F-X spectral analysis for the 1995 and 1999 3C-3D seismic data

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ABSTRACT

The 1999 Blackfoot 3C-3D data was reprocessed and the f-x spectra analysis was performed. The results show that the data of the natural bin size (40 x 80 m) in the 1999 seismic survey using the MEGA-bin technique have good frequency spectra and good resolution in time and in space. The f-x spectral analysis indicates that the 1995 and 1999 Blackfoot 3C-3D seismic data have similar signal bandwidths.

INTRODUCTION

In 1999, the 3C-3D seismic survey was conducted by PanCanadian Petroleum Ltd over the Blackfoot field located near Strathmore, Alberta, Canada. The seismic survey in 1999 is shown in Figure 1. This survey covered an area of 8 square kilometres (2 x 4 km), which is smaller than that of the 1995 seismic survey. [The 1995 seismic survey conducted by the CREWES Project, University of Calgary covered 16.6 km^2 (Stewart et al., 1996).]

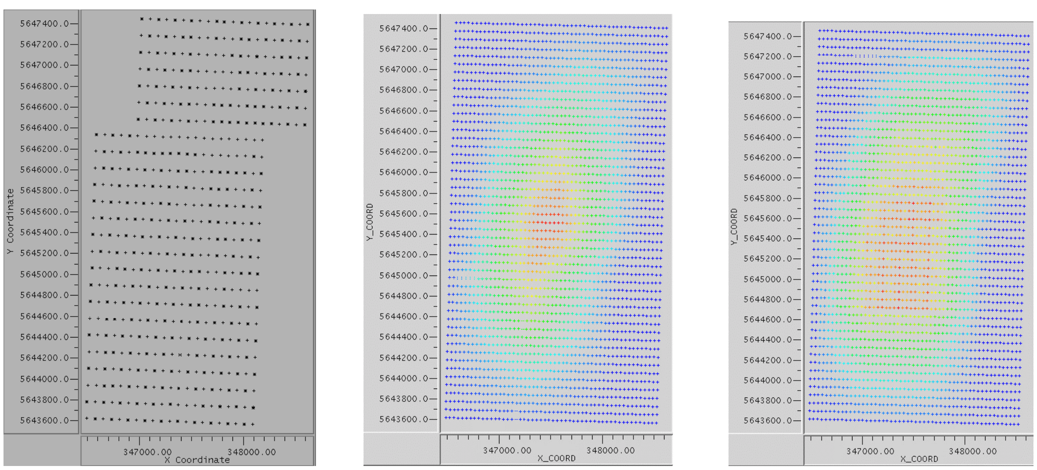

FIG. 1. The 1999 Blackfoot 3C-3D seismic survey is on the left. The stars present the shot points, the crosses indicate the receiver points. The CDP folds for the vertical component are in the middle; the CDP folds of the radial component are on the right (the Vp/Vs=2.2 for ACP binning).

RESULTS

The 1995 and 1999 seismic surveys were shot with different acquisition parameters. For the 1995 survey the source and receiver intervals were 60 m, while for the 1999 survey the source interval was 160 m and the receiver interval was 80 m. This survey was acquired using PanCanadian's Mega technique (Goodway and Tessman, 2001). The natural bin size for the 1999 seismic survey was 80 x 40 m. The vertical component of the data was processed using this natural bin size, and the radial component was processed using Vp/Vs=2.2. As shown in Figure 2, the migrated section for the vertical component ties nicely with the migrated section of the radial component. The time scale of the vertical component was stretched by 1.6 for this comparison.

The natural binning size for the 1995 3C-3D survey was 30 x 30 m. In order to compare the results of the 1999 seismic data with the results of the 1995 data, the migrated sections for both the vertical and radial components of the 1999 datasets were re-gridded to 30 x 30 m, using a sinc function to interpolate the post-stacked sections.

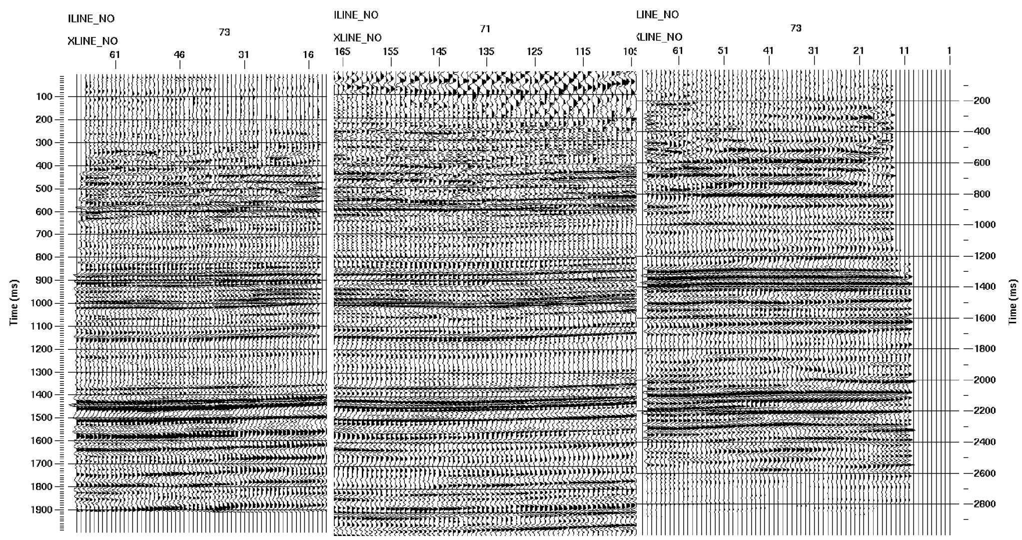

FIG. 2. The re-gridded migrated section of the vertical component of 1999 data is on the left; the migrated section of the 1995 vertical component is in the middle; the migrated section of the radial component of the 1999 data is on the right.

