

Seismic source comparison for compressional and converted-wave generation at Spring Coulee, Alberta. Part II: Heavy vibroseis-dynamite-mini vibroseis comparison

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ABSTRACT

Seismic data from three seismic sources were compared to investigate their characteristics and identify the best one for the Spring Coulee site in Southern Alberta. The sources employed included a mini vibroseis, which is a commonly used source for environmental and engineering applications. Comparison of raw shot gathers, spectral analysis and stacked sections showed that in the vertical channel, the mini vibroseis data was confined to the first 1.5 s, showing the same strong reflectors as in the dynamite and heavy vibroseis data. However, the mini vibroseis data showed a higher content of random noise, weaker look of the reflections, and lower resolution in comparison with the other two sources. For the radial channel, the mini vibroseis data is of much lower quality, with no energy below 1 s and discontinuous reflectors. From these results, we can conclude that the mini vibroseis is a good source for P-wave energy, but not very effective for converted-wave generation.

INTRODUCTION

The objective of the second part of the source comparison is to show the benefits and limitations of the use of 18,000 lb vibroseis trucks (IVI-envirovibe) for exploration projects that involve the use of converted-wave data. A very detailed comparison of the 48,000 lb vibroseis and explosive source was presented in the first part of this paper. In this second part, we still compare these two datasets but more towards their difference with the mini vibroseis data.

Beforehand, we know that the quality of the envirovibe data is not the best because it was used as a test line during the acquisition; added to the fact that not all the receivers were planted. However, having this type of source recorded with the same recording system as the other two, and enough data to establish a comparison, it was decided to present one of the few case studies where two commonly employed exploration sources are compared with a type of source used for shallow targets and environmental and engineering applications. Our analysis is going to be concentrated on the shallow section of the data and include some of the tools presented in the analyses of part one, such as f-x average Fourier analysis in raw and processed data.

The maximum number of traces per shot is 470 traces, so the fold for these data is decreased. For the vertical and radial channel of the mini vibroseis only 3 s of data were recorded, so all the datasets were shortened to 3 s.

PART II: HEAVY VIBROSEIS-DYNAMITE-MINI VIBROSEIS COMPARISON

1. Raw data: Characteristics of different types of signal and noise

Vertical channel: A first observation about the envirovibe data is the higher content of random noise and the weaker look of the reflections if they are compared with the other two sources (Figure 1). However, signal can be observed clearly up to 1.5 s as in the other two sources. The characteristics of the coherent noise are very similar to the heavy vibroseis data, with less prominent groundroll and low-frequency noise but stronger airwaves and high-frequency noise especially at short offsets and deeper times.

The shot-to-shot variability of the mini vibroseis is evaluated comparing shots from different locations along the line. For both of the vibroseis set of records, it appears to be more consistency in terms of the data character and in the level and nature of the ground roll. The amplitude levels from shot to shot are also more consistent than for the dynamite data.

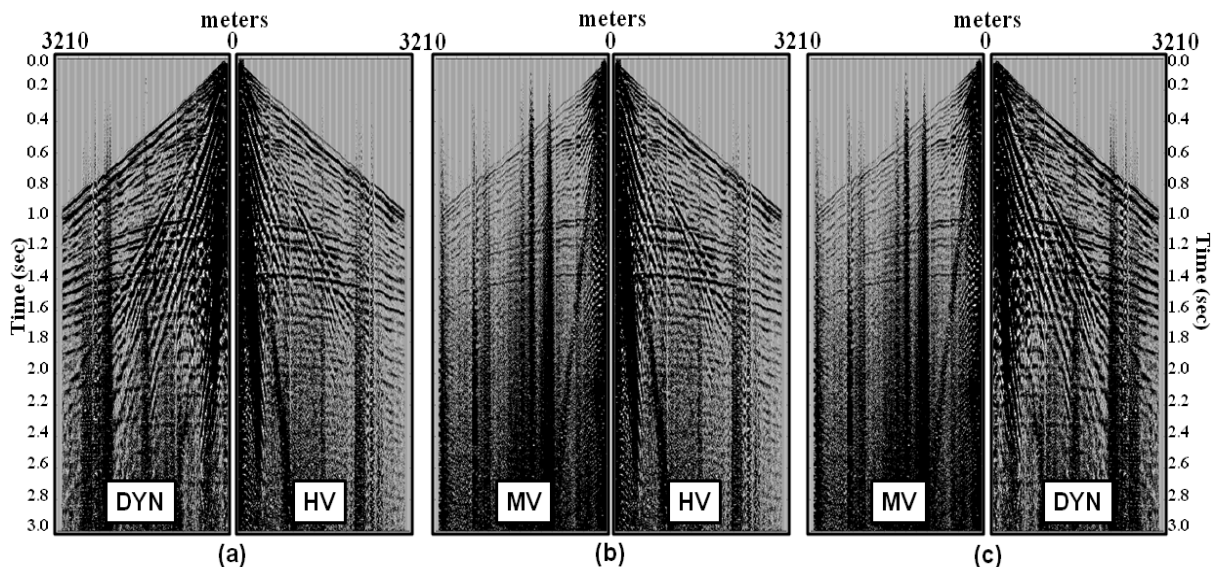


FIG. 1. Comparison of two vertical-component raw shot gathers. In (a), half of a split spread record from the dynamite line and heavy vibroseis line with the lateral coordinate reverse to ease the comparison. The same idea is shown on (b) but for the mini vibroseis and heavy vibroseis data. The final comparison between the mini vibroseis and the dynamite is shown on (c).

