Results from comparison tests between sources and geophones in a December 2010 survey at the Priddis test site

Malcolm B. Bertram, J. Helen Isaac, Kevin W. Hall and Kevin L. Bertram

ABSTRACT

An analysis is made of seismic data from a comparison study carried out in December 2010 at Priddis, Alberta. Comparisons are made between two different sources and three types of geophones. The analysis provides a quantitative and qualitative comparison between the onSEIS and EnviroVibe sources, and different geophones.

Filtered shot gathers show that both sources produce reasonable data, although the EnviroVibe seems to be a better energy source for this location with greater bandwidth, providing better definition of the shallow reflections as well as better imaging deeper layers. The processed sections also indicate better results from the EnviroVibe.

The higher sensitivity of the GS-One geophone shows a better signal to noise ratio than the SM24 and RTC4.5 geophones. As expected, the RTC4.5 geophones do have considerably more low frequency data than the 10 Hz geophones, and would be a preferable choice if the focus of the survey were at this end of the spectrum.

INTRODUCTION

The survey was a short field study performed at the University of Calgary Priddis test site in December 2010 to compare the onSEIS electromagnetic accelerated weight drop source with the University of Calgary EnviroVibe, and also to compare SM24 10 Hz geophones with 4.5 Hz geophones rented for the survey and GS-One 10 Hz high sensitivity geophones loaned for the survey by OYO-Geospace. The study presented here analyzes data from this survey.

THE SURVEY

This survey was conducted in the southern field at the University of Calgary test site at the Rothney Astrophysical Observatory. This is the same location used by several earlier surveys, resulting in many CREWES presentations. The survey was positioned to be approximately perpendicular to the regional strike at this location. Figure 1 shows the layout. The shot line was approximately 5 m to the north of the geophone line.

There were three geophone lines laid out parallel:

1. Line 1. Sensor SM24 10 Hz single vertical marsh case geophones spaced at 2.5 m (total of 317) from flag 101 to 180 on the quarter station. Receiver flags in the headers are 1101 to 1417. These were planted using a planting pole so they are close to vertical. These geophones belong to the University of Calgary. Note the header numbering of these receiver locations do not correspond to the flag numbers, but can be derived from them.

2. Line 3. RTC 4.5 Hz land case geophones spaced at 10 m with header values of 3101 to 3180, matching the flag numbers. They were planted normally (stomped) and some were far enough off vertical to reduce output. These geophones were in the standard case and proved difficult to plant in frozen ground. These geophones were rented from R. T. Clark.

3. Line 5. Forty-eight GS-One land case geophones at 10 m spacing over flags 101 to 148. Header numbers are 5101 to 5148. As for the 4.5 Hz geophones, planting was again less than optimal in some cases. These geophones were loaned to the University of Calgary for the survey by OYO-Geospace Canada.

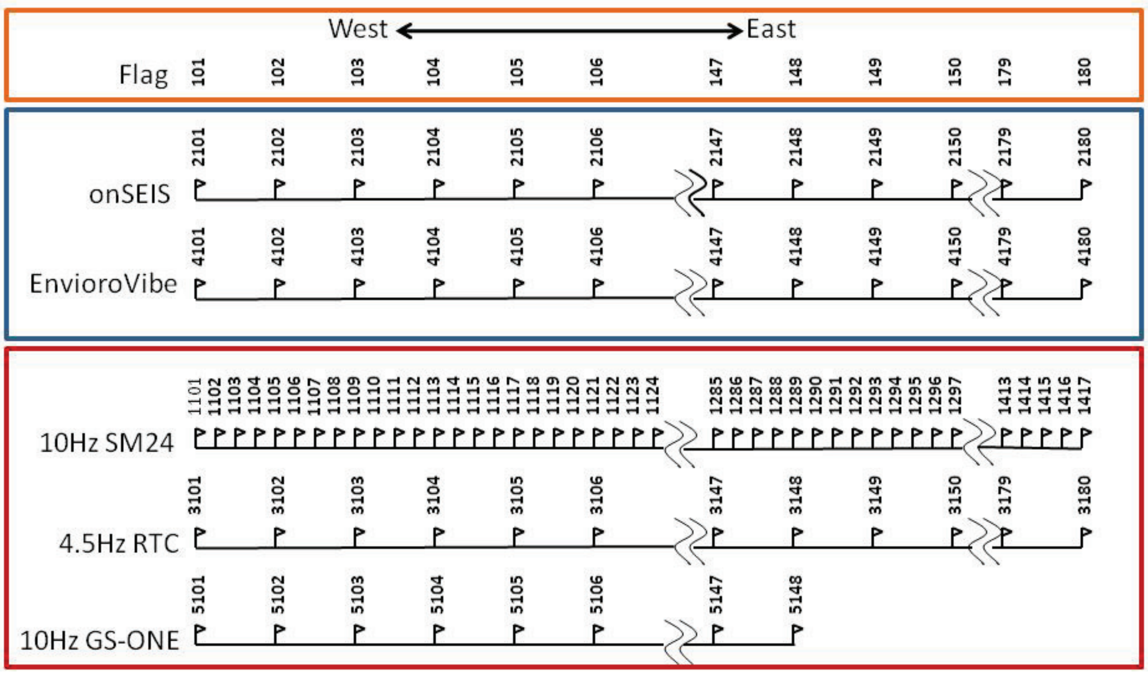

FIG. 1. The layout of the comparison survey.

The line was shot twice, first with the onSEIS, then with the EnviroVibe.

1. Line 2. onSEIS. Shot points were spaced 10 m apart with header values for the shot locations of 2101 to 2180. An onSEIS dual unit was provided by Geokinetics, Inc. This had perhaps less than the maximum output from one of the units but the diagnostic output was not adequate to determine the actual output. The line was started with 8 impacts per shot, then that was changed to 16 impacts per shot after shotpoint 2109. i.e. from 2110 to 2180 16 impacts per shotpoint were used. This source series was shot on Wednesday December 15 2010.

2. Line 4. EnviroVibe. Vibrator points were spaced 10 m apart with header values of 4101 to 4180. The sweep was 10-200 Hz linear over 20 seconds, 4 sweeps

per shot. The vibe pad was set down on the marks left by the onSEIS for exact relocation. This series was shot on Thursday December 16 2010.

The three sensors were grouped together at the flags as shown in Figure 2. The two sources are shown in Figure 3 (onSEIS) and Figure 4 (EnviroVibe).

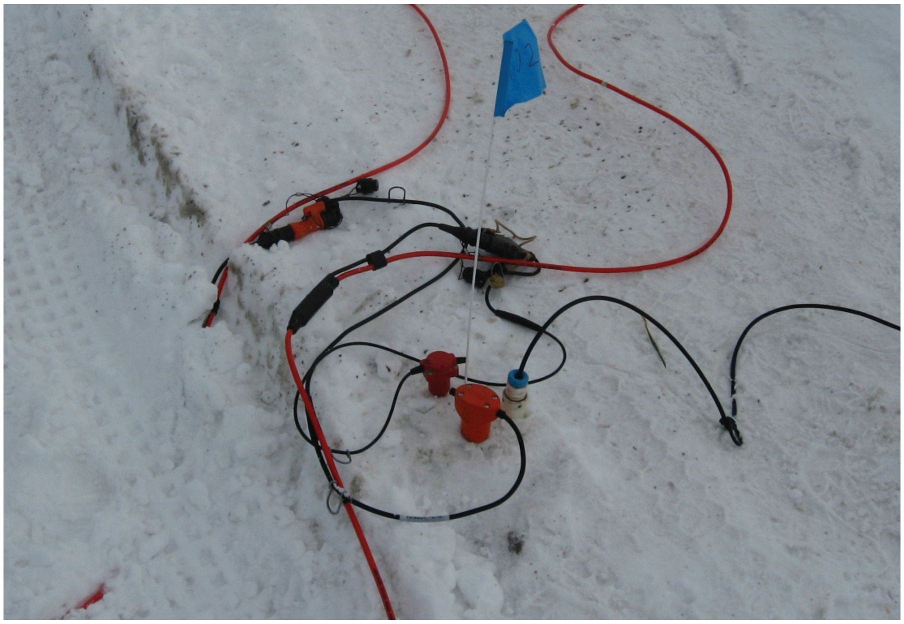

FIG. 2. The geophone cluster at one flag. The blue top case is the SM24 10 Hz, the larger orange case is the RTC 4.5 Hz and the red case is the GS-One 10 Hz.

FIG. 3. The rear of the onSEIS vehicle with the source resting on the ground ready for a shot.

FIG. 4. The University of Calgary EnviroVibe.

SOURCE COMPARISON

The purpose of the source comparison between the onSEIS and the EnviroVibe was to compare the output from the two in terms of both spectrum and power. The onSEIS was the first source used, as it was only available for a short time and had to be returned to Geokinetics. For this section of the analysis, the SM24 10Hz geophones were used for the shot gather plots and the processedsections.

Figure 5 (top) shows the raw data from the onSEIS shot at flag 110. This shot was the first after increasing the number of impacts per shot from 8 to 16; a decision made to try to improve the signal to noise ratio after inspecting the earlier shots. There is clearly data visible at 1 second at far offsets, and at 2.2 and 2.5 seconds. Figure 5 (bottom) shows the corresponding raw record from the EnviroVibe. The same data appear on this record, but with apparently higher amplitude. The noise trains on the two records are very different, as is expected from the different source types.

