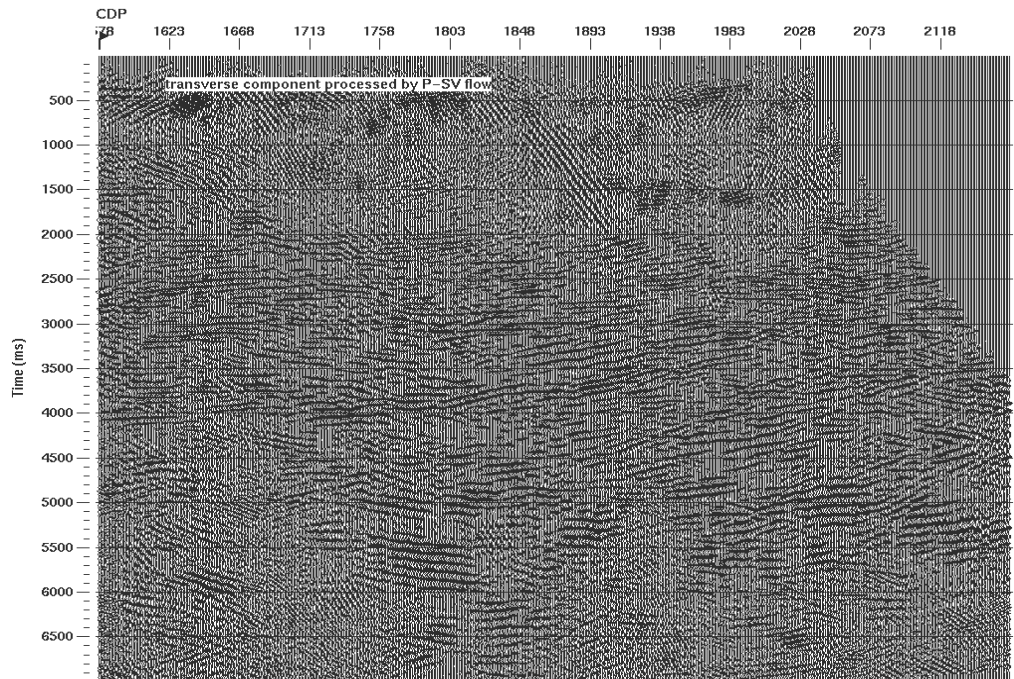
Figure 6. The transverse component was processed by P-S flow.