Radial channel: In Figure 2 is shown a comparison of half of a split spread shot for the radial channel of the three sources. In the radial channel, the difference with the mini vibroseis data is more dramatic (Figure 2). Not many reflections can be identified and the amplitude level shows a big difference with respect to the other two sources. Only weak data could be observed at the near offsets and early times. The random noise level appears to be stronger than for the vertical channel. Perhaps of the low signal-to-noise ratio of the envirovibe data, there is consistency from shot to shot.

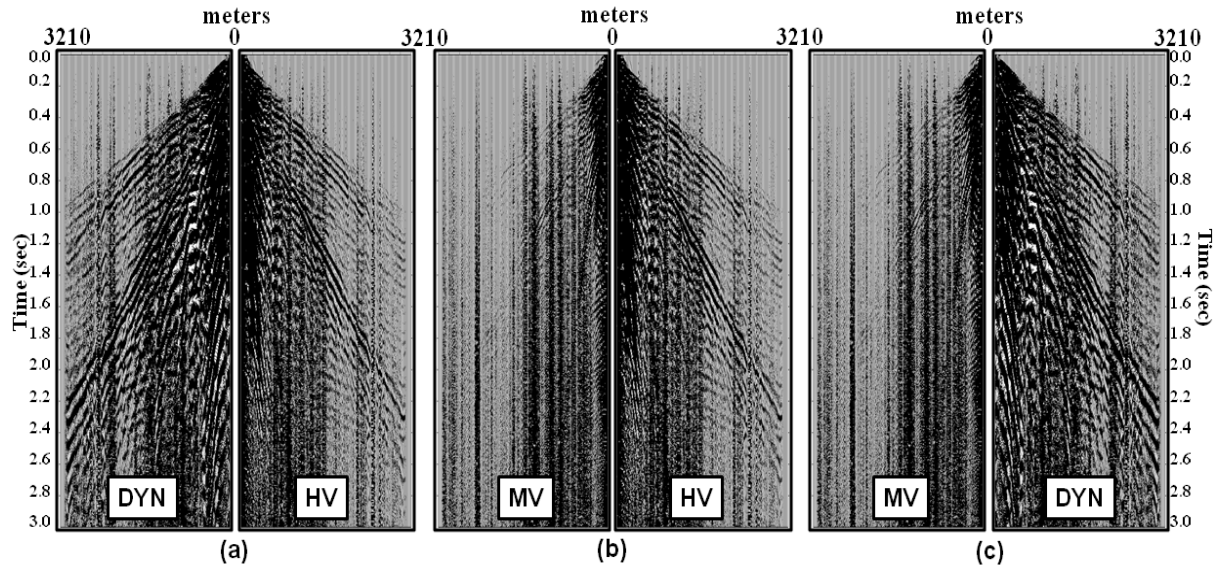


FIG. 2. Comparison of two radial-component raw shot gathers. In (a), half of a split spread record from the dynamite line and heavy vibroseis line with the lateral coordinate reverse to ease the comparison. The same idea is shown on (b) but for the mini vibroseis and heavy vibroseis data. The final comparison between the mini vibroseis and the dynamite is shown on (c).

Unmigrated stacked sections:

Vertical channel: Two portions of the stacked sections are presented in Figures 3 and 4. Figure 3 shows the shallow portion from 0-1 s and Figure 4 shows the portion of the section corresponding to the target zone (0.5 s to 1.5 s). In Figure 3, the events between 0-0.5 s look more continuous and stronger than for the heavy vibroseis and dynamite data. The events between 0 and 0.5 s are similar for the heavy and mini vibroseis.

In the range 0.6-0.8 s the events look more continuous and more resolved for the heavy vibroseis, than for the mini vibroseis and last for the dynamite. For the deeper part (0.8-1 s), the dynamite shows better energy penetration with higher vertical resolution and more lateral continuity of the events. The mini vibroseis shows lower high amplitudes and fewer events at this deeper part of the section.

