Effect of out-of-plane energy on a 3C-2D seismic line in the Foothills area

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ABSTRACT

A 3C seismic survey was conducted in the Sibbald Flats area, 40 km west of Calgary (Figure 1). The line is located in a triangle zone structure which contains hydrocarbon reservoirs. Vibrator sources were used in the first stage of this survey in October 2003, later dynamite sources were used at the same receiver locations. The receiver locations are same as the survey line using Vibrator sources, but source locations are slightly different (Figure 2).

Multi-component seismic surveying on land has been tested primarily in areas with little structural deformation. This survey tried to get more experience in the multi-component seismic in structural areas.

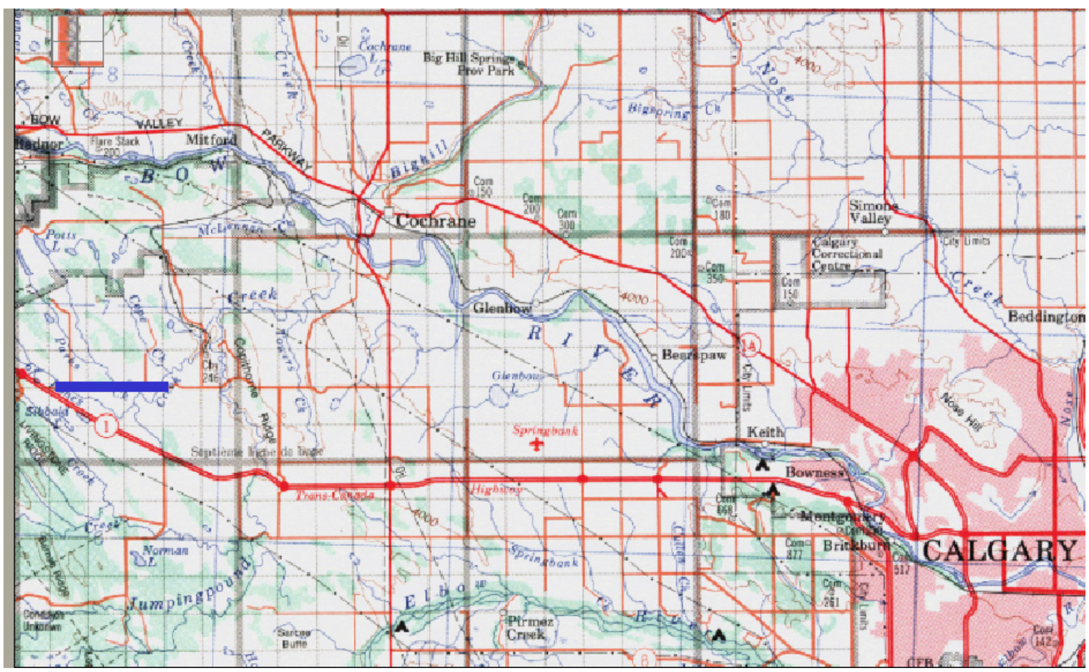

FIG.1. The survey line is shown in blue.

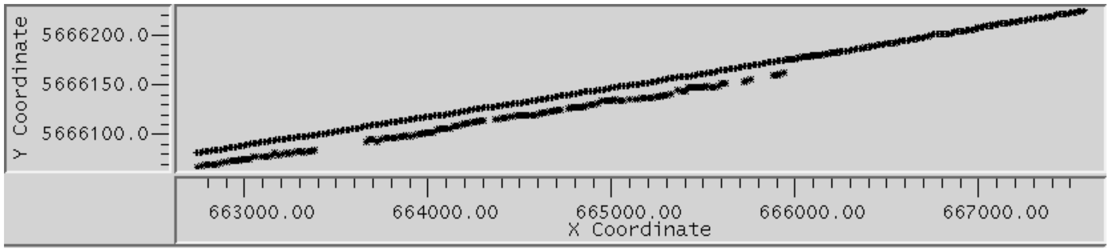

FIG. 2. Receivers are shown with crosses, source locations of the shots are shown by stars.

INTRODUCTION

The structural geology of the Western Canadian Foothills is dominated by a series of thrust faults, complex folds and steeply dipping formations. Seismic imaging is an essential tool in the petroleum exploration of such complicated geology. Such thrust belt geology often causes a violation of common midpoint assumptions.

In this survey, the elevation changes more than 150 m over 5 km. In some areas (from receiver station #1 to #40, and from station #101 to #140), the elevation changes quite rapidly (Figure 3).

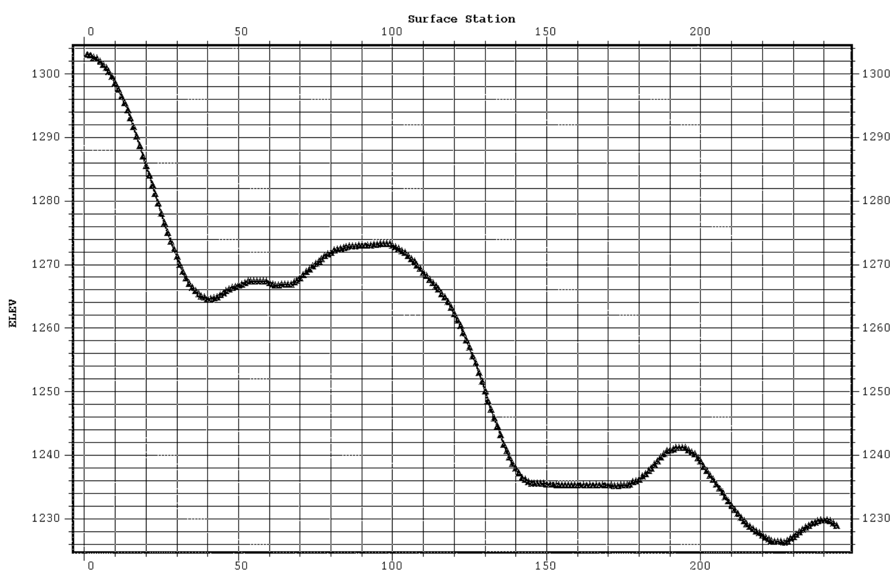

FIG. 3. Receiver elevations of this survey are shown in this figure.

It is expected that in 2-D seismic data the image of the structure in the vertical component must include energy from the 3-D structure in the Foothills area, but this cannot be proven only using vertical component data. The transverse component seismic data were processed using the same processing flow of the vertical component, and the same velocity function. The results based on the vertical and transverse components data reveal a very similar structure. It indicates that the image from the 2-D seismic line does indeed incorporate out-of-plane energy.