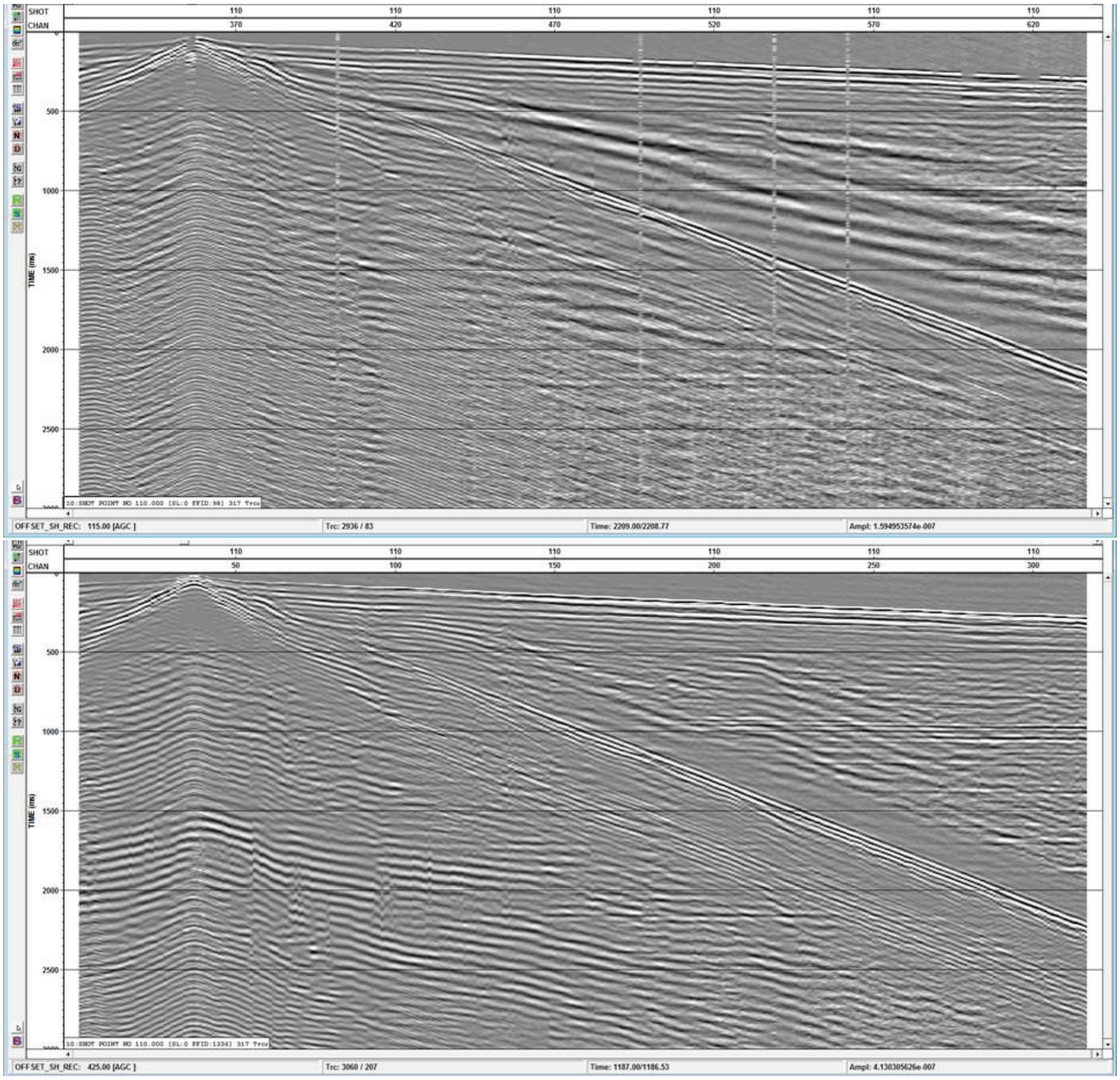

FIG. 5. Shot gathers at flag 110. AGC applied, no filters. onSEIS top, EnviroVibe bottom.

The spectra of these two shot gathers are shown in Figure 6. For this survey, the Aries system was operated with the low cut filter removed to ensure that all low frequency response limitations were due to the geophones and the sources. These plots show that the onSEIS has more low frequency content than the EnviroVibe. This is largely due to the sweep start frequency of 10Hz (the low frequency limit of the EnviroVibe).

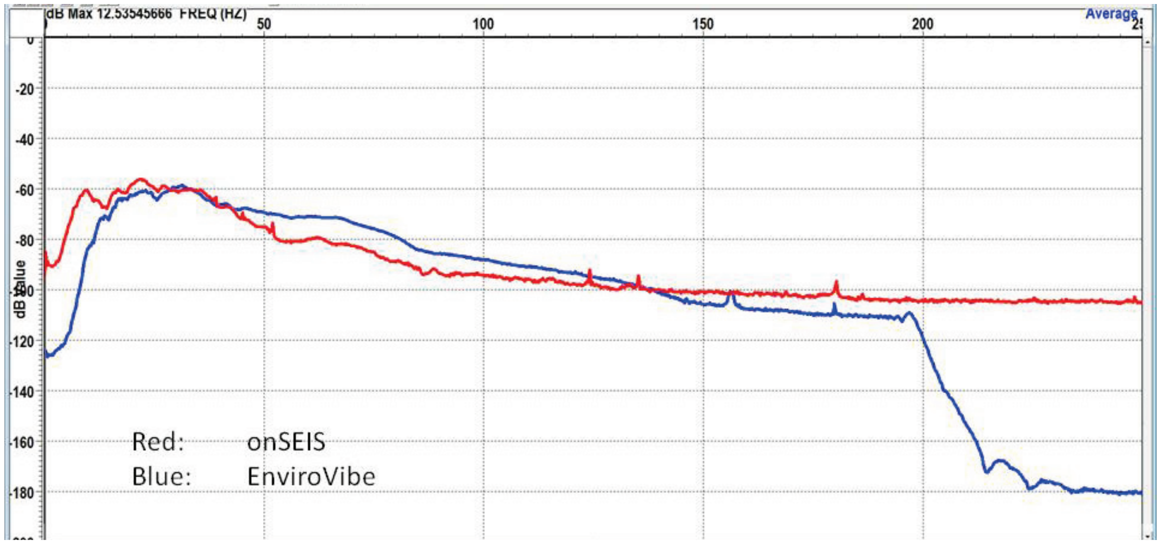

FIG. 6. The spectra of the raw shot gathers at flag 100.

A filter of 10-15-55-60 Hz enhances the events at 1 second and deeper. These filtered gathers are shown in Figure 7. Several events are now visible below 1.5 seconds, and the reflection at 1 second is enhanced. In this plot the onSEIS shows better resolution of the deeper events, with the EnviroVibe data showing more low frequency noise at near offsets. A close look at the 1 second event on these gathers indicates that there is a phase difference between them which was detrermined to be 90 degrees.

Figure 8 shows this 1 second event in detail. This event is stronger in the EnviroVibe data. The dominant frequency of this reflection is 35 Hz, as measured from the data and by spectrum detail.

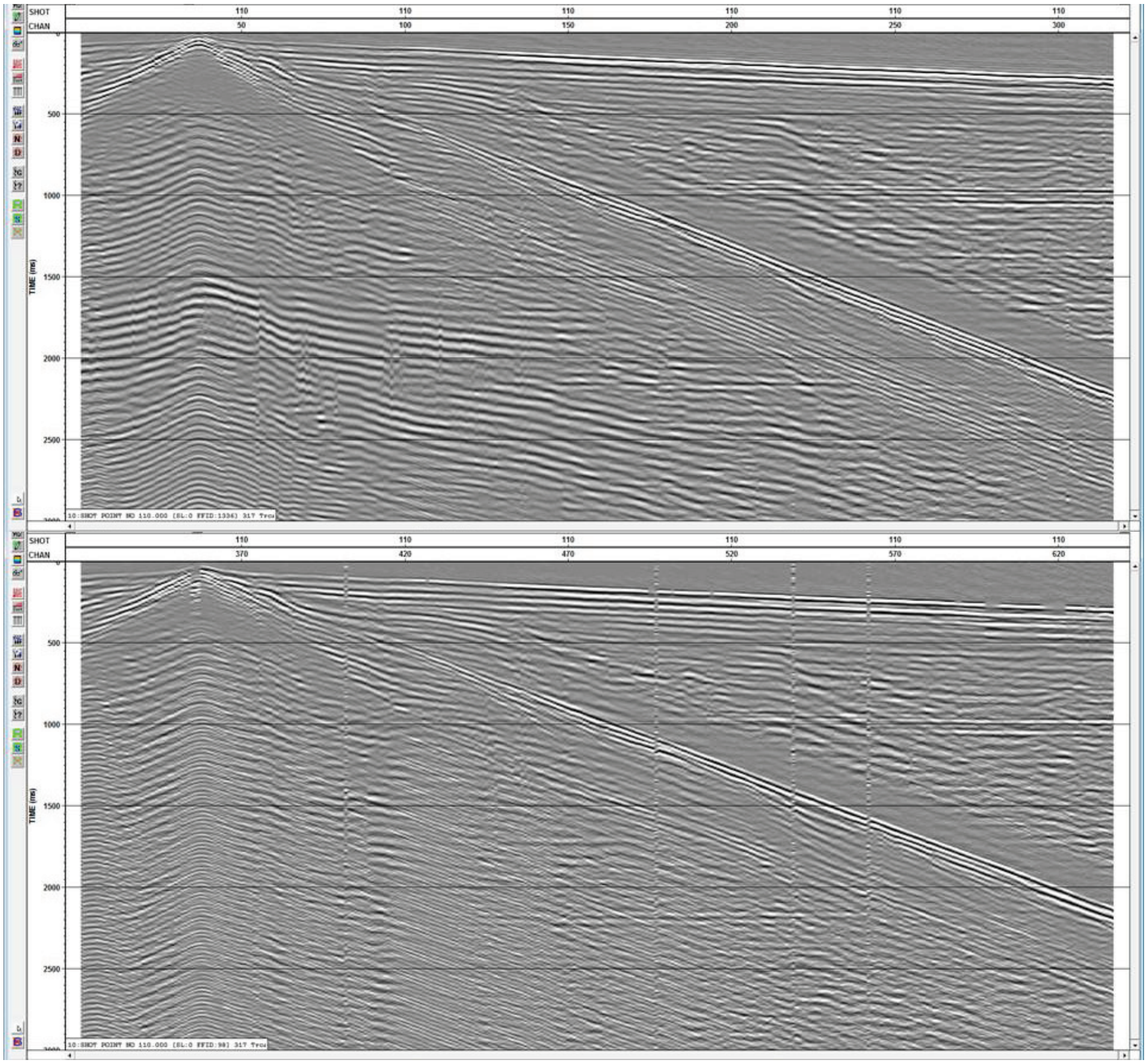

FIG. 7. The shot gathers at flag 110 with filter of 10-15-55-60 Hz. onSEIS top, EnviroVibe bottom.

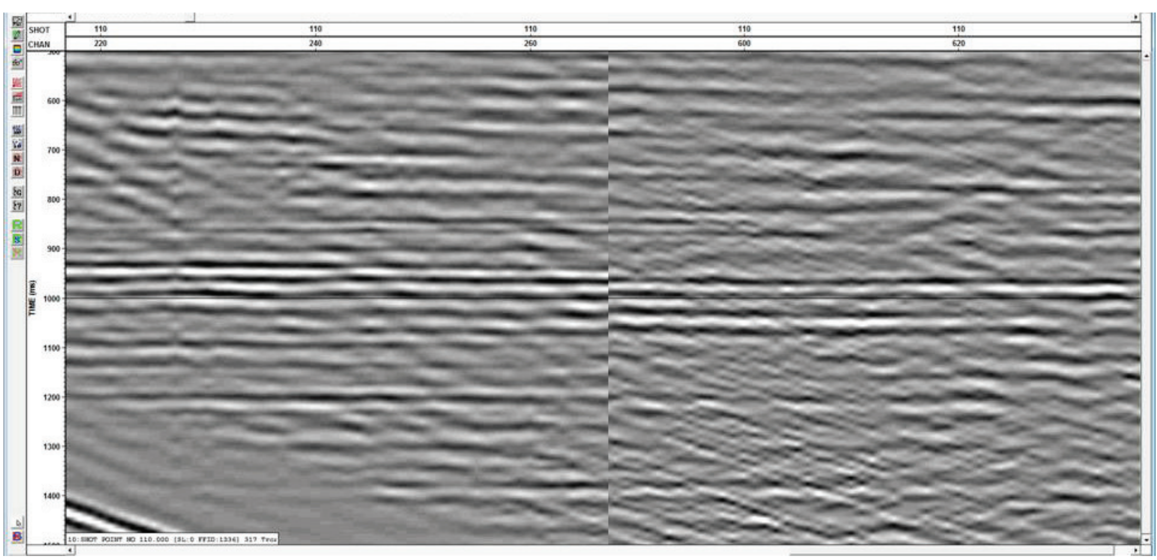

FIG. 8. Detail of the 1 second reflection. EnviroVibe on left, onSEIS on right.