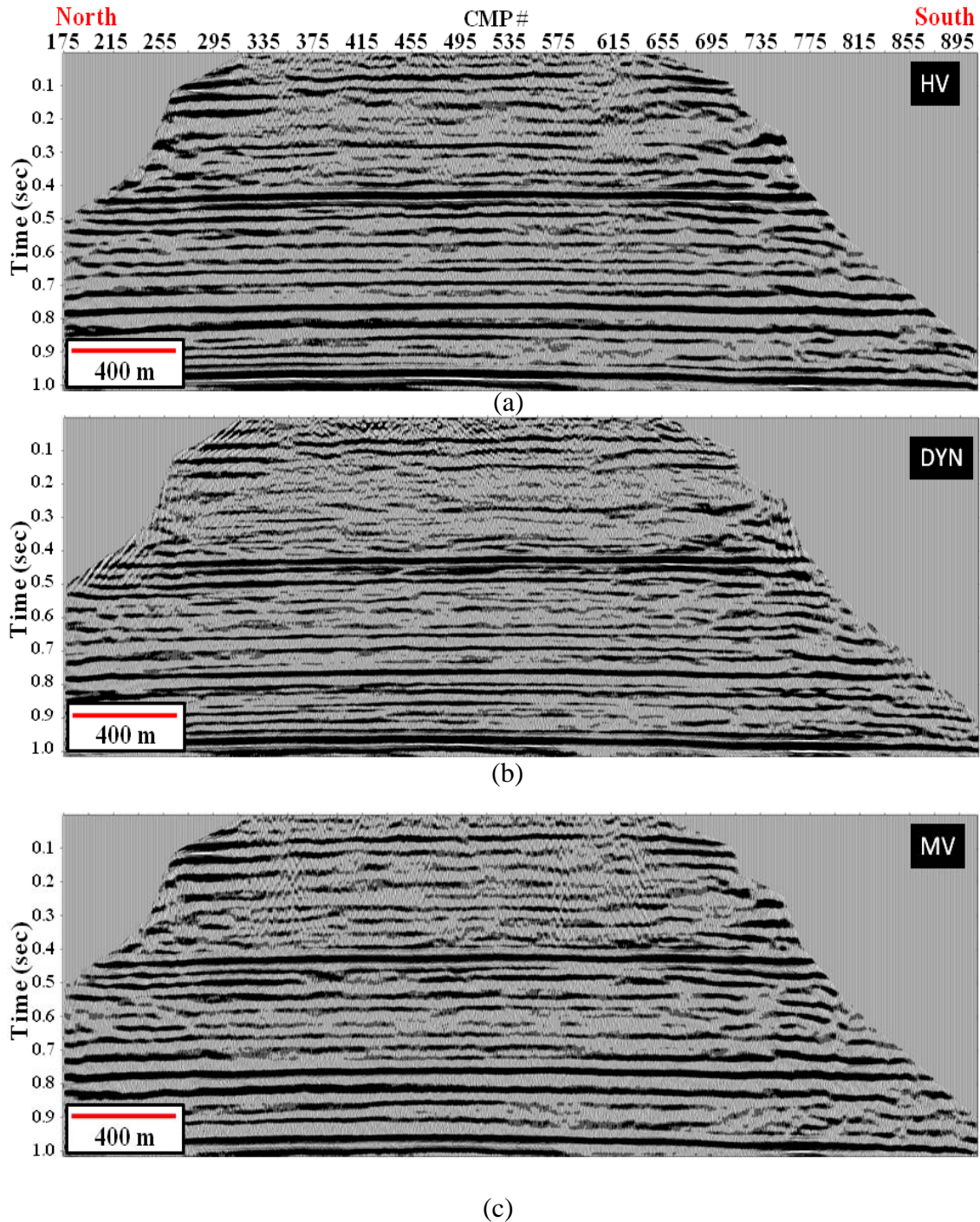


FIG. 3. Portion of the amplitude and phase matched, vertical-component, (a) heavy vibroseis, (b) dynamite and (c) mini-vibroseis stacked section, with zoom in the early times of the section (0-1000 ms).

For Figure 4, the mini vibroseis shows all major reflections for less than 1 s, some of them with better continuity but lower frequency content than for the same events in the heavy vibroseis data. The dynamite is superior at times below 1 s, with better resolution, and then I would say that the heavy vibroseis is second best and the mini vibroseis last.