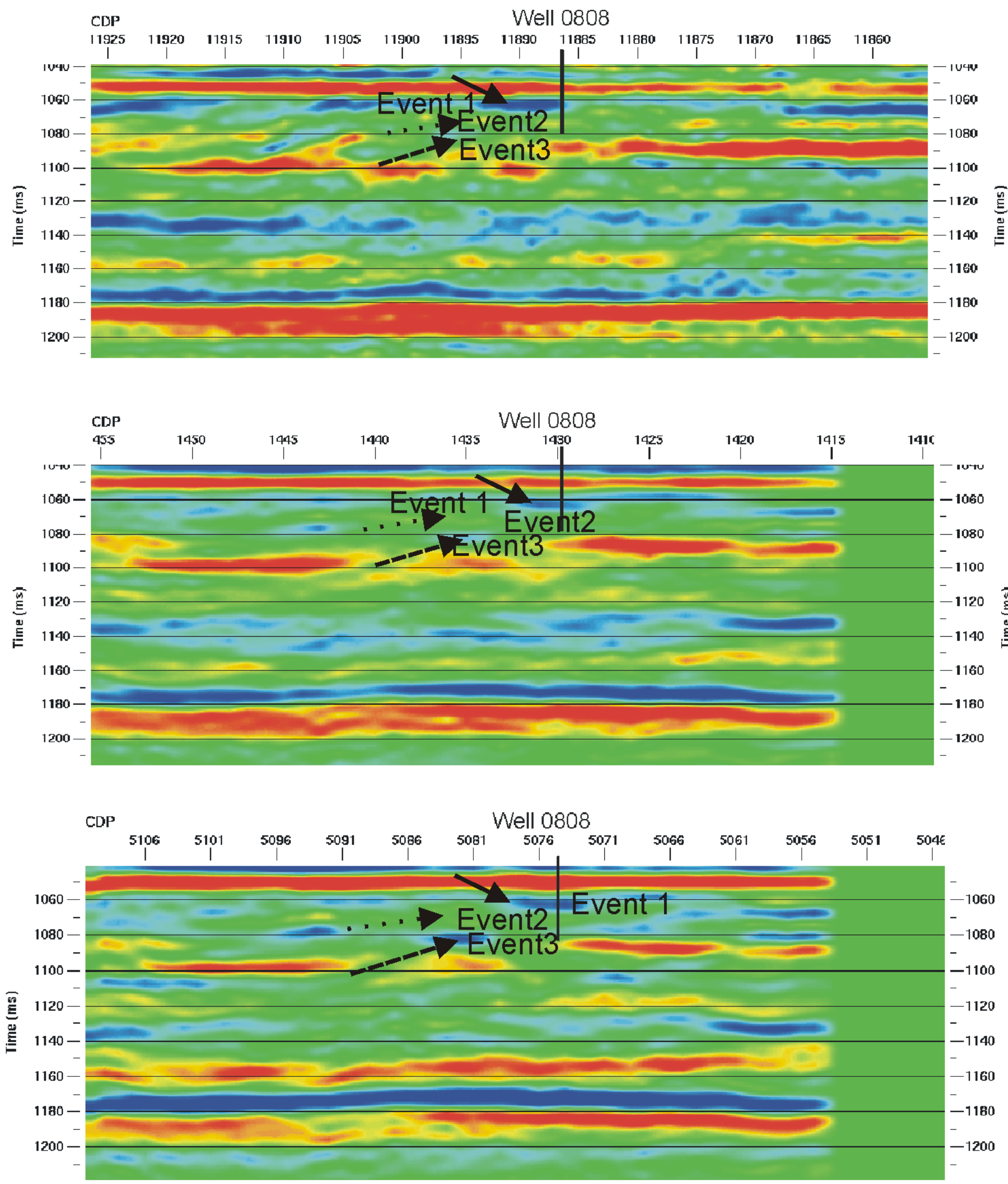

FIG. 3. This figure displays three migrated sections of the same location for the vertical component only. The upper panel is the 1995 data (inline71), the middle panel is the 1999 original data, and the lower panel is the 1999 re-gridded data. The Lower Mannville was flattened to 1050 ms. Location of the production well 0808 is shown by the solid line. Event 1 in the trough is the upper channel, event 2 in the peak is the intermediate amplitude event and event 3 in the trough is the Lower channel.