At this shot point (flag 110) both sources are showing information to better than 2 seconds, with the onSEIS appearing slightly higher in low frequency energy.

Another set of gathers, this time in the centre of the line at shot point 140, is shown in Figure 9.

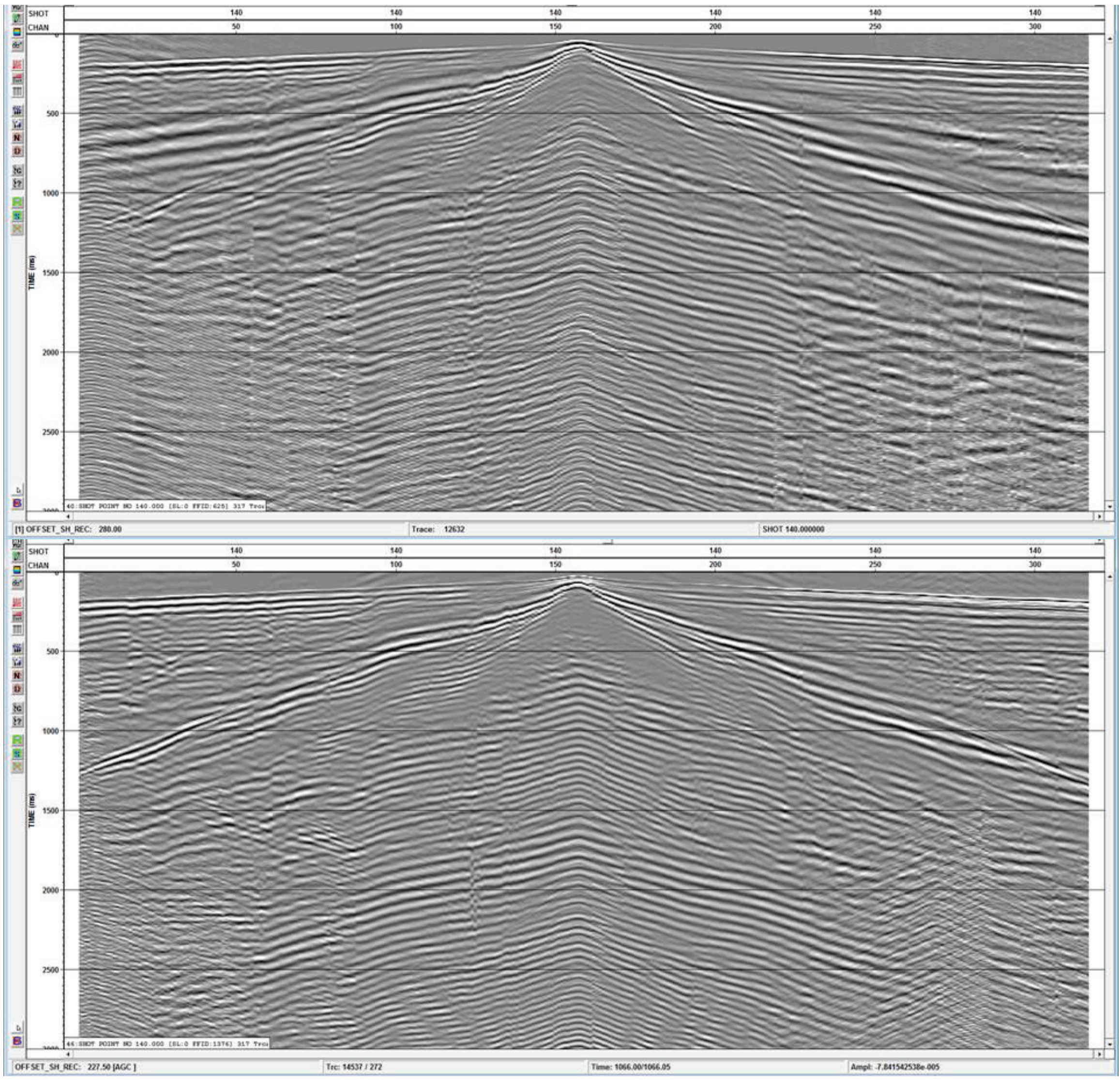

FIG. 9. The raw shot gathers from flag 140. onSEIS top, EnviroVibe bottom.

In this case the two gathers look more similar than the gathers at shot point 110. By applying the same filters as before (10-15-55-60 Hz) there is a disappointing result, as the deep data does not penetrate the noise as well as earlier on the line. Some of this is interpreted to be due to surface coupling in the centre of the line, as the deep data improves once again at the east end. This filter output is not shown here. However, a look at the shallow data is useful. Figure 10 shows the first second of the gathers with a 45-70-250-250 Hz filter appled.

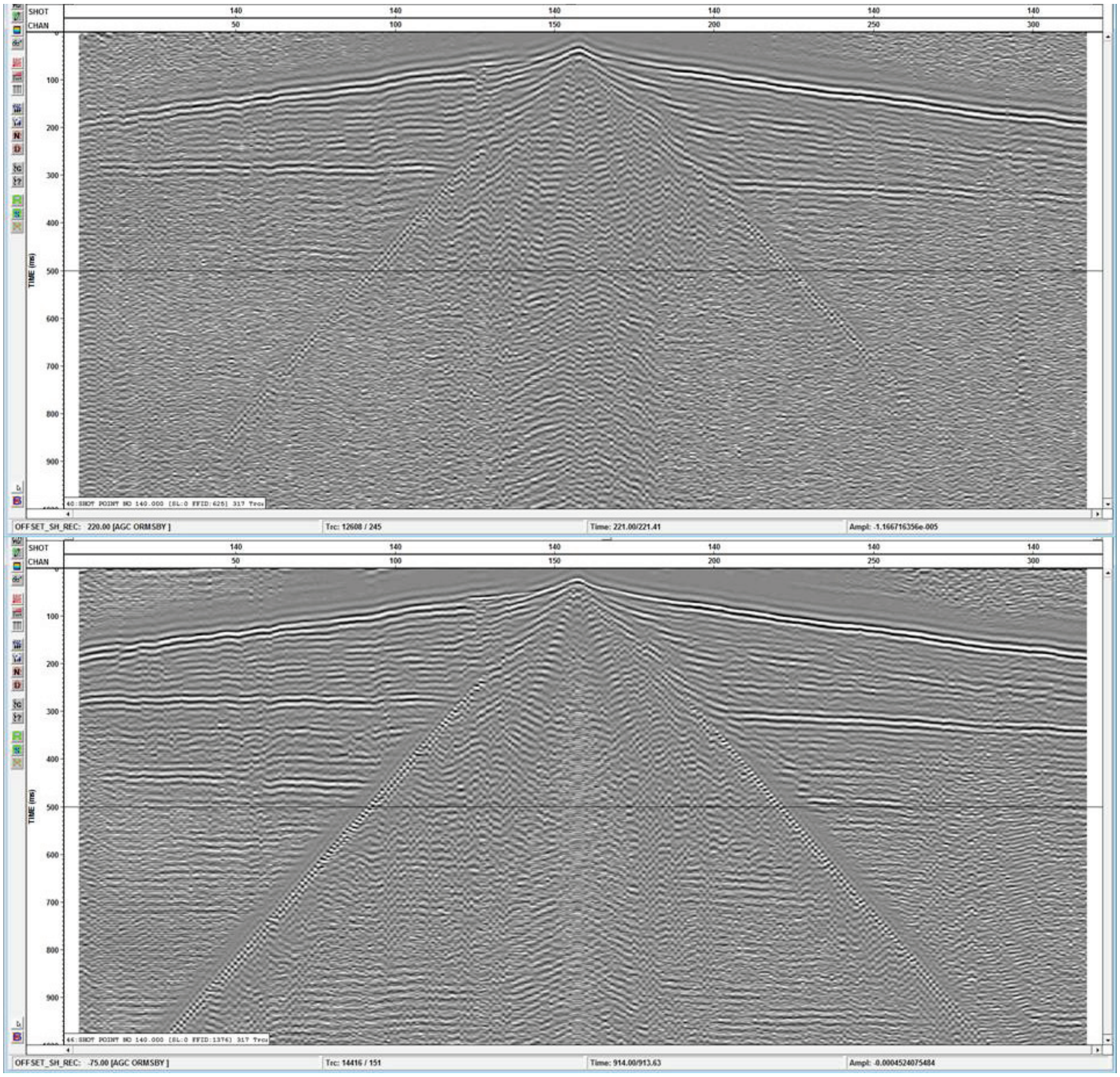

FIG. 10. Gathers at 140 with filter 45-70-250-250 Hz. onSEIS top, EnviroVibe bottom.

The dipping shallow horizons are well defined on both gathers, but the EnviroVibe has decidedly better energy. The 45 Hz low cut was used to remove the noise at the west end (left of the gathers) from the generator on the recorder and traffic on Highway 22. There are several more events visible on the EnviroVibe gather than on the onSEIS gather, indicating the lower output energy of the onSEIS at these frequencies.

The last shot location on the line is at flag 180. Figure 11 shows the raw gathers from this location and Figure 12 shows the gathers with filters of 20-25-40-50 Hz applied.

The filter range 20-25-40-50 Hz was dictated by a number of factors. These included that it was late in the day and traffic noise had increased, affecting the far offset traces, and there was also noise from the generator on the recorder. This is also a common peak in the spectrum for both sources, and this filter helps to enhance the deeper reflections. With the shot at this end of the spread (east) the coupled energy is less for both sources than at the west end. Previous surveys in this area have shown the same –the coupling at the west side of the property is better than further east due to thinner overburden in the west.

These filtered gathers show that the EnviroVibe is providing a better energy source for these conditions with greater bandwidth, although both sources are still showing the reflection at 1 second clearly. The deeper event at 2.2 seconds is not as good on this gather as on earlier ones, and the onSEIS is struggling to overcome the noise which can be seen coming from the west.