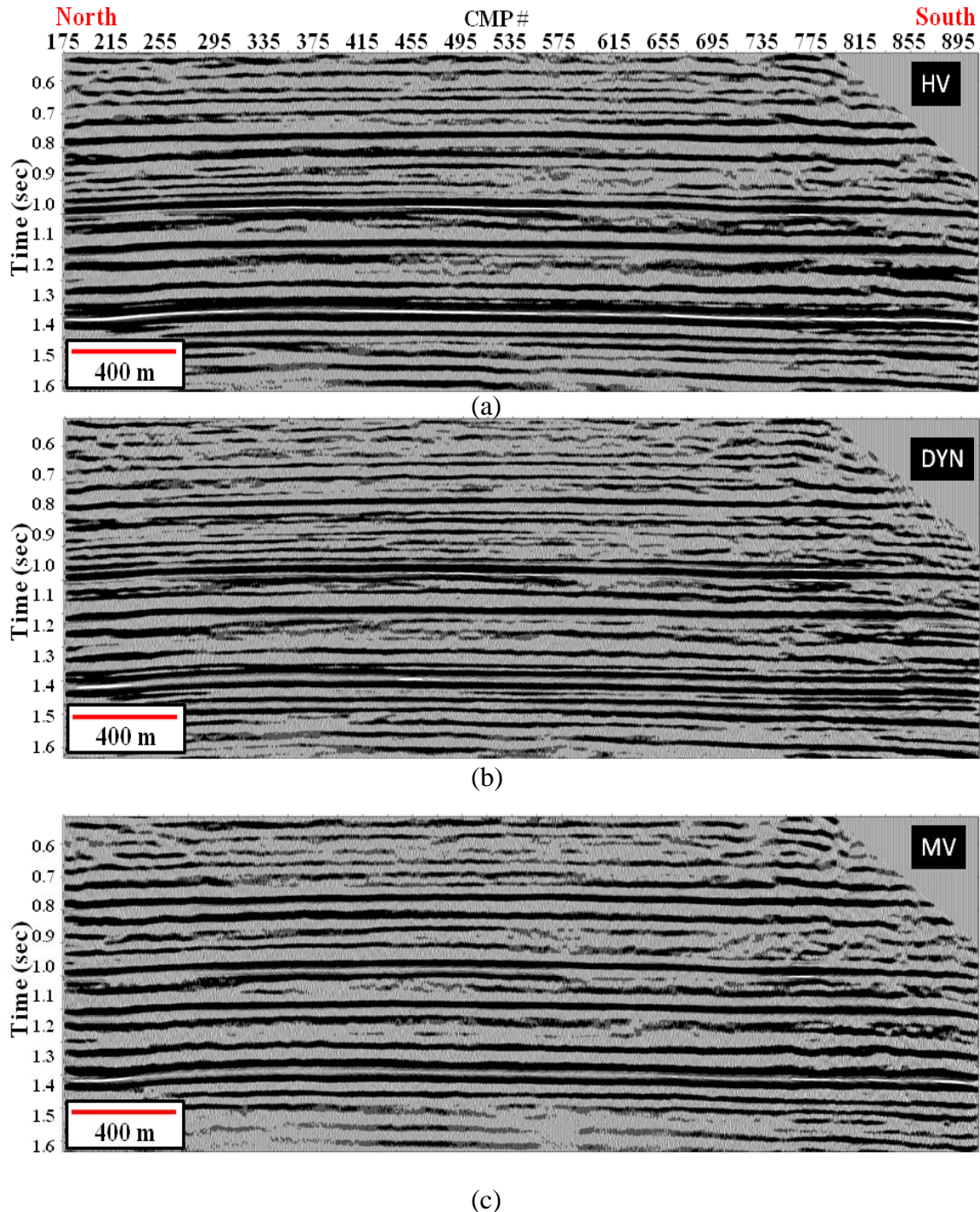


FIG. 4. Portion of the amplitude and phase matched, vertical-component, (a) heavy vibroseis, (b) dynamite and (c) mini-vibroseis stacked section, with zoom in the zone of interest (500-1500 ms).

Radial channel: For the radial channel, the mini vibroseis section is of much lower quality (Figure 5). There is not energy observed below 1s. The strongest reflectors are observed at the ends of the lines. In the center part of the section are not many continuous reflectors. In comparison with the other two sources and based on the stacked section quality, we would not choose the mini vibroseis as an optimum source for converted-wave generation.