The Blackfoot field, fifty kilometres east of Calgary, Alberta, encompasses a Glauconitic incised valley system. The upper and lower channels consist of mainly porous quartz sandstones, while the middle channel consists of relatively dense lithic sandstones. Oil is the primary hydrocarbon, although gas is also found in the Upper channel and whenever it comes out of solution. The channel can be seen in Figure 3, the inline located on the site of well 0808 was extracted for display: the upper channel is a trough in the seismic (event 1), the lower channel is another trough (event 3) and the intermediate amplitude event is in a peak (event 2). In Figure 3, the Lower Mannville formation was flattened to 1050 ms for both the 1995 and 1999 data. The migrated section of the 1995 data is shown in the upper panel (bin size is 30 x 30 m), the original migrated section for the 1999 data (bin size of 40 x 80 m) is shown in the middle panel, and the 1999 re-gridded section (bin size of 30 x 30 m) is shown in the lower panel. These three in-lines are at the same location so that the Lower Mannville and Mississippian formations follow a similar pattern in both surveys. The zone of interest is the Glauconitic channel zone between the Lower Mannville and Mississippian formations (1050ms-1100ms), as shown in Figure 3. The upper channel and the Lower channel can be seen at around 1058-1060 ms and 1068-1070 ms as a trough in both of the 1995 and 1999 seismic sections. A peak between the upper and the Lower channel can be seen clearly in the 1995 seismic section (event 2); the same peak was very weak and cannot even be seen in the 1999 sections. From Figure 3, the 1995 data shows higher spatial wavenumber than the 1999 data. This is expected from the smaller natural bin size in the 1995 data.

There is an apparent difference between the middle and the lower panels of the Figure 3, suggesting that the re-grid procedure for the post-stack section is not satisfied in this case. Perhaps the interpolation of the 3D data should be done with the pre-stack data.

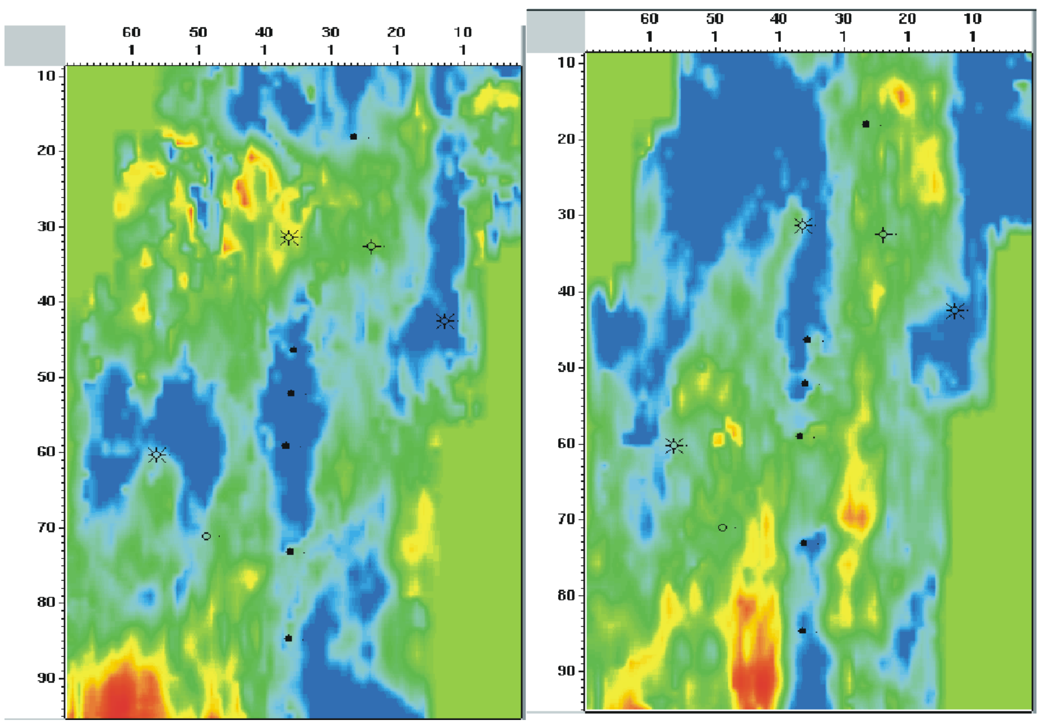

FIG. 4. In the vertical component of the 1999 dataset the time slice at the stratigraphic level of the upper channel is on the left and the time slice at the stratigraphic level of the lower channel is on the right, with the Lower Mannville flattened to 1050ms. Black dots represent producing wells.

The time slices for the upper channel and lower channel from the 1999 dataset are shown in Figure 4. The time slices from the 1995 dataset can be seen in this volume (Lu and Margrave, 2001). The Lower Mannville was flattened to 1050ms. The Glauconitic channel system extends from south to north through the Blackfoot area and is approximately 1560m below the surface. This is indicated by the negative amplitude anomalies (blue/dark) trending through the producing oil wells. The upper channel anomalies indicate a wide channel, while the lower channel is relatively narrow.

Between the upper channel and lower channel of the 1995 data there is an obvious positive amplitude event (event 2), but this could not be seen in the 1999 data (see Figure 3). This may be because the resolution of the 1999 data is lower or perhaps because production has altered the properties of the reservoir rocks.

F-X SPECTRAL ANALYSIS

In order to exclude the possibility of the lower resolution in the 1999 migrated section, an f-x spectral analysis was performed for the 1995, the 1999 un-gridded, and the 1999 re-gridded CMP stacked sections (Margrave, 1999, Hoffe et al., 1998).