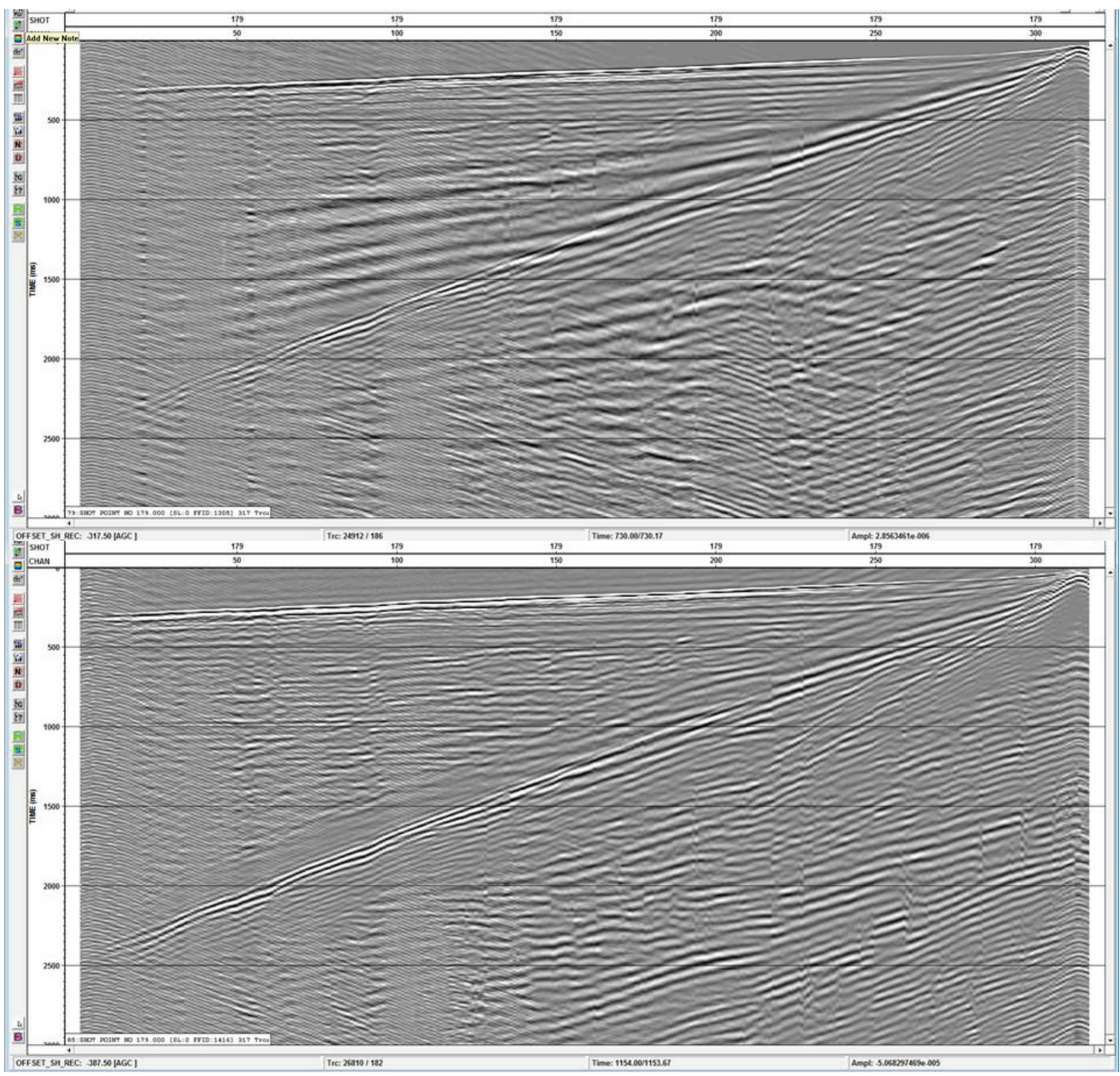

FIG. 11. The raw shot gathers at flag 180. onSEIS top, EnviroVibe bottom.

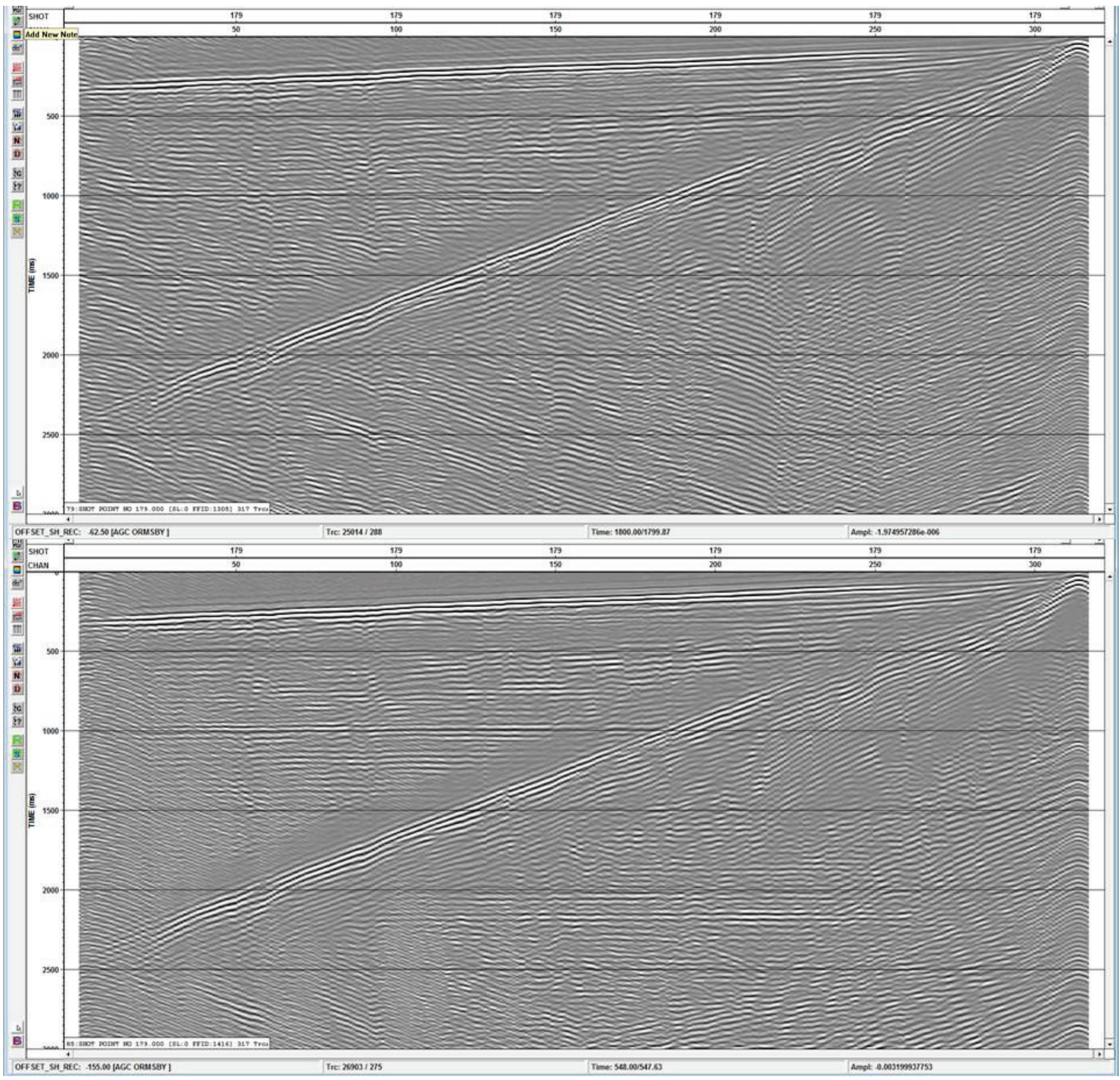

FIG. 12. The gathers at flag 180 with filter 20-25-40-50 Hz. onSEIS top, EnviroVibe bottom.

Once again focusing on the shallow data, Figure 13 shows the first second of data with a filter of 45-70-250-250 Hz as before.

As before, the EnviroVibe shows better data quality for the shallow events. Both sources show some shallow events dipping to the east and coming to surface along the spread. On these gathers the onSEIS shows poor energy in the one second reflector compared to the EnviroVibe.

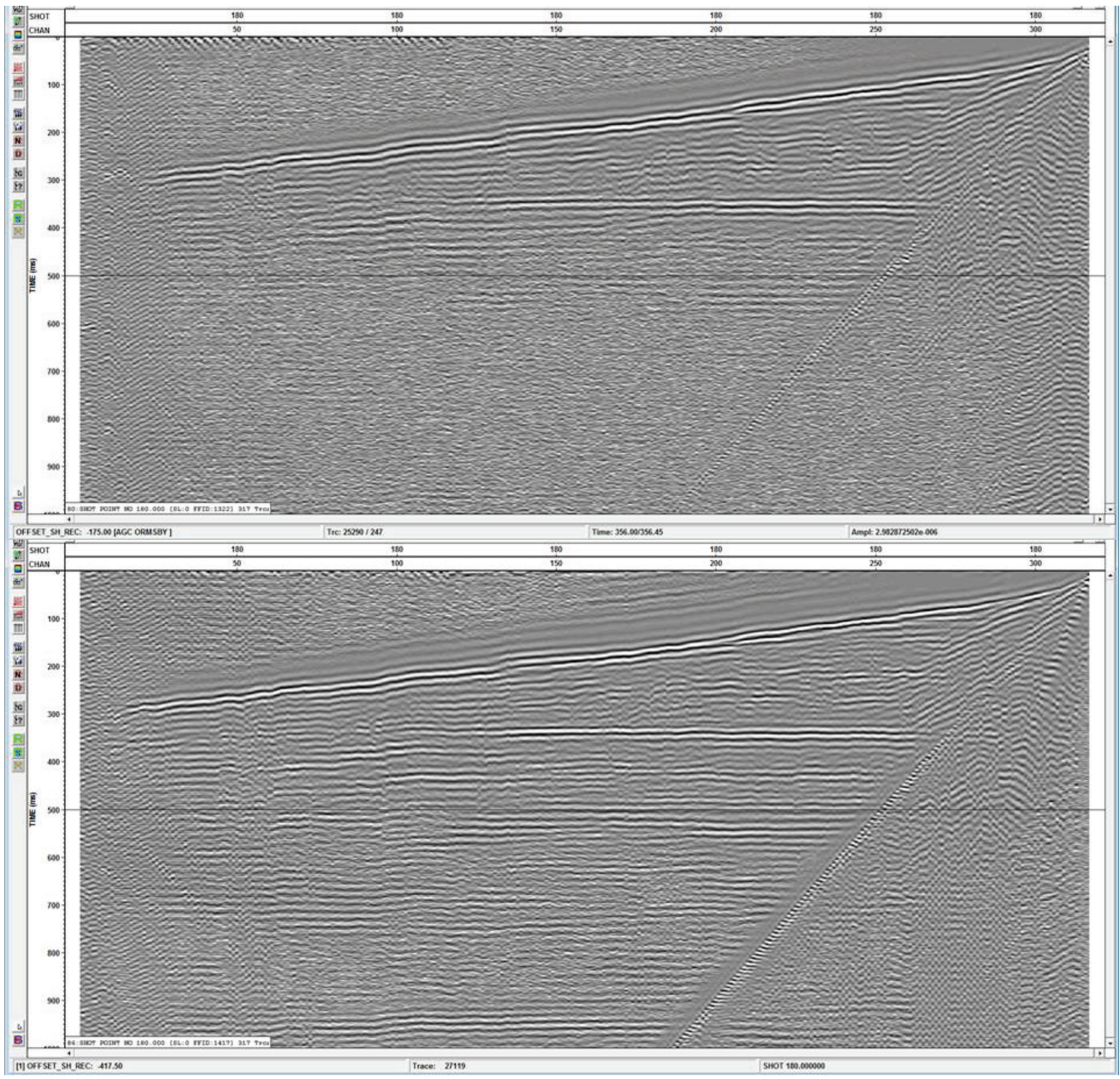

FIG. 13. The first second of the gathers at flag 180 with a filter of 45-70-250-250 Hz. onSEIS top, EnviroVibe bottom.