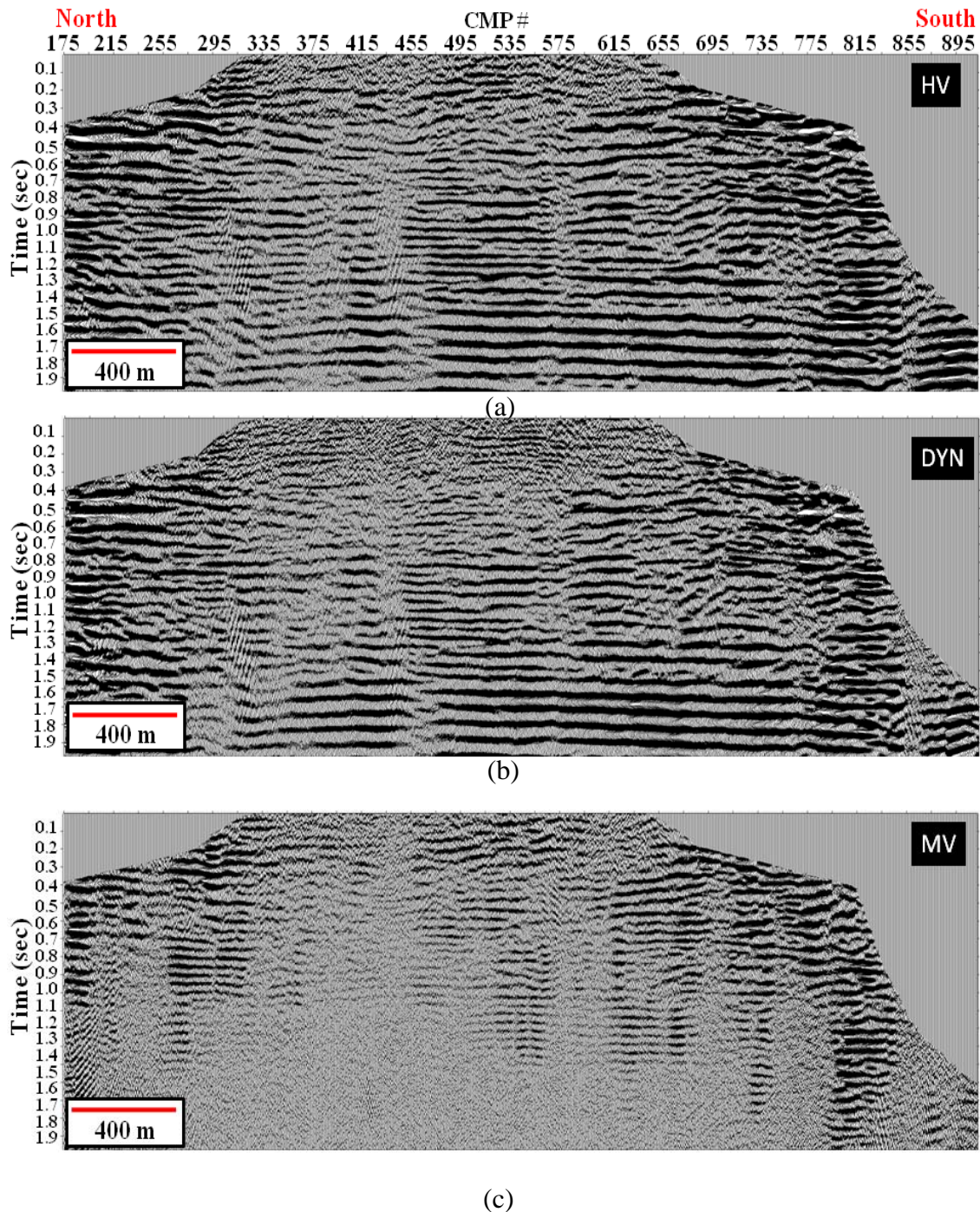


FIG. 5. Portion of the amplitude and phase matched, radial-component, (a) heavy vibroseis, (b) dynamite and (c) mini-vibroseis stacked section, with zoom in the early times of the section (0-1900 ms).

3. Seismic signal band estimation using f-x spectra

3.1. F-x analysis of the raw shot gathers

Vertical channel: An average Fourier amplitude spectrum was calculated on a raw shot gather for a window corresponding to a signal only area (Figure 6a). Up to 50 Hz the three curves have the same shape, but for the range 0-20 Hz the amplitudes are slightly

lower for the mini vibroseis. After 50 Hz, the mini vibroseis curve shows bigger amplitudes with differences of up to 15 dB. At 50 Hz it looks like the corner frequency is reached by the envirovibe. The big difference in the amplitudes after the envirovibe reaches the corner frequency might indicate higher levels of background noise.

The same analysis was done in windows that cover a portion of the first breaks and noise (Figure 6c and 6e). In the first window (Figure 6c), the behaviour of the curves for the three sources is similar in the range 20-50 Hz. For the low frequencies, the amplitude levels are lower for the mini vibroseis data, but for the frequencies higher than 50 Hz it shows higher.

For the window located in the noise area (Figure 6e and 6f), the mini vibroseis shows a much stronger Rayleigh wave with higher frequencies for the vertical and radial channels. In the range 0-20 Hz, apparently there is not any Rayleigh wave for the vertical channel, this is the same case for the radial channel but for the range 0-30 Hz.

Radial channel: The same Fourier analyses were done in the radial channel, for signal, refracted wave and noise windows (Figure 6). In the data window (Figure 6b), the same observations for the vertical channel applied to the radial channel, with the difference that after the corner frequency at 50 Hz the level of background noise look much higher than for the P-wave. For the refracted arrival window, there is not any similarity between the mini vibroseis, the heavy vibroseis and dynamite (Figure 6d). The amplitudes are much higher with almost constant amplitude values across the frequency range. A lack of low-frequency is observed for this refraction event for the mini vibroseis data.