THE RESULTS FROM VIBRATOR SOURCES

The acquisition parameters are:

Source: 3 x 44000 lb Hemivibes

Sweep: 5-120 Hz over 12 seconds

Stacks: 4 per VP

Receiver: 3 component geophone (natural frequency of 14 Hz for all three components)

Receiver interval: 20 m

VP interval (normal): 20 m

Offsets : Up to 5000 m

The data processing for the vertical component is conventional; the results indicate that there are lots of thrusts dipping from west towards east and structures extending to the surface (see picture in Figure 4). The basement is located at 2000-2200 ms. The stacks are quite noisy, but the events of the structures still can be seen clearly, and are aligned quite well (Figure 5). There are several events in the section at about 1000 ms; 1400 ms; 1600-1800 ms and 2000-2200 ms; above 1600 ms there is a series of thrusts. At CDP around 200 and a time of 1000 ms, there is an intersection between the horizons and dipping thrust, and at CDP around 230 and 1600 ms there is another intersection.

To process the radial component and the transverse component, a Vp/Vs ratio of 2.2 was used to reconstruct the common converted point gathers (see CCP folds in Figure 6). The refraction statics were applied to the shots by the shot refraction of the vertical component, and the refraction statics for the receivers were applied with the receiver statics multiplied by the Vp/Vs ratio of the vertical component. Then, initial P-S stacking velocities for the horizontal components were reconstructed using the final velocities of the vertical component, and the Vp/Vs ratio. This initial P-S velocity function to get a brute receiver stacked section. Then an event (usually close to the zone of the interest) was picked, and the picks are flattened as hand refraction statics for the receivers. After conventional processing analogous to what was done for the radial component, the stacked section was obtained (Figure 7); the scale is stretched for comparison between the vertical and the radial component. The results show the perfect match between these two components at the two groups of horizontal events at times between 1600-1800 ms and 2000-2200 ms in the vertical component stack.

FIG. 4. The topography of the site of the survey line shows the outcrop of the thrusts (from Kevin Hall's talk at 2003 sponsors meeting).

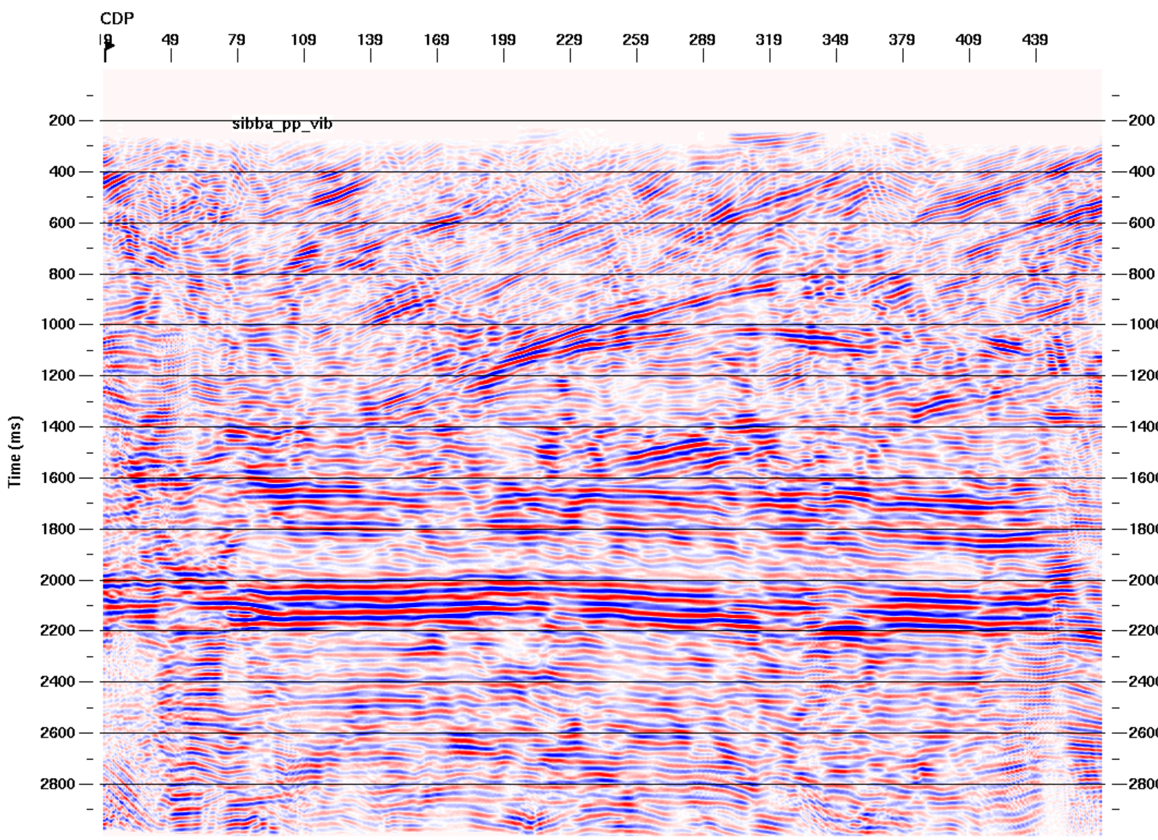

FIG. 5. The stacked section for Vibrator sources of the vertical component.

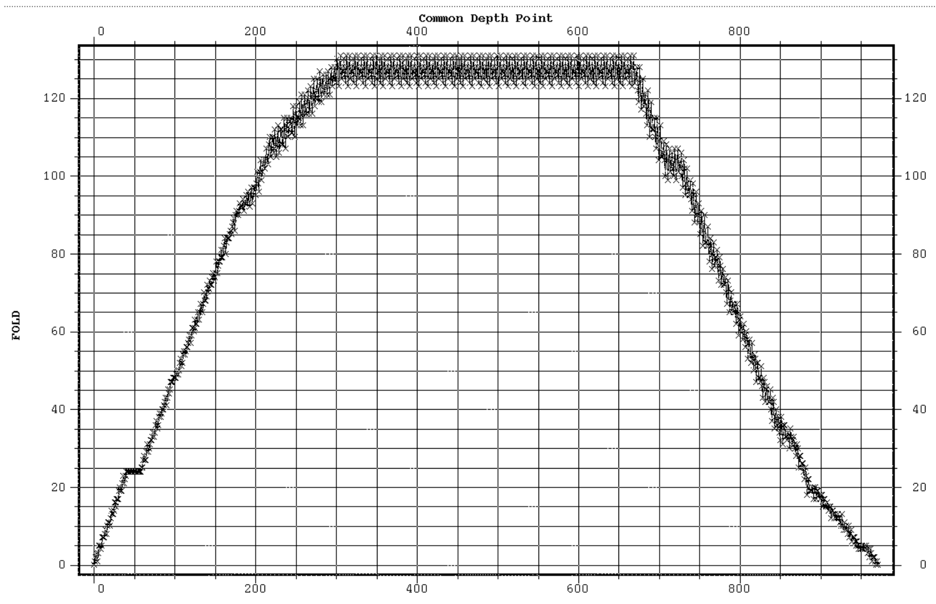

FIG. 6. CCP folds for Vp/Vs=2.2 used for the horizontal components processing.