The data was processed to a brute stack without any mutes applied and using a simple velocity model. Figure 14 shows the spectra obtained from these brute stacks. It is interesting that both spectra have a peak close to a frequency of 20Hz. The onSEIS shows the lower frequency content evident on the gathers, while the EnviroVibe shows the higher frequency content between 30Hz and 130Hz.

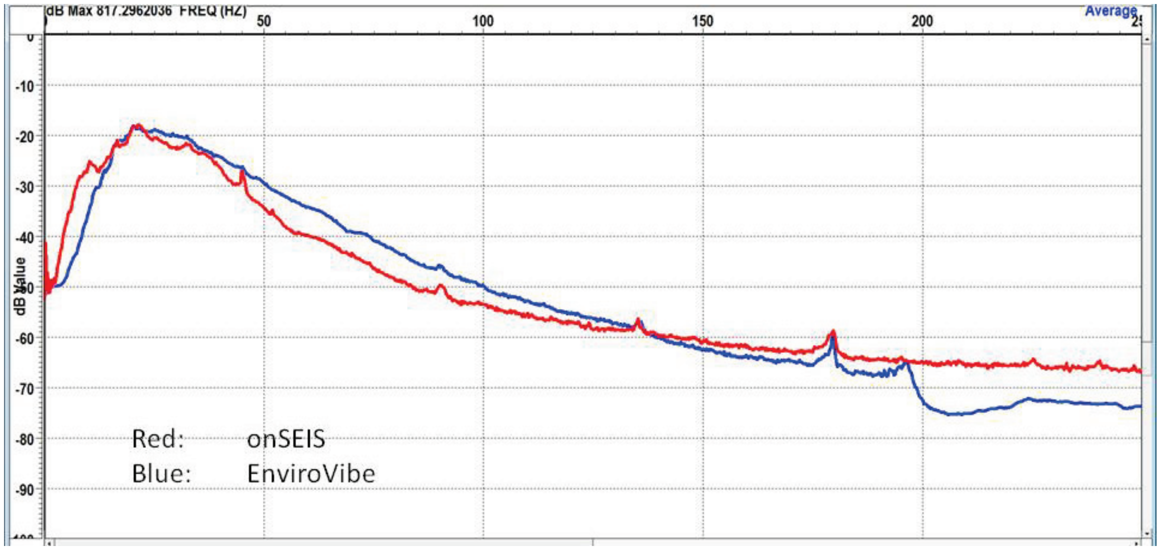

FIG. 14. Spectra of the brute stacks.

We also processed with the same parameters both data sets recorded by the SM24 geophones. The processing included elevation statics to a datum of 1250 m, surface wave noise attenuation (targeting frequencies of 330 m/s and 600 m/s) true amplitude recovery, predictive deconvolution, phase-amplitude Q-compensation and spiking deconvolution.

As noted earlier, a phase difference is observed between the two data sets. A phase rotation of about 90 degrees applied to the onSEIS data rotates the data to have the same first break times as the EnviroVibe data.

We experimented with different stacking velocity functions and different post-stack bandpass filters. The semblance velocity analysis indicated a very low stacking velocity of 2500 m/s in the west, compared with 3200 m/s in the east, which is much closer to the well sonic interval velocities. We ignored these low stacking velocities and stacked the entire line with the higher velocities. This resulted in a continuous dipping reflector at about 300 ms whereas the lower stacking velocities gave a better focussed event in the far west but a large break in continuity in the centre, where the velocities changed. The phase difference between the two stacks can be seen on the unfiltered stacked sections (Figure 15). The EnviroVibe data has more depth penetration than the onSEIS, and images better events below 1.2 s.

Application of bandpass filters cleans up the stacked section. With a low end of 25/30 we still see deeper events at 2.2 s but these events disappear when the low end filter is raised to 35/40 Hz. After experimenting with various bandpass filters to observe the enhancement of reflections at different times, we finally applied a time-variant filter of 0-200 ms: 30/35-100/120 Hz, 200-800 ms: 20/25-100/120 Hz, 800-1200 ms: 15/20-70/80 Hz, 1200-3000 ms: 10/15-45/50 Hz. Figure 16 shows both datasets with the time-variant bandpass filter applied and a phase rotation of 90 degrees applied to the onSEIS data. The onSEIS section now has the same phase as the EnviroVibe data but is shifted slightly later in time. Figure 17 is the same data as in Figure 16 post-stack time migrated.

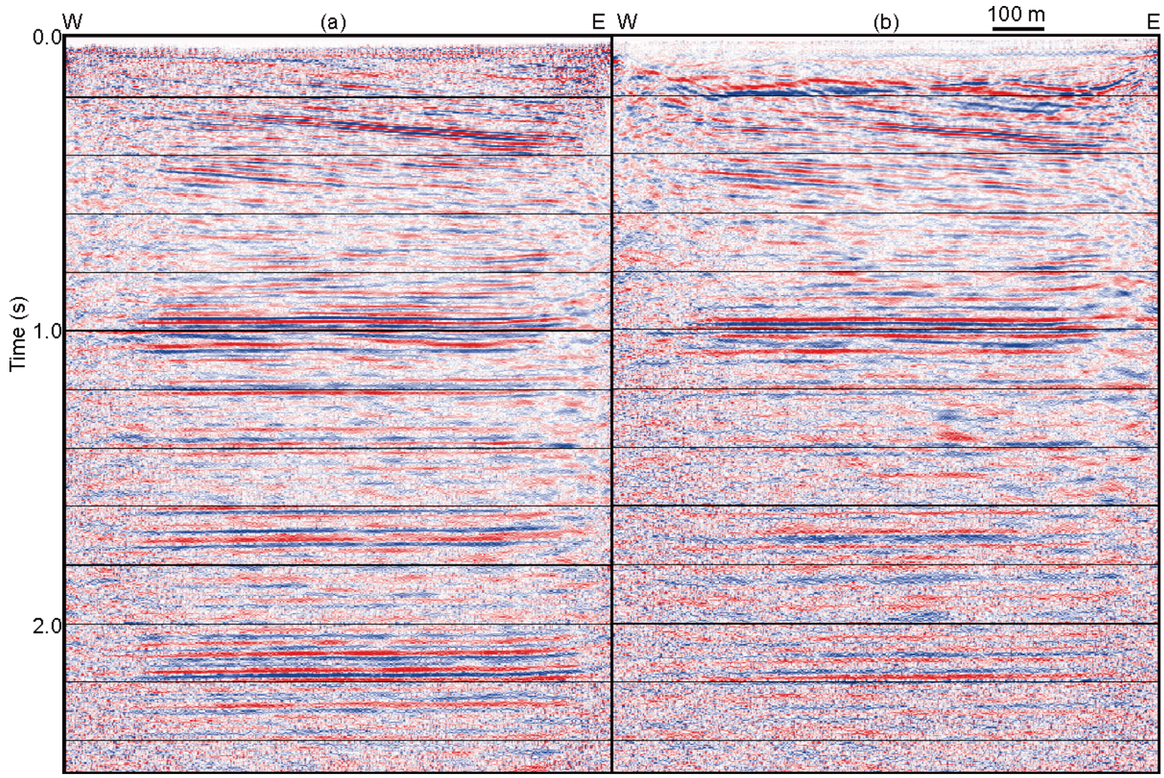

FIG. 15. (a) EnviroVibe and (b) onSEIS stacked sections with no bandpass filter applied.

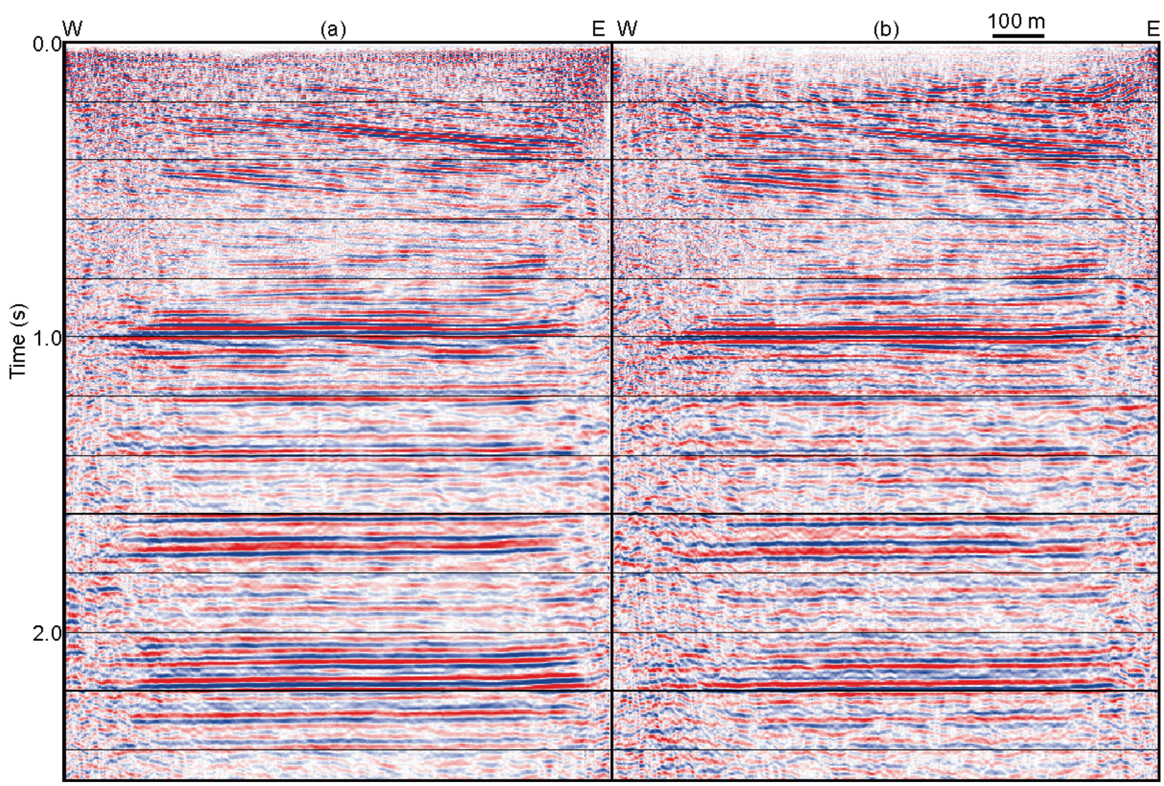

FIG. 16. (a) EnviroVibe and (b) onSEIS stacked sections with a time-variant bandpass filter applied. The onSEIS section has also had a 90 degree phase rotation applied.