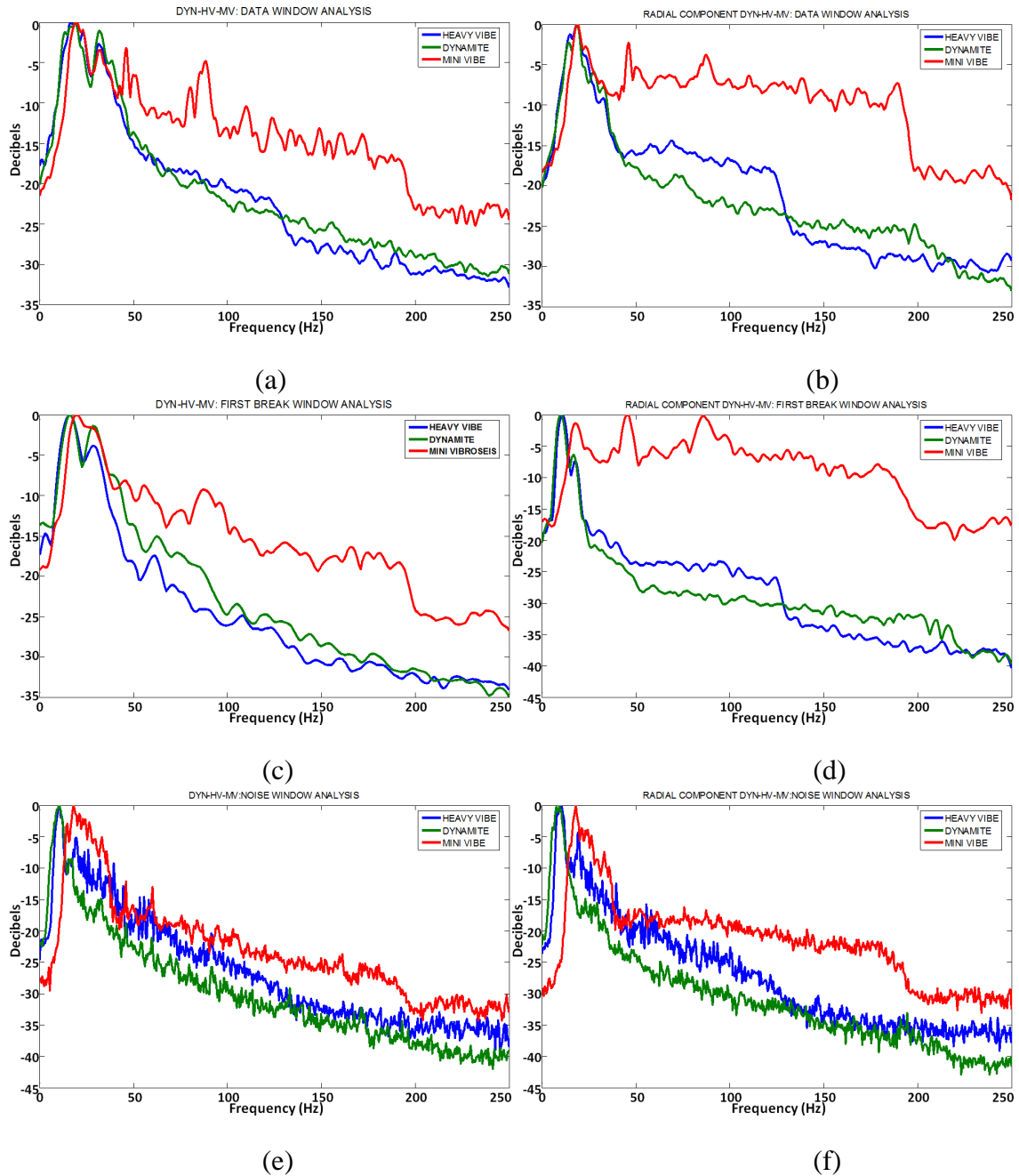


FIG. 6. Average Fourier amplitude spectrum of a raw shot gather for the vertical channel ((a), (c) and (d)) and radial channel ((b),(d) and (f)) of the heavy vibroseis, dynamite data and mini vibroseis, with windows corresponding to: (a and b) signal only area, (c and d) first break area and (e and f) groundroll/noise area.

3.2.F-x analysis of the unmigrated stacked sections

Vertical channel: An f-x analysis of both unmigrated, unfiltered stacks is shown in Figure 5.5 to estimate the realized signal band. While in the dynamite and heavy vibroseis there is a drop in spectral power at 45-50 Hz (Figure 7a and 7c), for the mini vibroseis happens at about 30-35 Hz (Figure 7e). After this frequency there is not any signal. The lower frequencies show up at around 18 Hz, while for the other two sources the events start to be seen at 8-10 Hz.

The phase coherence of the three datasets is contrasted in Figure 7(b), (d) and (f). For the heavy vibroseis and dynamite, there is a reduction in phase coherence at around 60 Hz, for the mini vibroseis this reduction is seen a 40 Hz and its coincident with the drop in spectral power. However, subtle phase coherence persists up to at least 95 Hz for the heavy vibroseis and dynamite, and up to 70 Hz for the mini vibroseis. These observations could be interpreted as a similar signal level below 40 Hz for the three sources.

Radial channel: The same f-x analysis for both unmigrated, unfiltered CCP stacked sections is shown on Figure 8. The f-x amplitude spectrum for the mini vibroseis shows little signal for the range 12-25 Hz (Figure 8e). For the other two sources, clear and strong signal is shown in this range (Figure 8a and 8c). One possible explanation is because of the lack of reflection's continuity for the mini vibroseis data.

The phase coherence of the three datasets is contrasted in Figure 8(b), (d) and (f). The mini vibroseis data shows almost no coherent events, the only weak and coherent event is seen for frequencies between 15-20 Hz and in the CMP range 500-800; this same event is seen in the CMP range 200-500 but with less coherency (Figure 8f).