The spatial and temporal resolution is directly determined by the signal bandwidth. The signal band of the reflection seismic data may be estimated by the interpretation of appropriately constructed f-x spectra (Neidell and Taner, 1971). The resolution of the reflection seismic data (stacked) is controlled by many factors, such as the source power spectra, depth of the source burial, anelastic attenuation, spherical divergence, transmission and mode conversion loss, random noise, coherence noise, near-surface conditions, recording geometry, recording instrument and subsurface velocity structure. Furthermore, the resolution of the seismic data also can be determined by the data processing sequences. Therefore, the signal band is a strong function of the processing sequence and can be taken as a measure of the success of the processing.

In this paper, the f-x spectral analysis was carried out in Matlab. The “phase” spectra are computed in a non-conventional way and are called “complex phase” (Margrave, 1999). The “complex phase” spectrum of each trace display below is actually the complex spectrum divided by its magnitude. This kind of display contains the same information as conventional phase and has the intuitive interpretation of being a “perfectly whitened” spectrum.

The spectral coherence indicates signal, and the absence of coherence is noise in the seismic data. All of the spectral analyses were applied to unfiltered stacked data.

Figure 5 shows the amplitude spectra and complex phase spectra in a time window of 0.9-1.3 s, which is the Glauconitic channel time zone of the vertical component for the 1995 seismic (upper panel), 1999 seismic (middle panel) and 1999 seismic after re-grid (lower panel). All three spectra have the same basic patterns, but it appears that the highest frequency in the 1995 data is about 100 Hz. The highest frequency content is up to 90 Hz in the 1999 original and regridded data. The quality of the results for the 1995 data is better than 1999 data. The long wave refraction statics problem can be seen in the 1993 and 1995 datasets (and less obviously in the 1999 data) but it does not affect our interpretation, as when the interpretation was performed, the Lower Mannville formation was flattened into the same time for these three datasets. The bandwidths in the 1995, 1999 original, and 1999 regridded seismic are very similar, but the spatial resolution in the 1995 data is higher than that in the 1999 data.