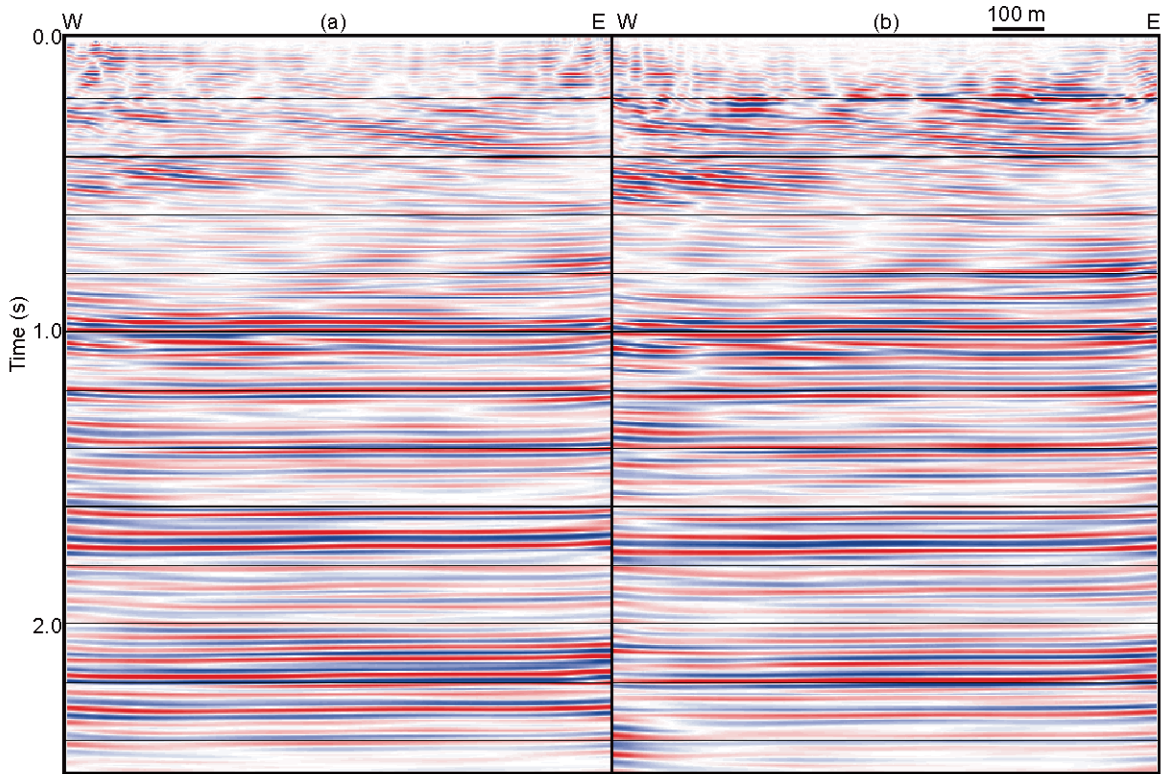

FIG. 17. (a) EnviroVibe and (b) onSEIS post-stack Kirchhoff time migrated sections with a time-variant bandpass filter applied.

CONCLUSIONS ON THE SOURCE COMPARISON

The comparison of the two sources shows that they are both able to provide reasonable data in this area, with events below 2 seconds being imaged. The onSEIS shows a lower frequency content than the EnviroVibe, which is limited to a low end of 10 Hz for mechanical reasons. The EnviroVibe does show much better output at higher frequencies (above 80 Hz) which is an advantage for shallow reflection surveys.

For this survey, the EnviroVibe shows more energy output than the onSEIS, but this is dependent on the number of impacts versus number of sweeps and sweep length. For this survey the onSEIS was giving 16 impacts at each source point, taking between 3 and 4 minutes per flag, while the EnviroVibe was running 4 sweeps each of 20 seconds duration which took just over 2 minutes per flag. To increase the energy output of the onSEIS, either more impacts per station or more onSEIS units firing together would be required. The onSEIS cycle time was not optimized for this survey, but a check of the specifications shows that it should be able to fire again 4 seconds after the previous impact, in which case the time per shot would be about the same as the EnviroVibe (for 16 thumps). The cycle time for this survey (from the observer logs) was about 9 seconds.

THE PRIDDIS GEOPHONE COMPARISON

The use of the onSEIS source with the lower frequency output makes it possible to compare the response of the three different sensors used in this survey. The Sensor SM24 10 Hz geophones belong to the University of Calgary and are an industry standard unit. The RTC 4.5 Hz geophones were rented from R. T. Clark and are of Chinese manufacture. The OYO-Geospace GS-One is a recently developed high sensitivity geophone with a higher coil resistance, and 48 were loaned to the University of Calgary by OYO-Geospace for this survey. When using these higher coil resistance geophones (1800 ohms) the damping factor for the sensor is largely dependent on the input resistance of the instruments. The specifications are for a 70% damping with an instrument input resistance of 20 Kohm.

The geophone output comparisons are made using receiver gathers, as there are only 48 of the GS-One geophones on the spread, at flags 101 to 148. The data has not been gained or muted in any way before this analysis. Figure 18 shows the gathers for the geophones at flag 109. The flags below this were too noisy for a good comparison, as the recorder was parked near flag 101 and this was also very close to Highway 22.

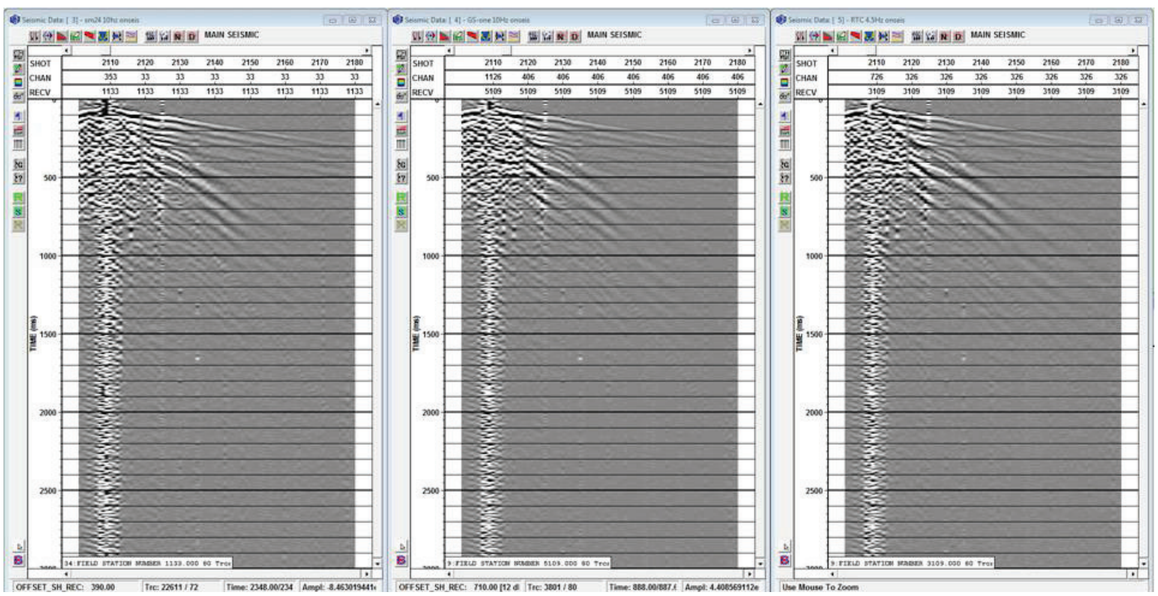

FIG. 18. Receiver gathers for flag 109 for all onSEIS shots. From left: SM24, GS-One, RTC4.5.

Figure 19 shows the spectra for these receivers, and a zoom of the range 0-50 Hz. From this plot the main power of the onSEIS is clearly below 50 Hz, with a peak at about 20 Hz. From the full plot, the GS-One has about a 10 db improvement in signal over the SM24 and the RTC4.5. This shows as the gap between the traces at the high frequency end of the plot. This same 10 db improvement is also apparent at the very low frequencies, visible in the zoomed plot where the GS-One plot also shows about 10 db separation from the SM24. The frequency at which the signal devolves into noise on the GS-One also appears to be lower. If the minimum on the trace is considered to be the apparent noise point, then the SM24 gives about 2 Hz, the GS-One about 1 Hz and the RTC4.5 is also about 1 Hz. For most of the spectrum, the RTC4.5 matches the SM24 very closely, with the expected separation below 12 Hz as the SM24 response begins to drop off. At frequencies below 10 Hz, the RTC4.5 shows about 10db higher output than the SM24 as is expected. From the plot of the RTC4.5 it appears that the onSEIS source is providing good energy down to 10 Hz, with a fall off from there to 5 Hz, below which point the geophone response obscures the information. From work on the source comparison in the first section of this paper, it is apparent that there is useful reflection energy up to about 80 Hz from the onSEIS. At this point the spectra show a level about 30 db below the peak at 20 Hz.

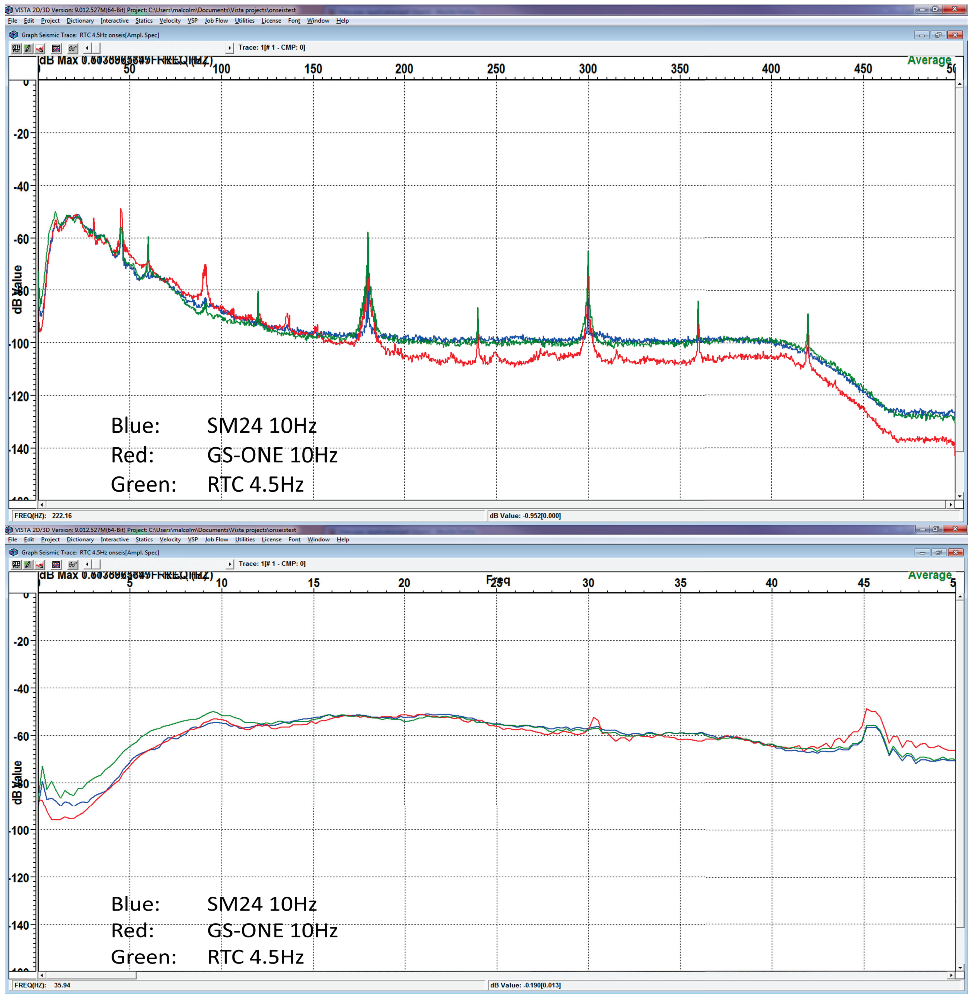

FIG. 19. The spectra of the geophones at flag 109 for all shots. Lower panel is a zoom to 50Hz.