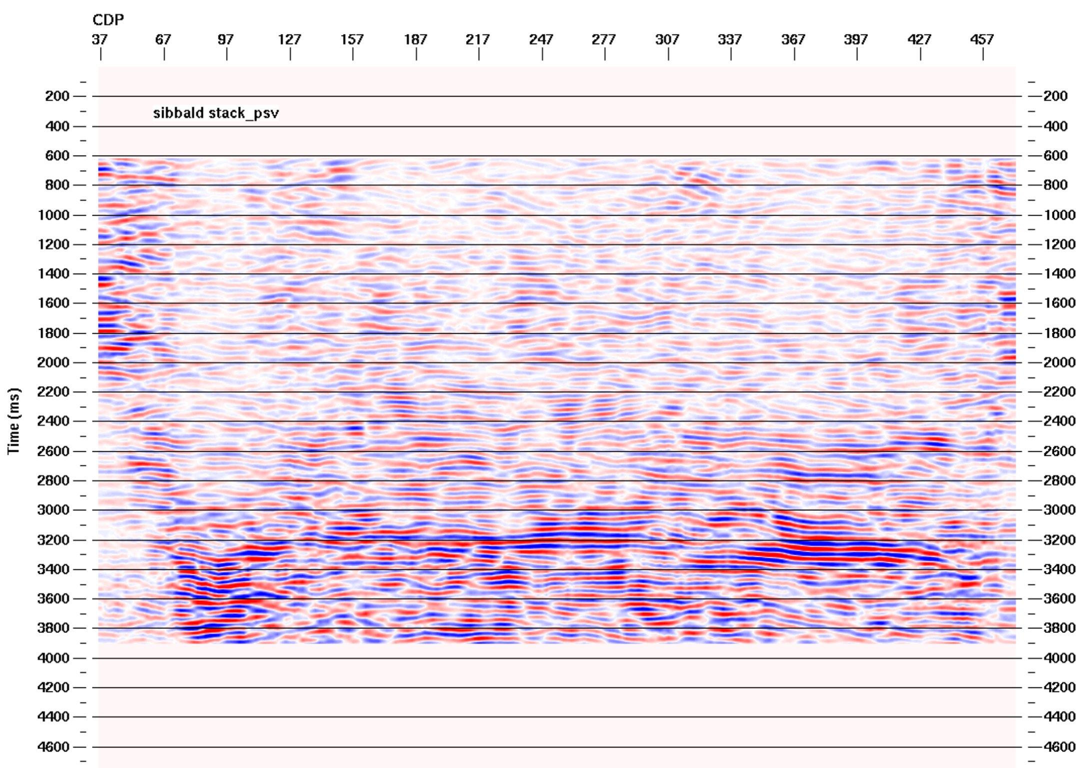

FIG. 7. The stacked section of the radial component for Vibrator sources; Vp/Vs=2.2.

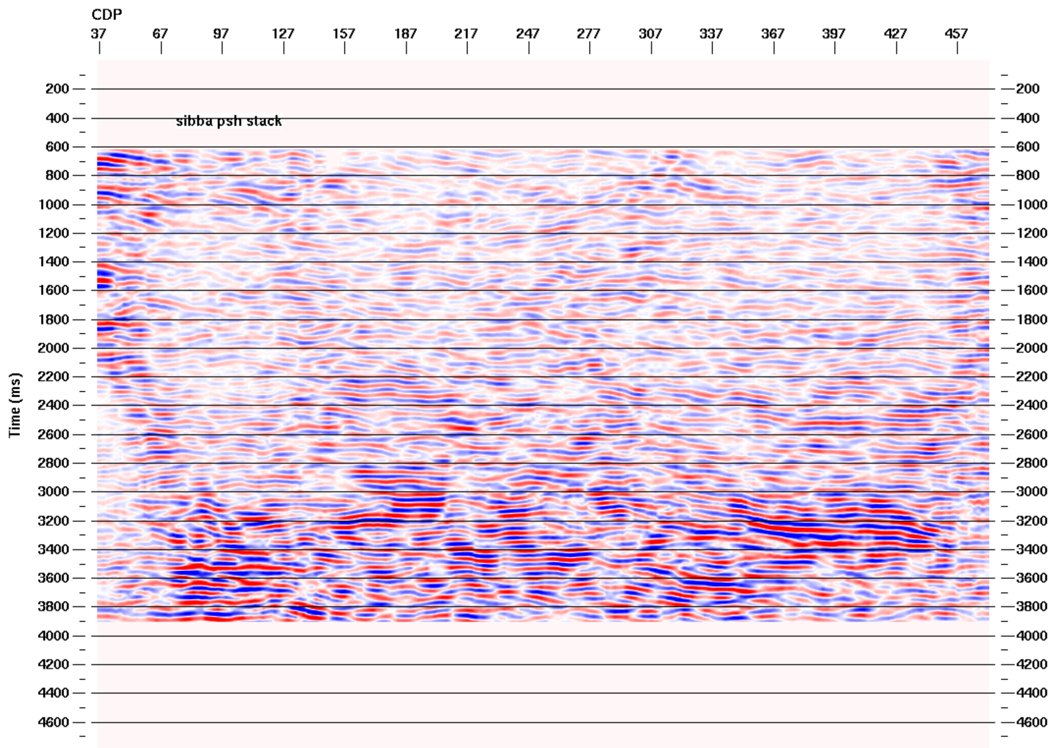

FIG. 8. The stacked section of the transverse component; Vp/Vs=2.2.