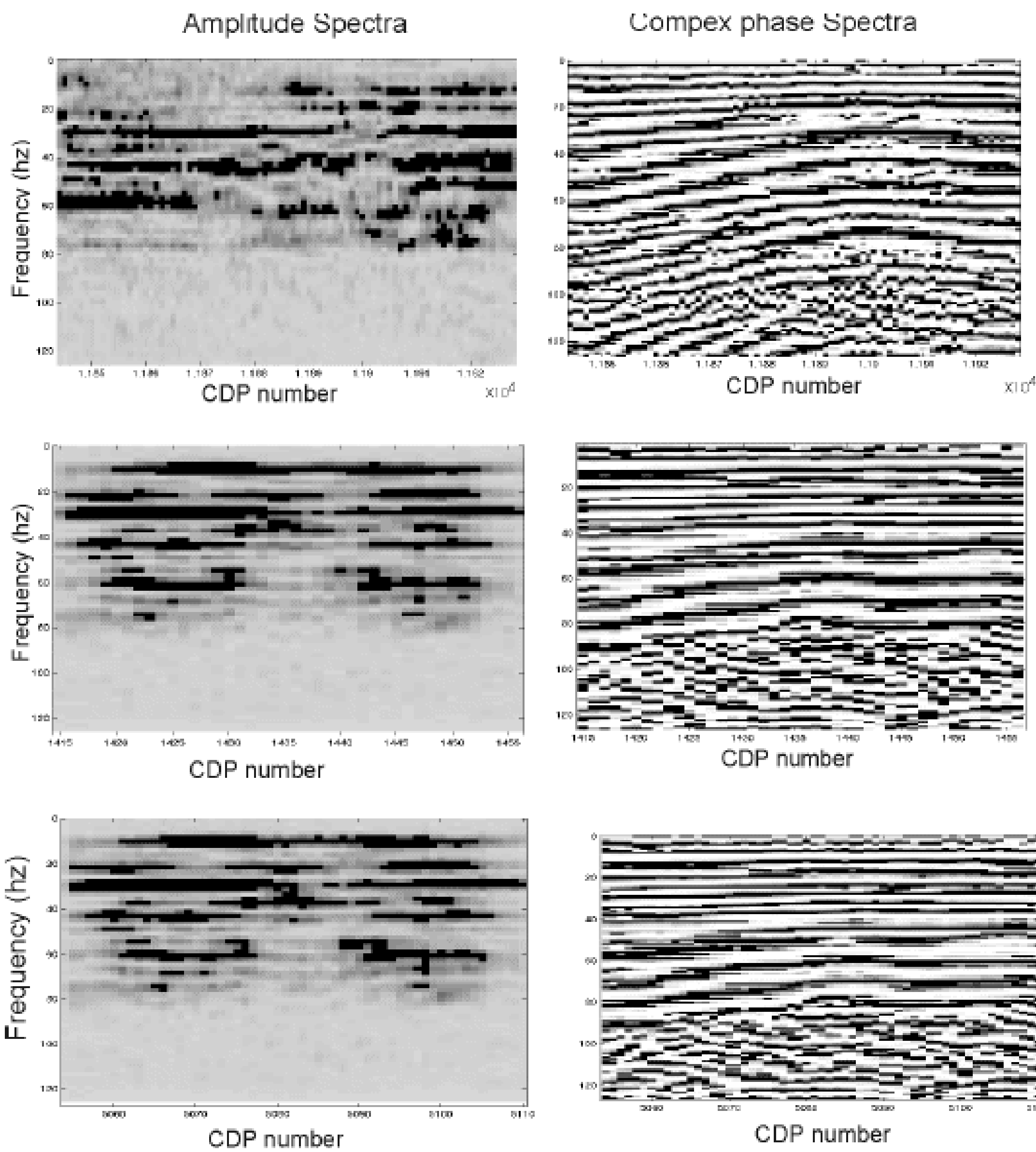

FIG. 5. The f-x spectral analysis for a time window of 0.9-1.3 s in the Glauconitic channel time zone for the vertical component of the Blackfoot area. The f-x spectral analysis of the 1995 data are in the upper panel, the results for the original 1999 data are in the middle panel, and the re-gridded 1999 data are shown in the lower panel.

In Figure 6 is shown the f-x spectral analysis for the vertical data of the 1995 seismic in different time windows. The amplitude spectra and phase spectra are shown for a window of 0.2-0.7 s (upper panel), for 0.7-1.1 s (middle panel) and for

1.1-1.5 s (lower panel). The results for the regridded 1999 seismic data in the same time windows are shown in Figure 7. The different signal bandwidths in different time windows can be seen very clearly in Figure 6 and 7. In the 0.2-0.7 s windows, non-coherence indicates a relatively noisy background. The lower resolution in the 1.1-1.5 s window is due to the earth's filtering effect and is reflected in a lower density of coherent events.

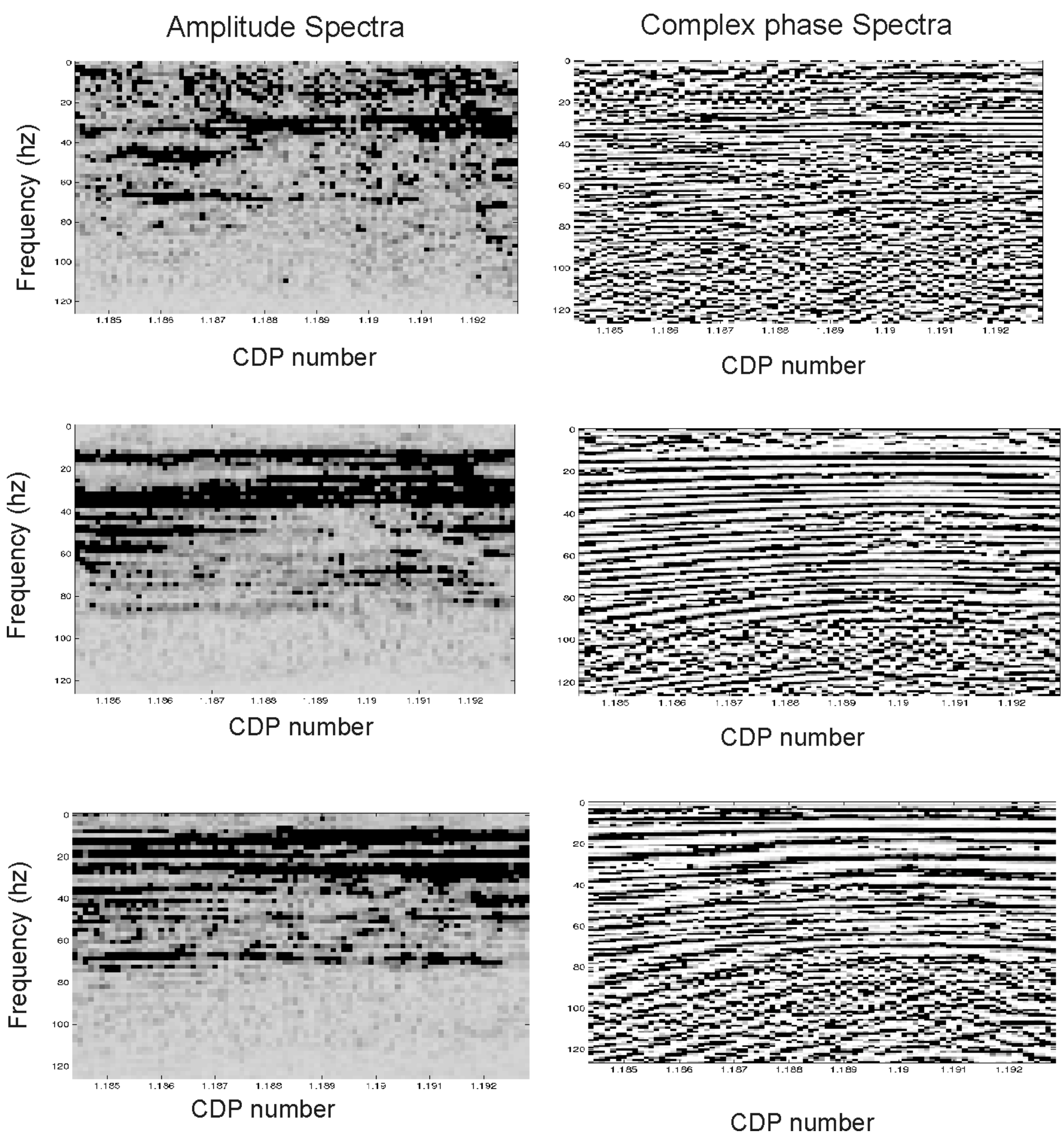

FIG. 6. The spectral analysis for the vertical component of the 1995 data in various time windows (0.2-0.7s, 0.7-1.1 s, 1.1-1.5 s). The amplitude spectra are on the left and the complex phase spectra are on the right.