Figure 20 shows the spectra for these gathers for shots from 112 to 180. This discards the first 9 shot points, which had only 8 impacts per shot rather than 16, and also limits the near offset to 30 m. Again the SM24 and the RTC4.5 track very closely over the whole plot, with the GS-One again showing the 10 db separation at the noise floor. In the zoomed plot, the results are almost exactly the same as before, except that the traces are now smoother than in Figure 19, suggesting there was some distortion due to the proximity of the shot for a few traces of the gather.

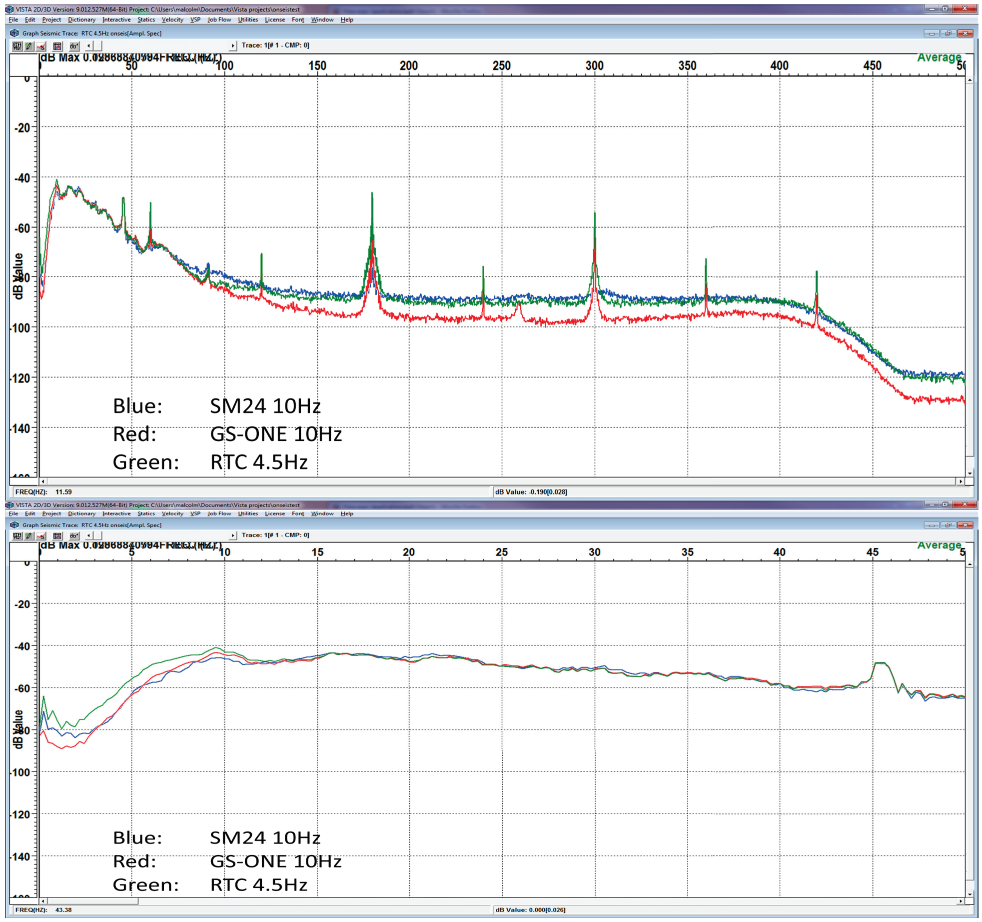

FIG. 20. The spectra of the receiver gathers at flag 109 including onSEIS shots from 112 to 180 only. Lower panel is a zoom to 50 Hz.

The next process applied to the onSEIS receiver gathers was to apply the convolution method to recover the frequencies below resonance of the geophone (Bertram and Margrave, 2010). The results for these gathers at flag 109 for shots at flags 112 to 180 are shown in Figure 21. It is no evident that the onSEIS output spectrum drops away below 4Hz, where the geophone spectrum plots all show noise becoming dominant as the curves start to rise towards 0Hz. As shown in the 2010 report, the recovery method has no effect on the data above the resonant frequency, where all three curves already match very closely, but below resonance there are major changes. Now the SM24 shows a point at about 6Hz where the curves diverge with the SM24 climbing as the noise content starts to become more dominant. The other two geophones' curves follow almost identical trajectories, with the minimum being about 4Hz. The most interesting feature of this plot is this close curve match, showing that the GS-One 10Hz geophone is providing exactly the same data as the 4.5Hz geophone after low frequency recovery. This suggests that either the RTC4.5 or the GS-One are preferable to the SM24 for surveys where the emphasis is on low frequencies. In the case of the EnviroVibe data, this correction has less import since the sweep start frequency was 10Hz.

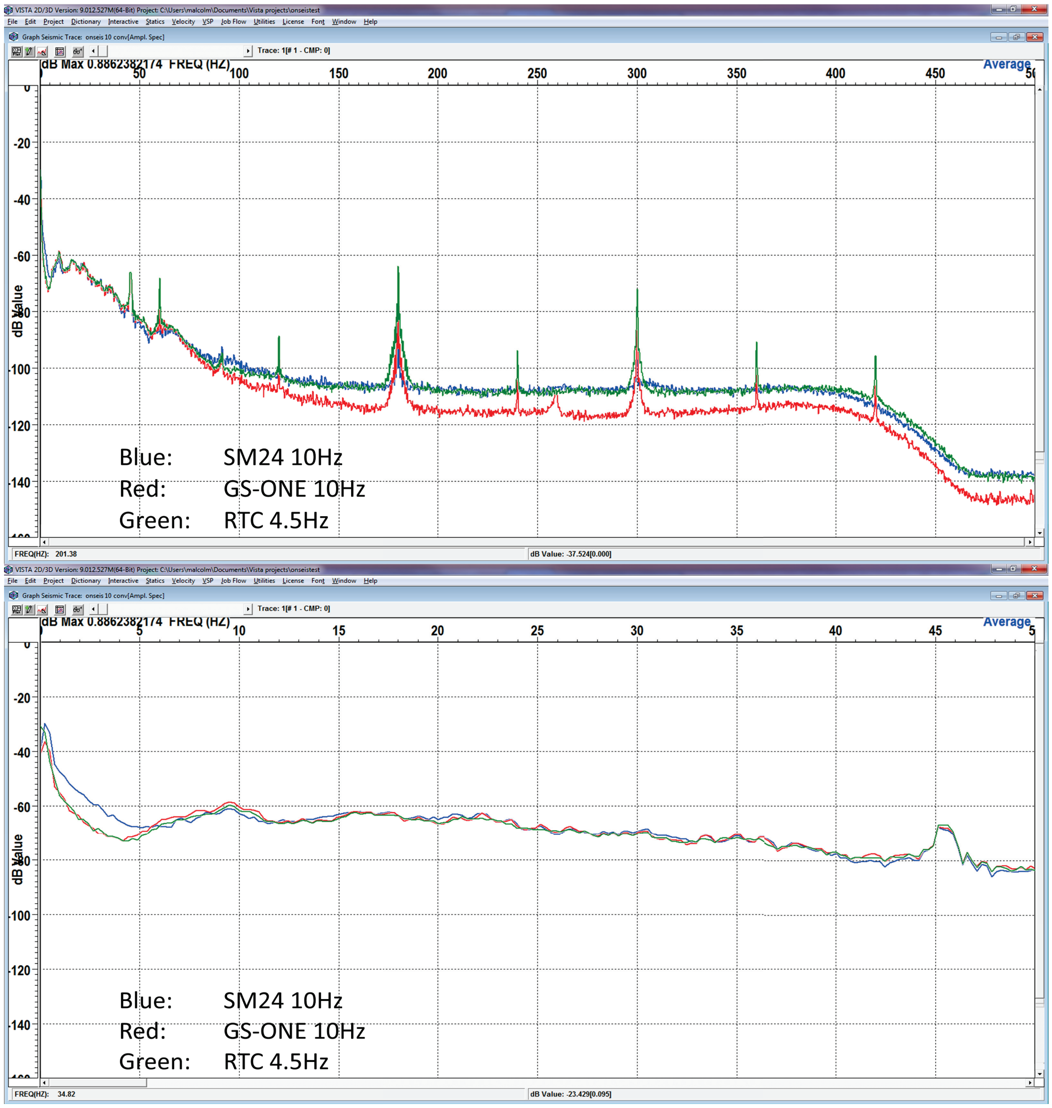

FIG 21. The receiver gathers from Flag 109 after low frequency recovery.

The same plots are created at another receiver flag, 148. This is the last flag that has a GS-One geophone, and is approximately in the middle of the spread. The receiver gathers are shown in Figure 22. In this case, the shots from 101 to 109 are removed, as are all shots with offsets less than 30 m (146-150). The spectra are shown in Figure 23. The similarity to the earlier plots is apparent, showing that we are getting a fair representation of the data spectrum. Again, the GS-One shows a 10 db improvement in signal to noise, and at the very low frequencies, the results are also very similar, with the SM24 and the GS-One tracking very closely. The difference in response of the two 10Hz geophones at the low frequencies in this case is not quite the 10 db of the other gathers, but is more like 5 db. Also, in this plot, the noise point is about the same for the SM24 and the GS-One at about 2Hz, while the RTC4.5 is at about 1 Hz. As expected the RTC4.5 again displays a higher output below 10 Hz and separates to about a 10 db difference from the 10 Hz geophones as before.

The results are similar for other geophone groups at other flags, showing that this is a valid representation of the geophone response.