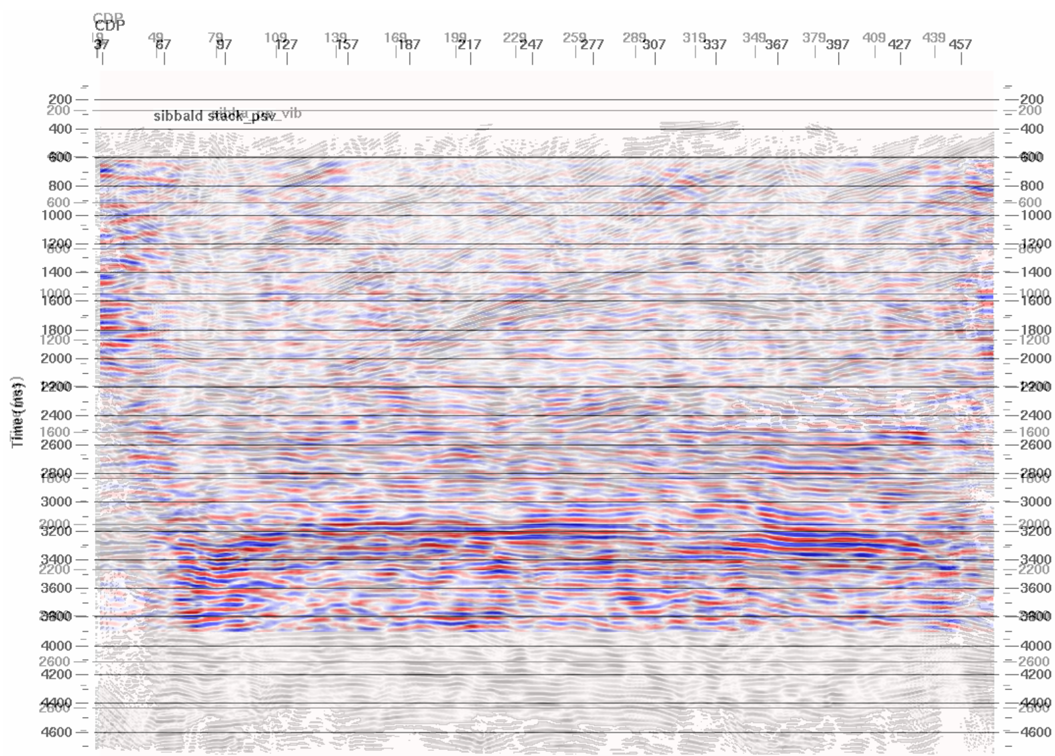

FIG. 9. The results from the vertical component and the radial component (after scaling stretching) are overlaid, the black lines are for the vertical component, the colour image is for the radial component.

Almost the same procedure was applied to the transverse component except the polarities at the negative offsets were not reversed. The results are shown in Figure 8. It shows no obvious events in the results, as expected.

As mentioned before, it is suspected that in a 2-D seismic line there is a 3-D effect (the energy from out of the plane). To test this, the transverse component data were processed using the processing flow from the vertical component.

The results shown in Figure 10 indicate that the images from the transverse component data processed with the vertical component processing flow are perfectly matched by the images from the vertical component. This means that the transverse component has quite strong energies compared to those of the vertical component. There are several possible reasons: one is a leak between the vertical geophone and the transverse geophone. This was tested in our group, and the results indicate the energy leak is very weak; a second possibility is that the angles of emergence are not perfectly vertical to the surface, but this would not have the strong energies to produce the image shown in Figure 10; the only remaining possibility is that this P-P energy comes from out of plane i.e. the 3-D effects in the 2-D seismic survey line. In Figure 11, we overlaid the results from the vertical component and the results from the transverse component processed by the vertical component processing flow (exactly the same procedure and the same parameters).

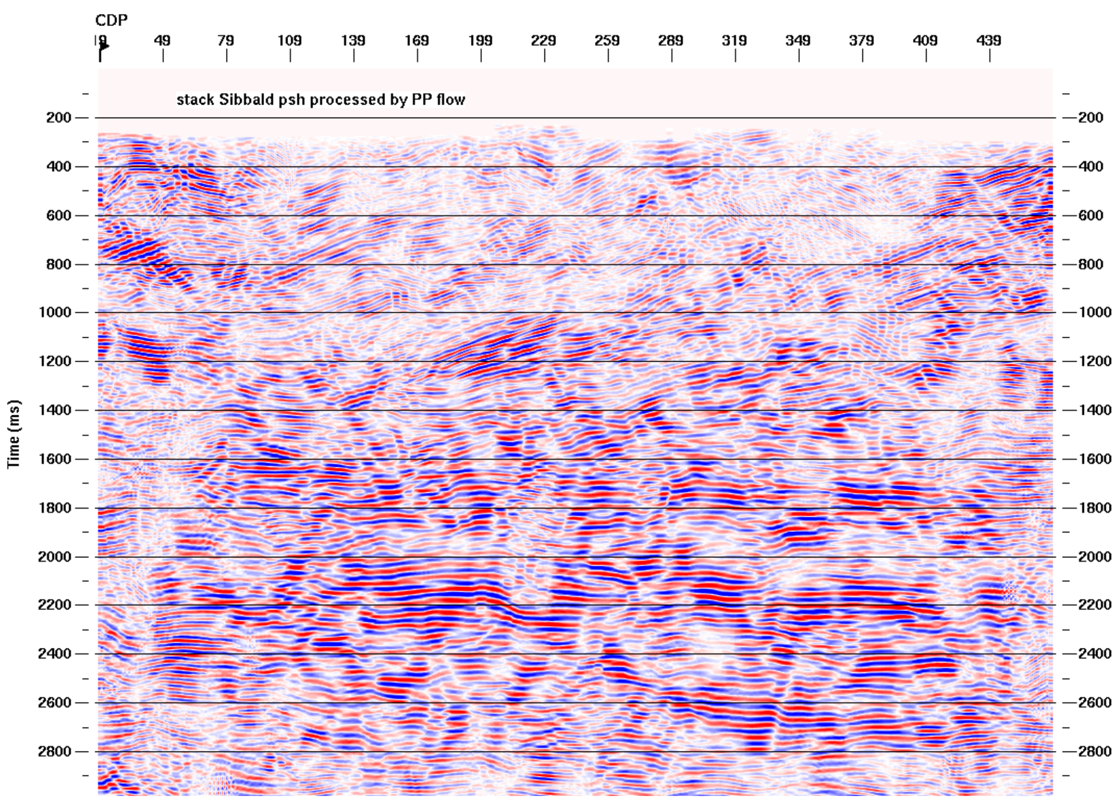

FIG. 10. The stacked section of the transverse component processed using the P-P processing flow. The strong P-P energy can be seen in this section.