In another experiment, the P-SV and P-SH components were processed using the vertical component processing flow (the static corrections of the vertical component were applied to both of sources and receivers; CMP gathers were created for NMO correction; Vp was used as the stacking velocity), the results are shown in Figures 7 and 8. The results show that the migrated sections in the radial and transverse components contain strong P-P energy. In these sections (radial and transverse components processed by P-P flow), the major events tie well with those events in the vertical migrated section (Figure 4). From the geological base map it is apparent that to the east of the line there is an anticline structure and to the west there is a syncline structure. The horizontal components could record the P-P wave from these structures (out of the 2D line plane). This supports the previous interpretation that the shear wave energy on the horizontal components was also coming from out of the plane.
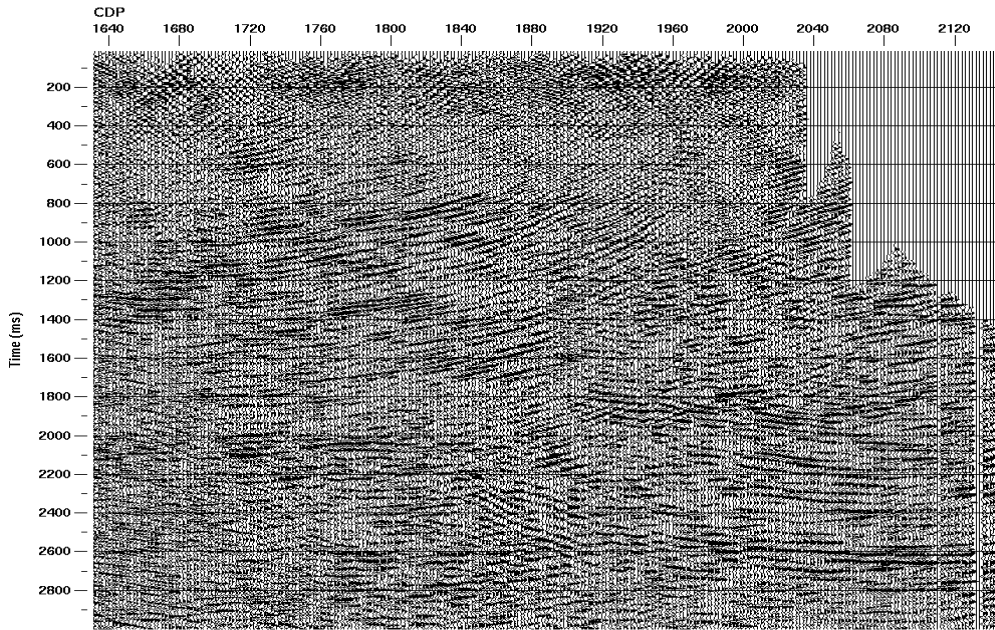
Figure 7. Radial (P-SV) component processed by P-P processing flow.
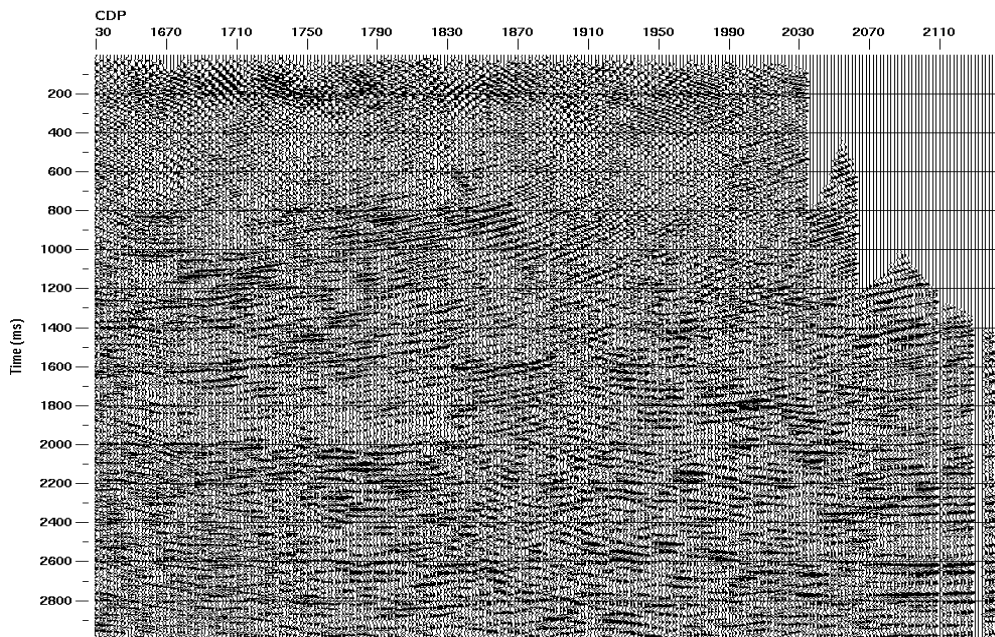

Figure 8. Transverse component (P-SH) processed by P-P processing flow.

CONCLUSION

The goal of this project was to test the possibility of using the commercial processing software "ProMAX" to process the structural 3C seismic data. Conventional processing produced a fairly good stack section for vertical component, considering the quality of the data. Regarding the radial component, however, there

are more difficulties in producing good results, because of low signal/noise ratios, the imperfectly orientated radial component, and complicated structural effects.

In a geologically complex area like the foothills, a lot of seismic energy from out of plane can be detected in 2D seismic data. From the migrated section of the transverse component processed by radial processing flow (Figure 6), there is strong energy of the radial component in this migrated section; and there are strong P-wave energies in both radial and transverse components (Figure 7 & 8). This is most likely due to the three dimensional effects from the complex geology. In order to minimize the 3D effect as much as possible, the 2D seismic survey line should be designed perpendicular to the strike of the structure. The best way is to conduct a 3C-3D seismic survey with 3-D processing to get true structural image.

ACKNOWLEDGEMENTS

REFERENCES

Guevara S. and Stewart R.R., 2000, Determining multicomponent source-receiver azimuths from polarization analysis, CREWES annual report.

Rajasekaran, S. and McMechan G.A., 1995, Prestack processing of land data with complex topography, Geophysics, Vol. 60, No. 6, p1875-1886.

Harrison M.P., 1992, Processing of P-SV surface-seismic Data: Anisotropy Analysis, Dip Moveout, and Migration. Ph.D. Thesis.

Lu H. and Margrave G.F., 1999, Study of the multi-mode conversions of the Blackfoot 3C seismic data, CREWES Annual Report.