Figure 7 shows the results of the spectral analysis for the vertical component of the re-gridded 1999 seismic data in various time windows. In this seismic data, the shallow parts are noisier than in the 1995 dataset, so the time windows were chosen as 0.2-0.7 sec, 0.7-1.1 sec and 1.1-1.5 sec. The same conclusion about the resolutions can be obtained in the different windows. Another difference from the 1995 data is that there are fewer problems in the long wave refraction statics. The processing parameters for the 1995 data were used again with the 1999 seismic, so the reason for this phenomenon is unknown.

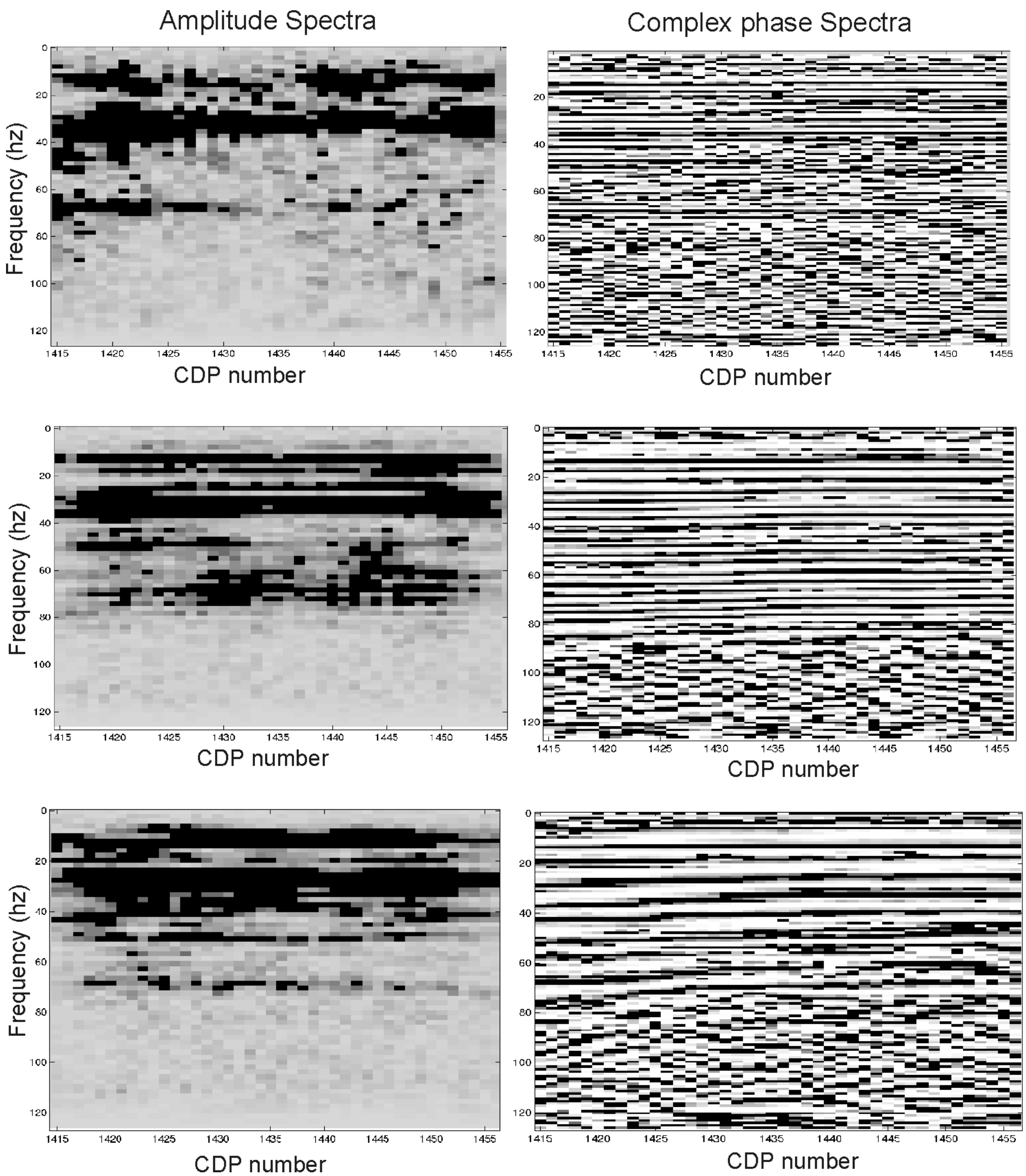

FIG. 7. The spectral analysis for the re-gridded 1999 3C-3D vertical component in different time windows (0.2-0.7 s, 0.7-1.1 s, 1.1-1.5 s).