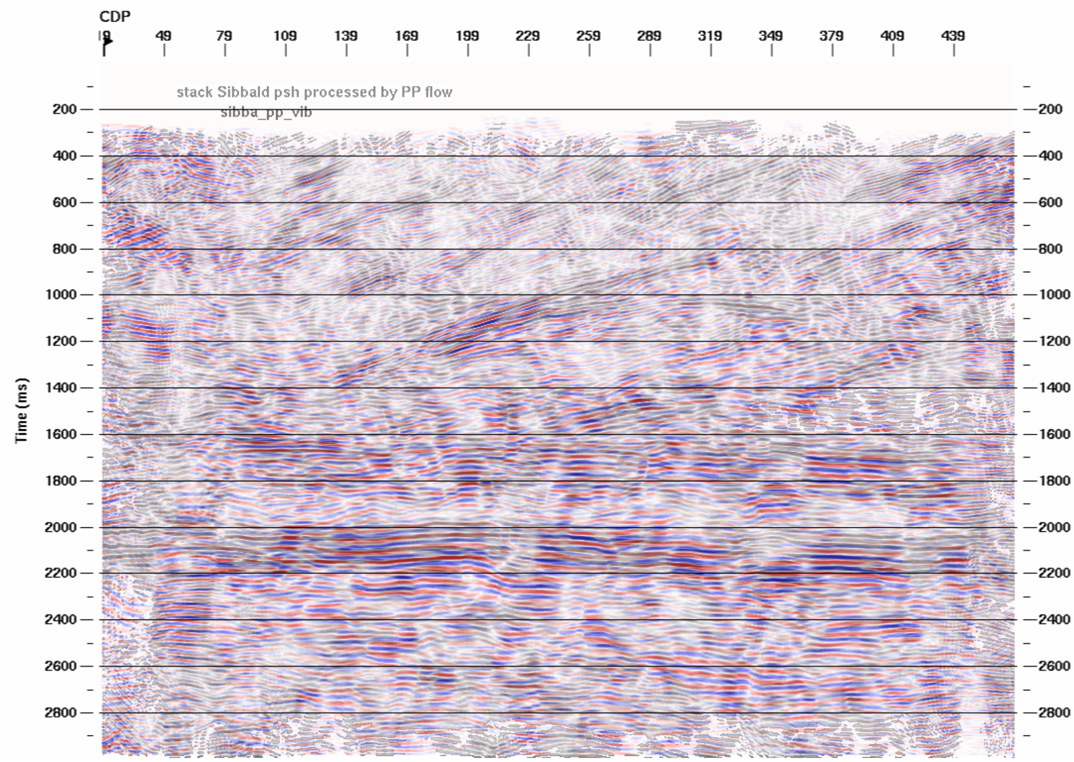

FIG. 11. Results from the P-P component are shown in black, and the results from the transverse component processed by the vertical component's flow are shown in colour.

Figure 11 shows that the image from the transverse component processed with the P-P flow is perfectly matched by the results from the vertical component, except that the P-P stack is noisier. This means that using only a 2-D seismic survey to get the true structure is not possible in a structural area; a 3-D seismic survey is really needed to get real structure.

We still can see the noise in the section of the transverse component processed by the vertical component flow. It is worth trying to stack the results from the vertical component, the results from the transverse component processed by the vertical component flow, and the results from the radial component processed by the vertical component flow, to see whether or not it will attenuate random noise. The results is shown in Figure 13. It doesn't show better results than individual section of the vertical component and the transverse component processed by the vertical component.

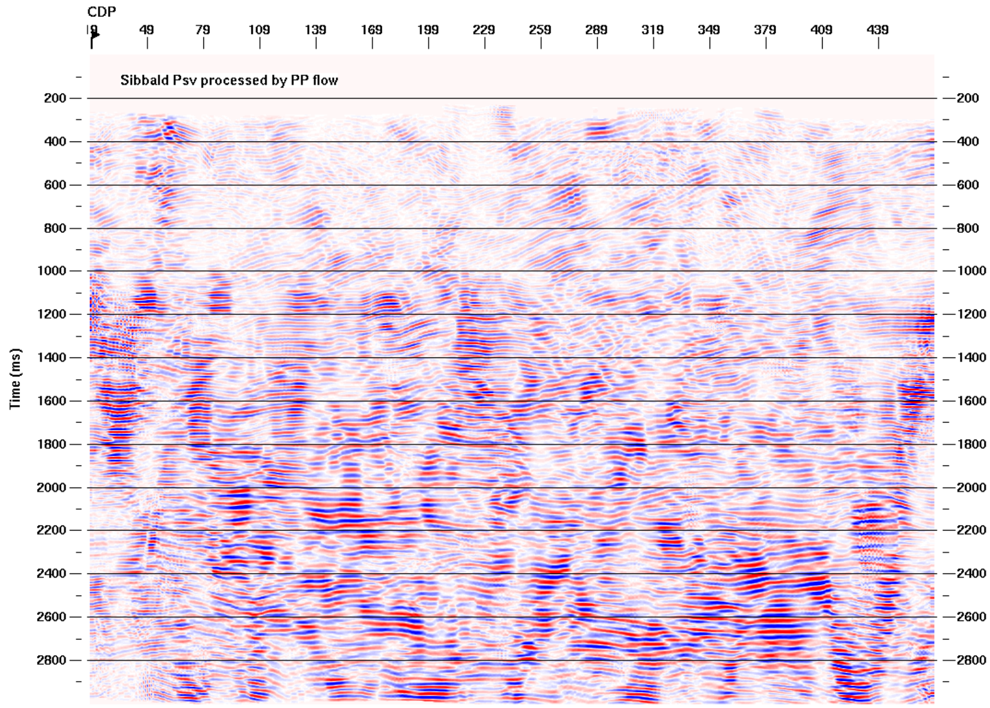

FIG. 12. The stacked section of the radial component processed with the vertical component processing flow shows only little similarity with the results from the vertical component.