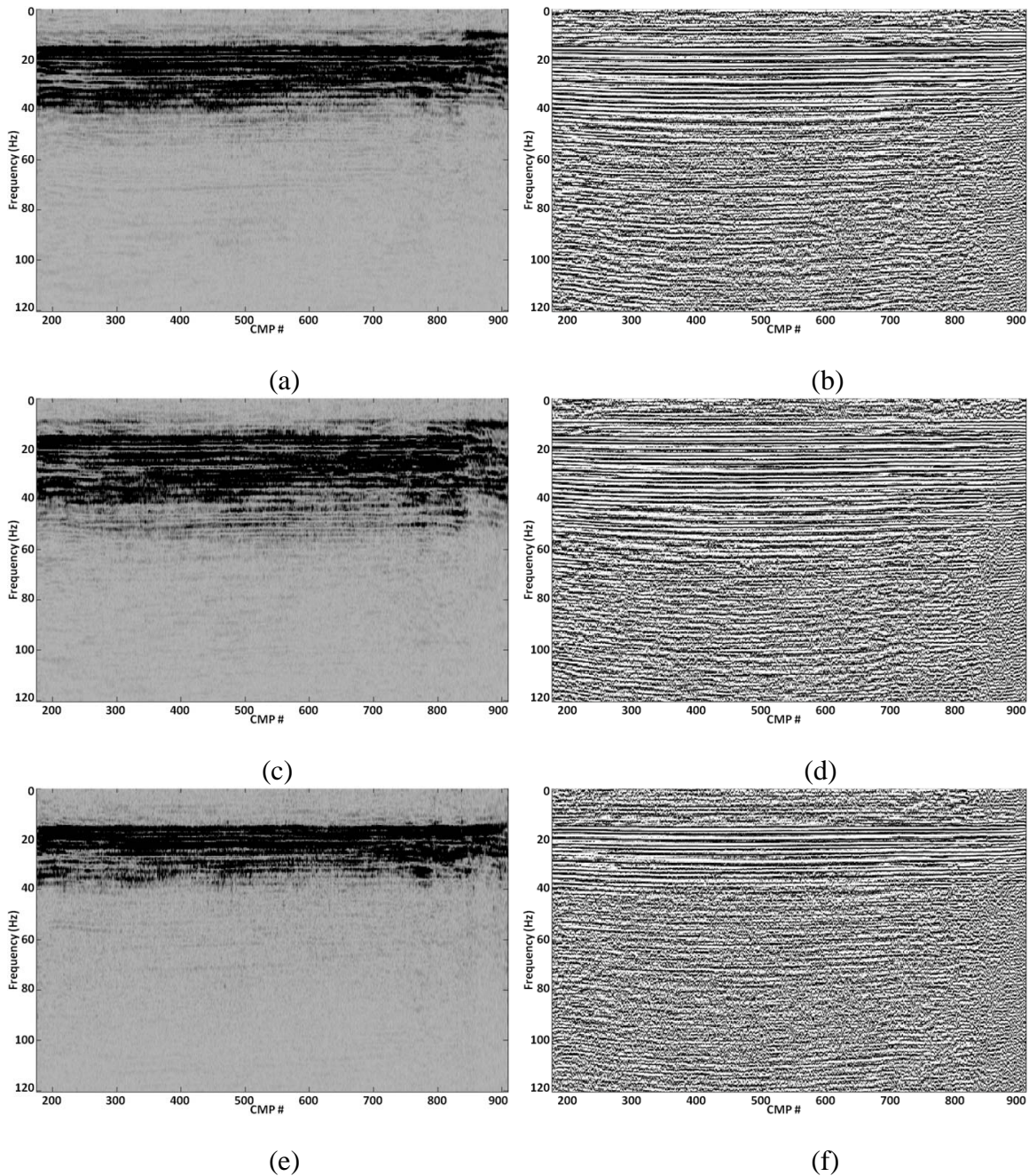


FIG. 7. F-x spectral analysis for the final unmigrated, unfiltered P-wave stack for the comparison heavy vibroseis, dynamite and IVI-mini vibroseis data computed over the time zone 432-1467 ms. The f-x amplitude spectrum for the heavy vibroseis is shown in (a); (c) and (e) shows a similar spectrum for the dynamite and mini vibroseis data, respectively. In (b), (d) and (f) are shown the f-x phase spectra corresponding to (a), (c) and (e), respectively.