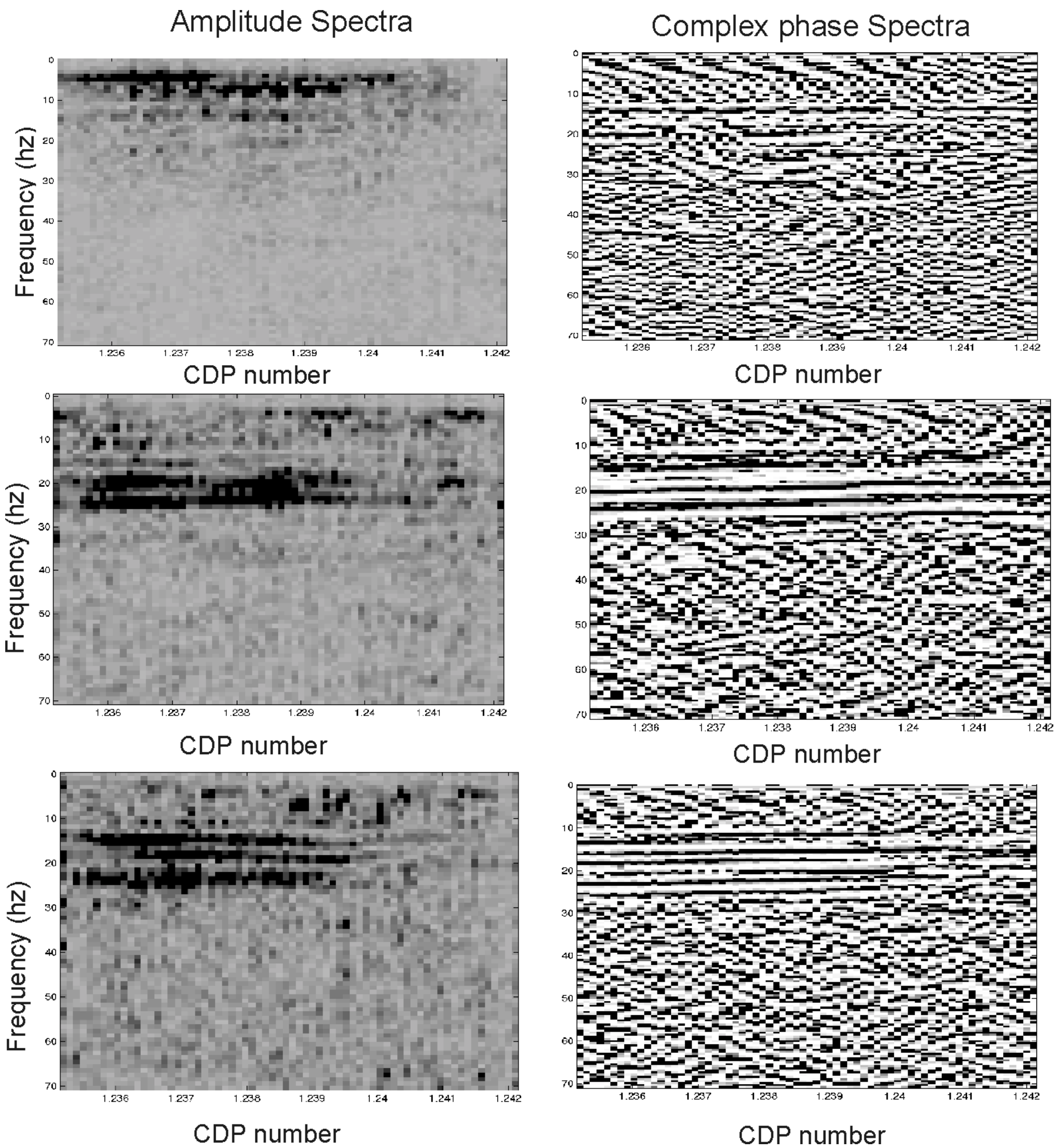

FIG. 8. The f-x spectral analysis for the radial component of the 1995 data in different time windows. Analysis of 0.32-1.12 s is in the upper panel, analysis of 1.12-1.76 s is in the middle panel, and analysis of 1.76 -2.40 s is in the lower panel.