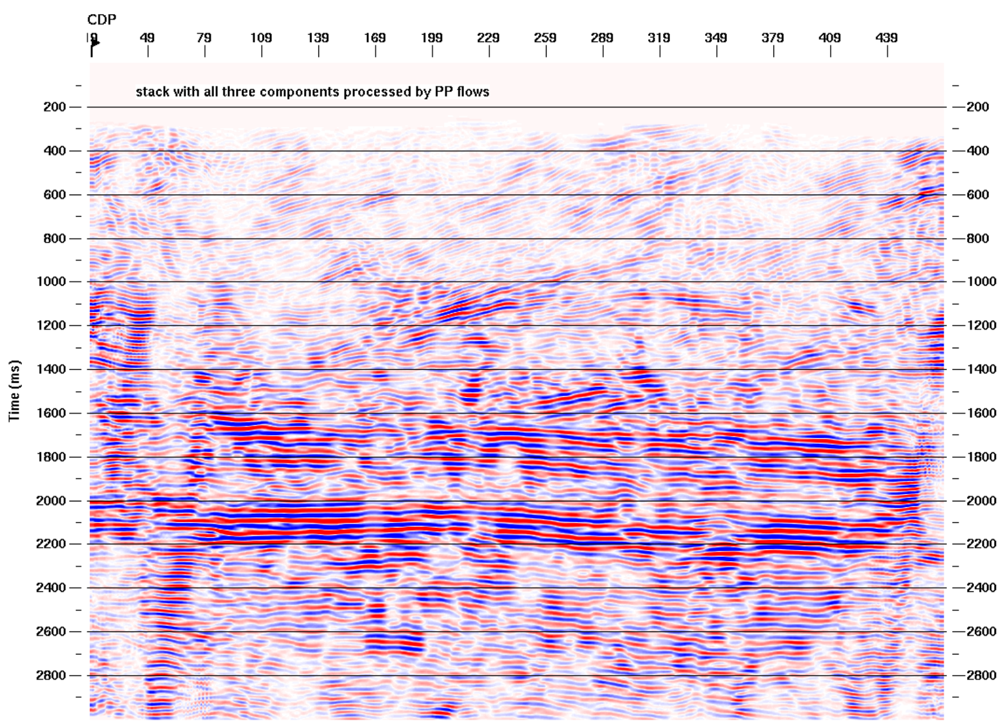

FIG. 13. Results of the vertical component, the radial component processed by the vertical component flow, and the transverse component processed by the vertical component flow are stacked to reduce the random noise.

THE RESULTS FROM DYNAMITE SOURCES

This seismic survey was conducted in late November, 2003 at the same locations, except that the locations of the sources were slightly different (Figure 2). The sources were 3 kg of dynamite at 18 m depth. The source interval was 20 m and the group interval was 10 m. A Sercel DSU digital sensors and recording system were used in this seismic survey.

The results from the dynamite sources are very similar to the results from the Vibrator sources, but it seems that the frequency contents are higher than in the section from the Vibrator sources (Figure 14–19). In processing both seismic data sets, traces with offsets less than 400 m are eliminated to avoid the source noise (especially the Vibrator source near offset noise).

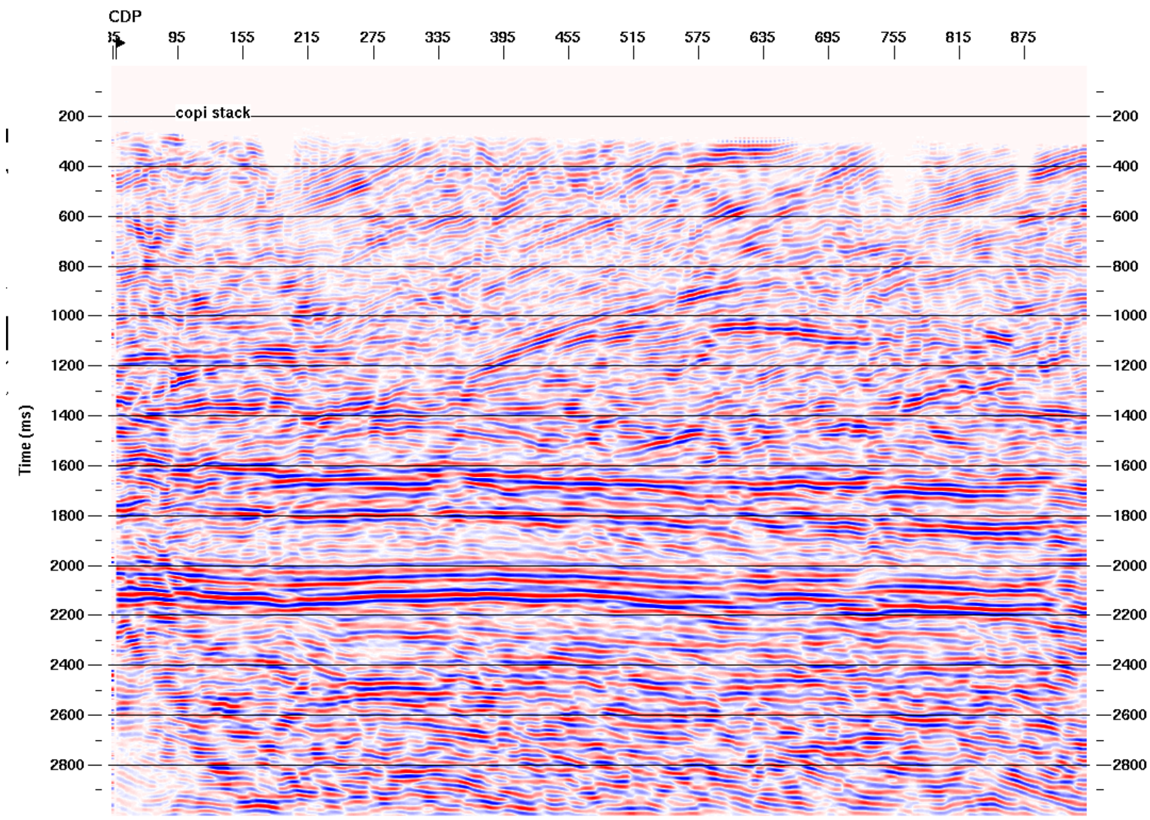

FIG. 14. Stacked section of the vertical component (P-P) from dynamite sources.