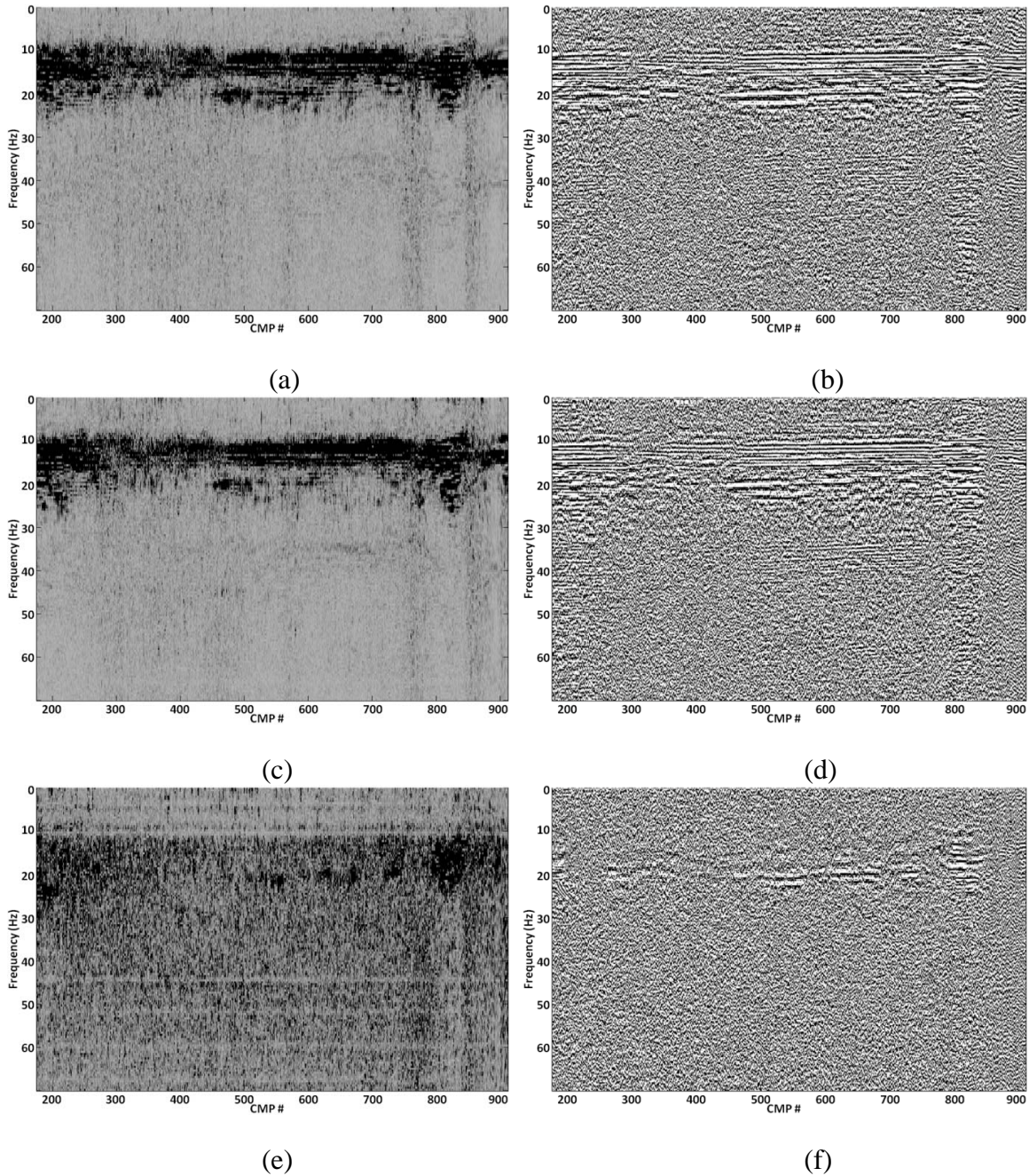


FIG. 8. F-x spectral analysis for the final unmigrated, unfiltered PS-wave stack for the comparison heavy vibroseis, dynamite and IVI-mini vibroseis data computed over the time zone 700-2500 ms. The f-x amplitude spectrum for the heavy vibroseis is shown in (a); (c) and (e) shows a similar spectrum for the dynamite and mini vibroseis data, respectively. In (b), (d) and (f) are shown the f-x phase spectra corresponding to (a), (c) and (e), respectively.

CONCLUSIONS

Most of the analyses undertaken to compare the heavy vibrator and the dynamite, were repeated to include the 3 s of data acquired with our mini vibroseis. The analyses were concentrated on the shallow section of the data. The mini vibroseis vertical-component raw shot gathers showed data up to 1.5 s, and indicated a higher content of random noise and weaker look of the reflections in comparison with the other two sources. The radial channel raw shot gather did not contain many reflectors, only weak data at early time and near offsets could be observed.

The mini vibroseis vertical-component unmigrated stacked sections corroborated some of the raw gather observations: data confined to the first 1.5 s of data, with lower resolution. For the radial channel, the section is of much lower quality than the other two sources, with no energy below 1 s and discontinuous reflectors.

Once again, average amplitude spectra were calculated for the raw shot gathers on three windows for both components. In the vertical-component, the data window showed higher amplitudes for frequencies above 50 Hz that might indicates higher levels of noise; and lower power for frequencies between 0-20 Hz. The noise window indicated much stronger Rayleigh waves for the minivibe for frequencies higher than 20 Hz. In the radial channel, there were no similarities between the three sources for the refracted arrival window; for the data and noise windows, similar observations to the vertical-component applied.

For the signal bandwidth estimation of the mini vibroseis we used the same methods employed in the first comparison. The results of these analyses indicated an apparent signal bandwidth of 18 to 40 Hz for the P-wave and little signal for the range 12-25 Hz for the converted wave. For the P-wave, low frequencies are not observed, while for the converted waves there are not many coherent events.

In general, the mini vibroseis proved to be a good source for generating near-surface P-wave data but not very efficient for converted-wave generation.

ACKNOWLEDGEMENTS

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