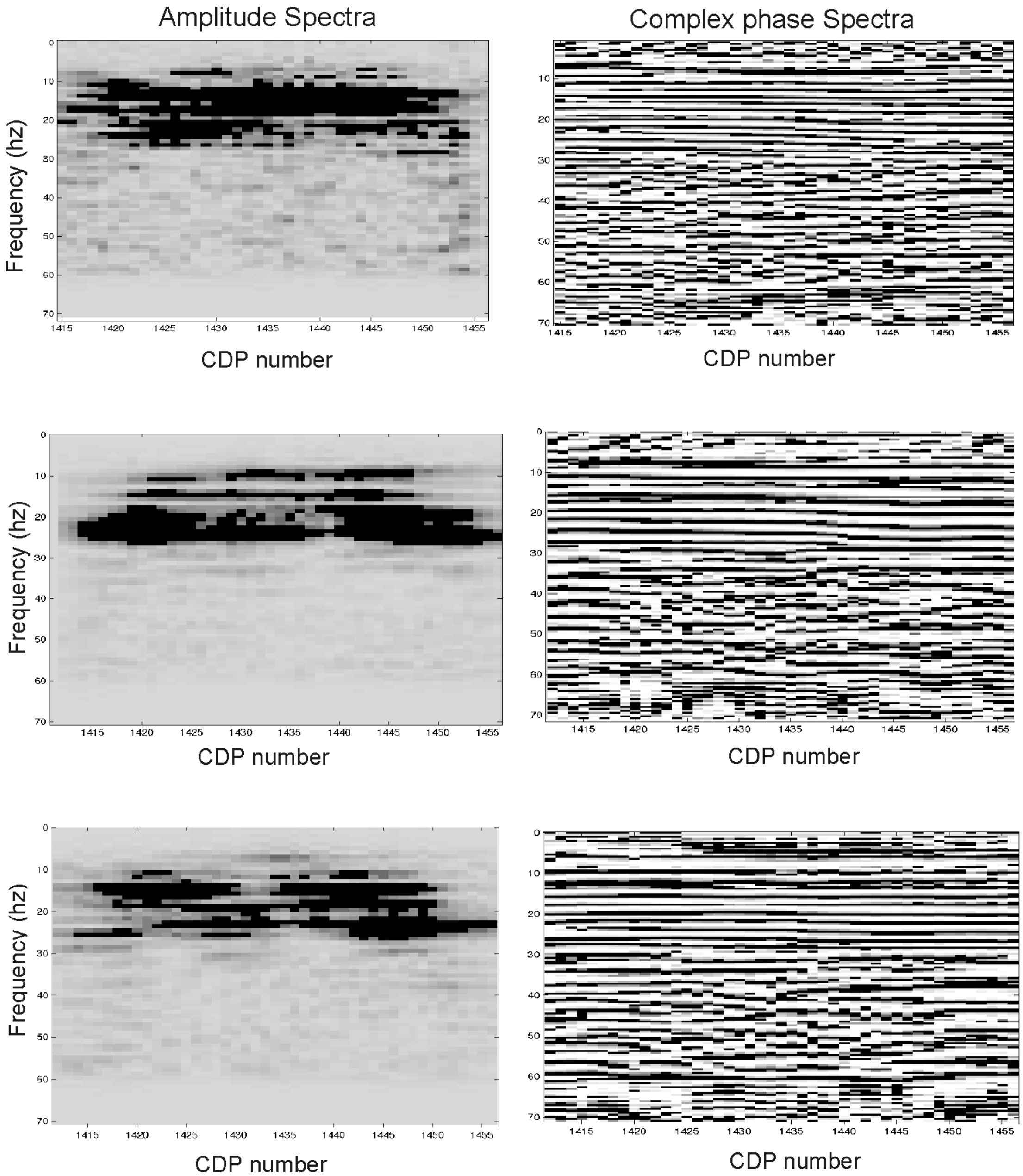

FIG. 9. The f-x spectral analysis for the radial component of the 1999 data in different time windows. Analysis of 0.32-1.12 s is in the upper panel, analysis of 1.12-1.76 s is in the middle panel, and analysis of 1.76-2.40 s is in the lower panel.

Figure 8 and 9 show the results of the f-x spectral analysis for the radial component of the 1995 and 1999 seismic respectively. In the Blackfoot area the S-wave velocities are about half those of the P-wave velocities. From the phase spectra, the 30-35 Hz portion of the signal band can be seen in the all the time windows. Because the receiver hand-statics were applied to the radial component in this data, the long wave refraction statics problems were corrected by flattening the receiver-stacked section.

CONCLUSIONS

The estimation of the signal bandwidth on the stacked seismic section provides a measure of the success of the processing. F-x analysis was applied to the 1995 and 1999 unfiltered migrated section, and the results show that the 1995 data has a higher spectral wavenumber than the 1999 data, perhaps because of the smaller natural bin size determined by the acquisition parameters. From f-x analysis it appears that the migrated seismic sections of the vertical component for the 1995 and 1999 data have similar signal bandwidths. A missing event in the channel area on the 1999 data is probably production related.

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REFERENCES

Goodway, W. and Tessman, D. J., 2001, Blackfoot 3C/3D, A VectorSeisTM case history: CSEG Abstracts, p. 14-17.

Hamarbatan, N.S. and Margrave, G.F., 1998, Spectral analysis of a ghost: CREWES Research Report, Vol. 10, ch. 4.

Hoffe, B. H., Foltnek, D. S. Bland, H.C., Margrave, G. F. and Manning, P. M., 1998, Analysis of array forming using the Blackfoot high-resolution 3-C data: CREWES Research Report, Vol. 10, ch. 1, p. 1-27.

Lu, H.X. and Margrave, G.F., 2001, Reprocessing the 1999 Blackfoot 3C-3D seismic data and anisotropy analysis for the radial component: CREWES Research Report, Vol. 13.

Margrave, G.F., 1999, Seismic signal band estimation by interpretation of f-x spectra: Geophysics, Vol. 64, No. 1, p. 251-260.

Neidell, N.S., and Taner, M.T., 1971, Semblance and other coherency measure for multichannel seismic data: Geophysics, 34, p. 482-497.

Stewart, R.R., Ferguson, R., Miller, S., Gallant, E. and Margrave, G.F., 1996, The Blackfoot seismic experiments: Broad-band, 3C-3D, and 3D VSP surveys: Can. Soc. Expl. Geophys., Recorder, Vol. 21, June, p. 7-10.