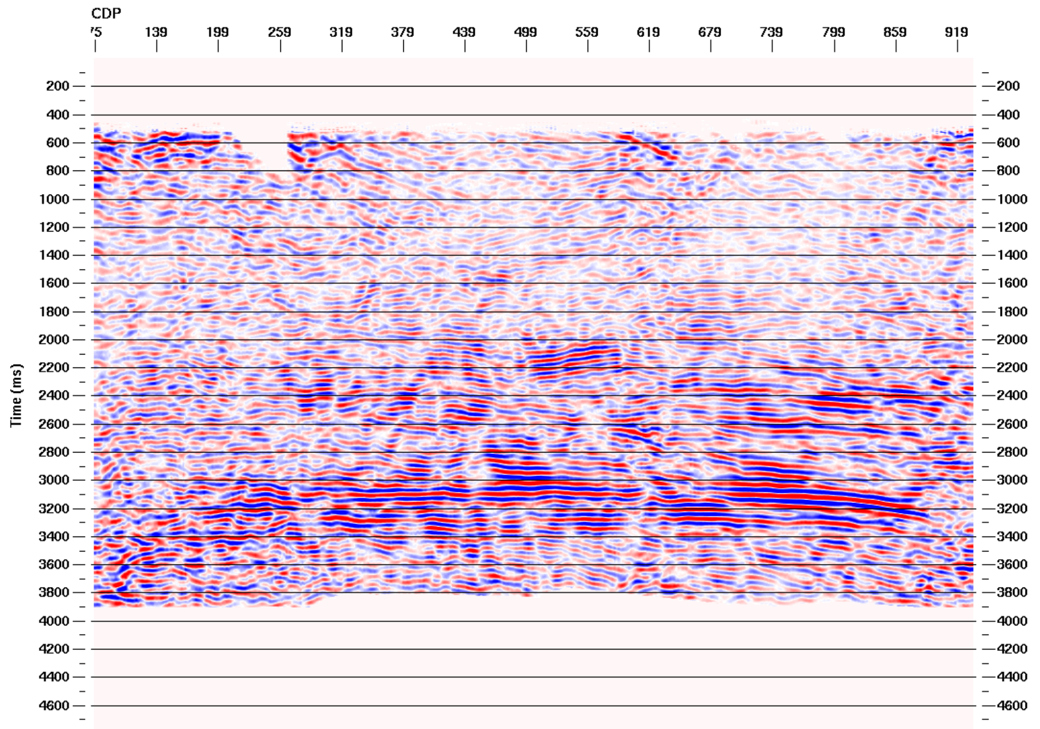

FIG. 15. Stacked section of the radial component (P-SV) from the dynamite sources.

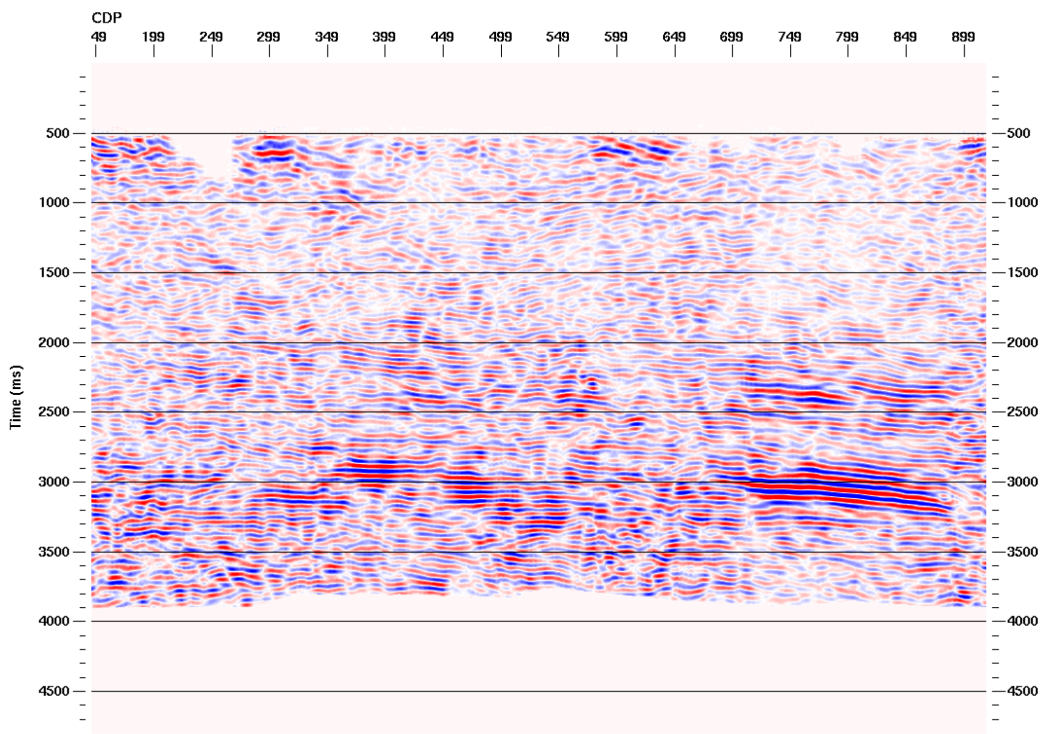

FIG. 16. Stacked section of the transverse component (P-SH) from the dynamite sources.

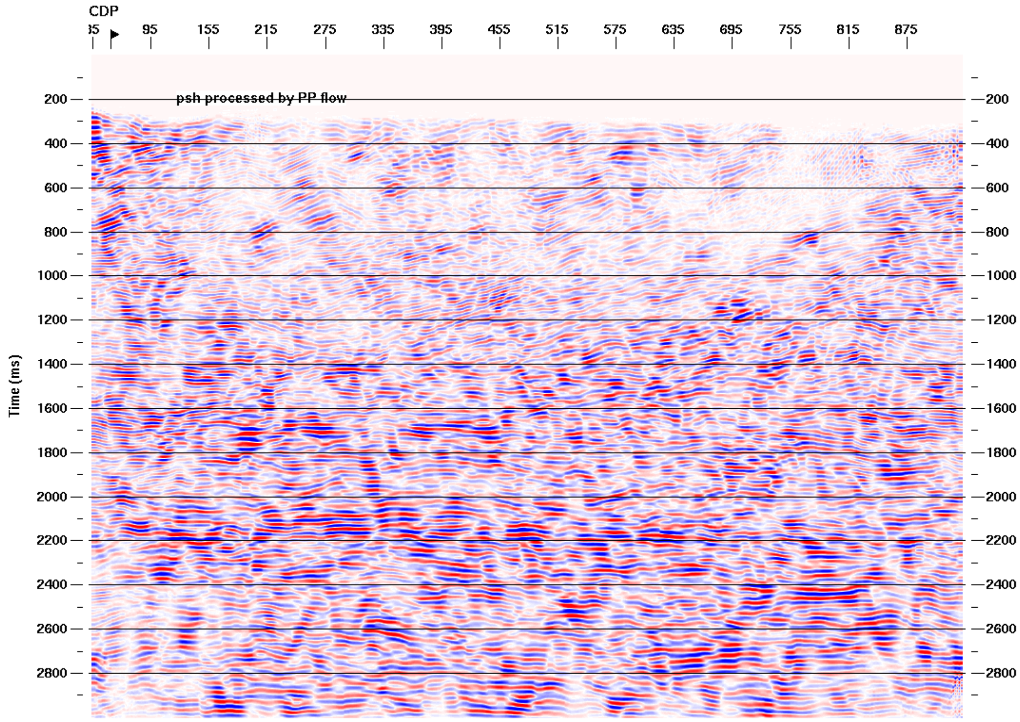

FIG. 17. The stacked section of the transverse component processed with the vertical component processing flow for the dynamite sources.

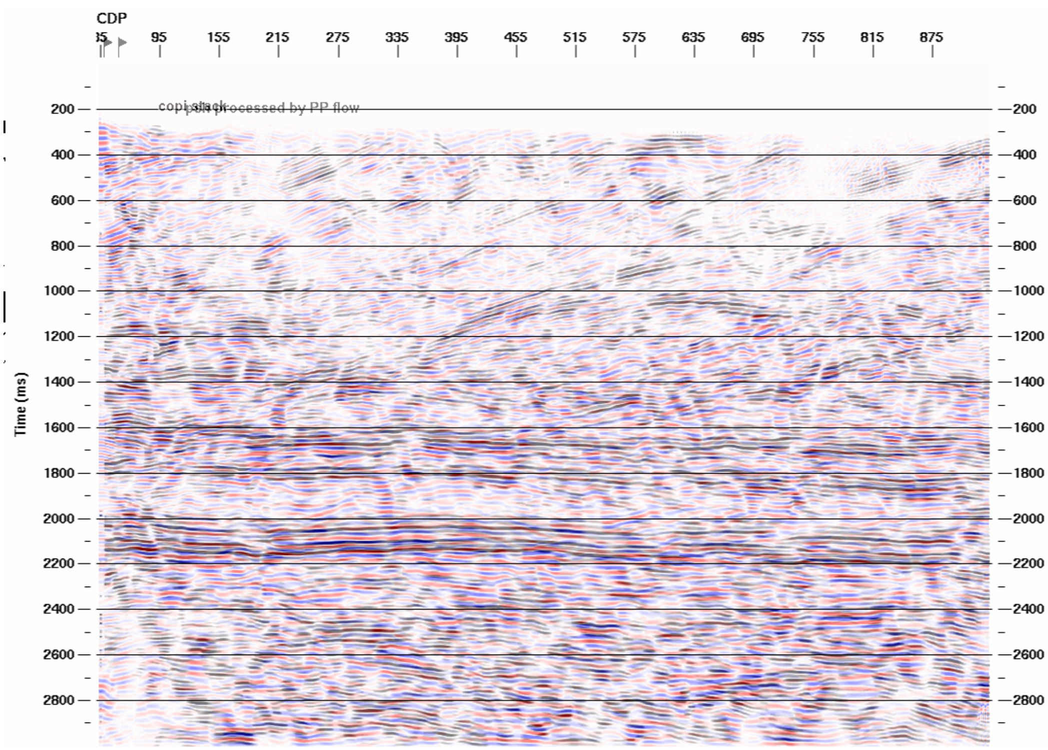

FIG. 18. The stacked section of the vertical component (in black) and the stacked section of the transverse component processed by the vertical component flow (in colour) from dynamite sources are overlaid.

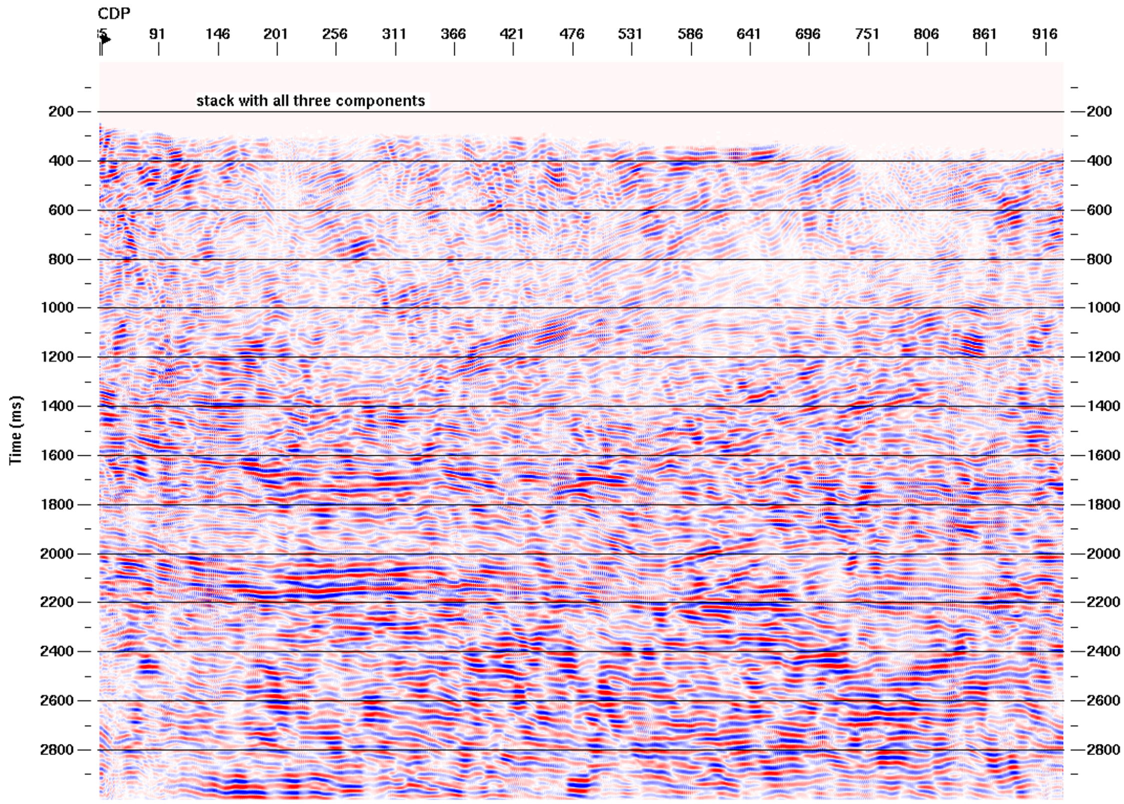

FIG. 19. The stacked section of the vertical component and the stacked section of the radial component and the transverse component processed by the vertical component flow from dynamite sources are stacked together into one section.

CONCLUSIONS

When processing -2D seismic data, it is assumed that the recorded seismic energy comes from directly beneath the 2-D line. In data processing it is assumed that energy propagates in the vertical plane through this 2-D seismic line. But in a real situation, especially in structural areas (for example, Foothills area in western Canada), there are reflections and scattered energy from lithologic change or structures away from the 2-D seismic line. Thus it is necessary to put 3-D seismic survey lines in the structural areas to avoid smearing the image of the structures.

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