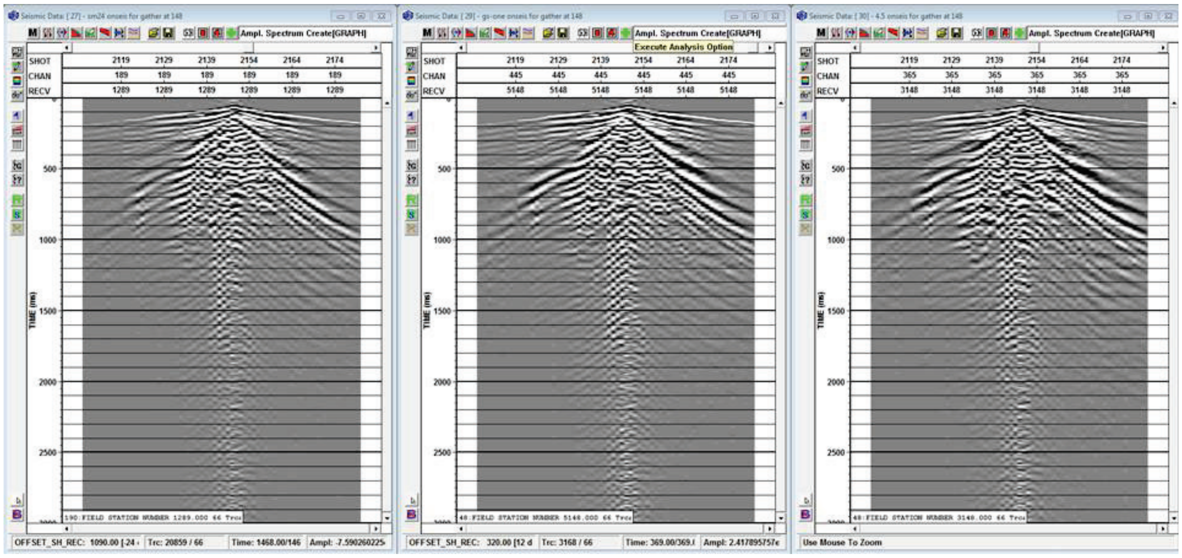

FIG. 22. Flag 148 with shots from 109 to 148, offsets less than 30m not included. From left: SM24, GS-One, RTC4.5.

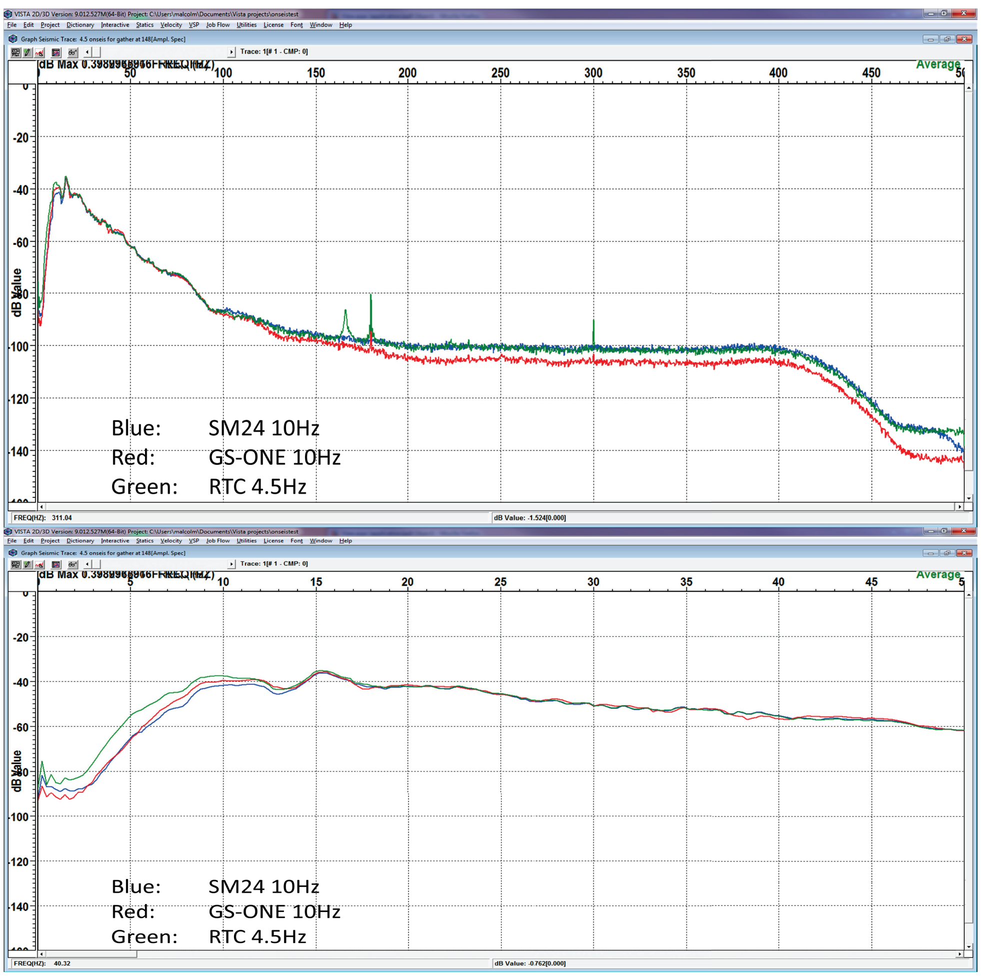

FIG. 23. The spectra for the receiver gathers at flag 148 for selected shots. Lower panel is a zoom to 50 Hz.

Again applying the low frequency recovery technique to the gathers at flag 148, the spectrum plots are shown in Figure 24. The fact that there is slightly less agreement between traces for the frequencies 20 to 40Hz suggests that there might have been a planting problem at this location. However, the two 10Hz geophones match closely to just below 10Hz when the GS-One starts tracking the RTC4.5 curve. As before, this shows the better signal to noise ratio of this geophone.

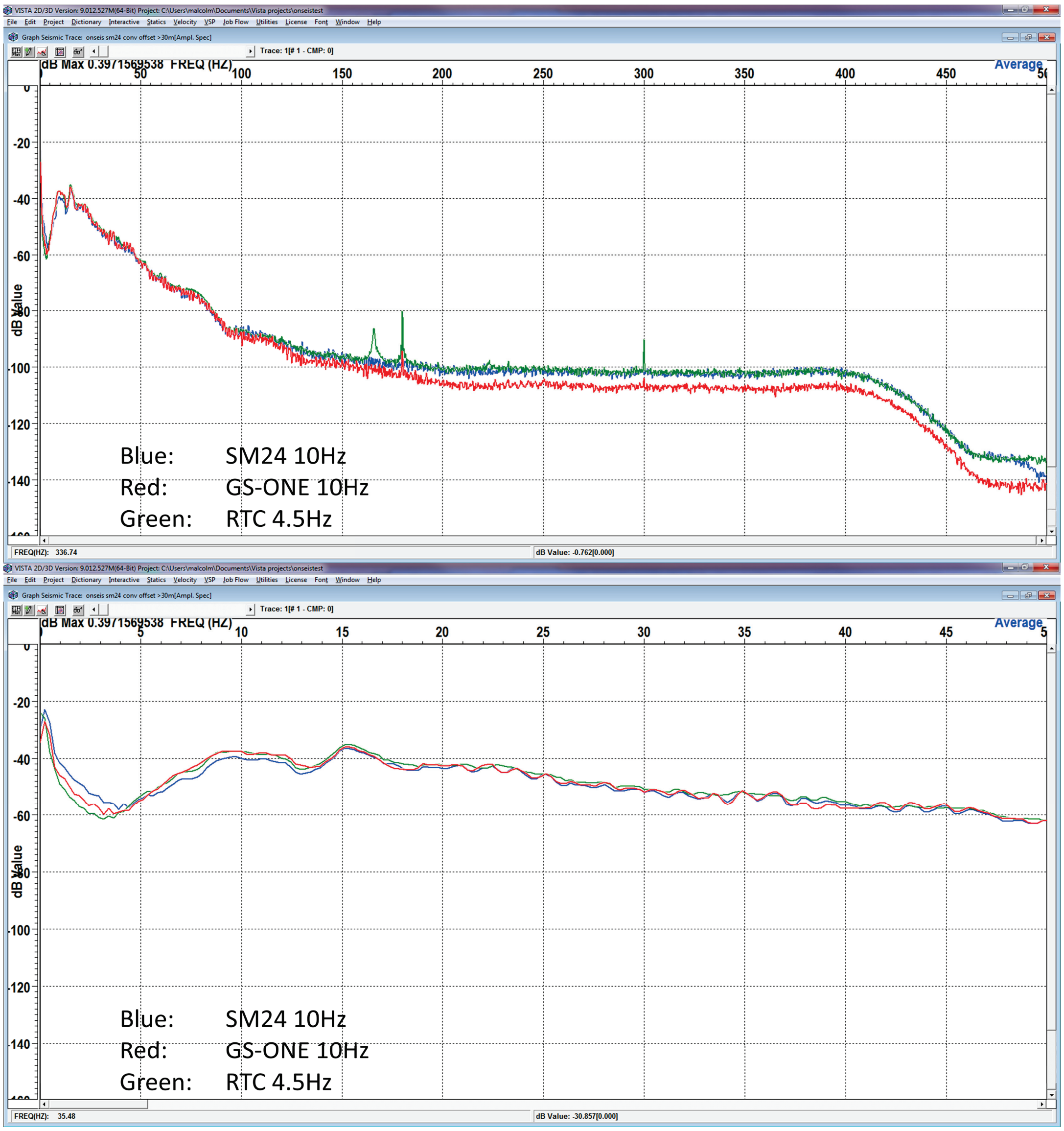

FIG 24. Receiver gathers at flag 148 with offsets >30m after low frequency recovery.

From the data sheets for the SM24 10 Hz geophone, the sensitivity is 21 V/m/s, and the sensitivity for the GS-One is 78.7 V/m/s, giving about 11 db difference. This is close to the separation seen on the spectrum plots, indicating the GS-One is providing this improvement in signal to noise ratio. The data sheet for the RTC4.5 geophone elements gives the sensitivity as 22 V/m/s which is 0.4 db higher than the SM24, so that the SM24 and the RTC4.5 are basically identical. This is shown in the spectrum plots where these two curves almost exactly match.

As a check on these onSEIS results, Figure 25 show the spectra for the receiver gathers at flag 109 for the EnviroVibe shots from flags 112 to 180. Here again the curves track closely, with the GS-One showing some separation at the high end of the sweep, and also a lower noise floor above the sweep frequencies. At the low frequencies, since the sweep began at 10 Hz, the curves almost coincide, with the RTC4.5 showing about 3 db higher output, as might be expected from the roll off of the 10 Hz geophones. The GS-One again shows better noise performance below 5 Hz. The benefit of the higher sensitivity is not so apparent here after correlation – a better analysis would be to use the uncorrelated data, but this was not available for this survey. Because of the 10Hz sweep start frequency, the low frequency recovery was not applied to these gathers.

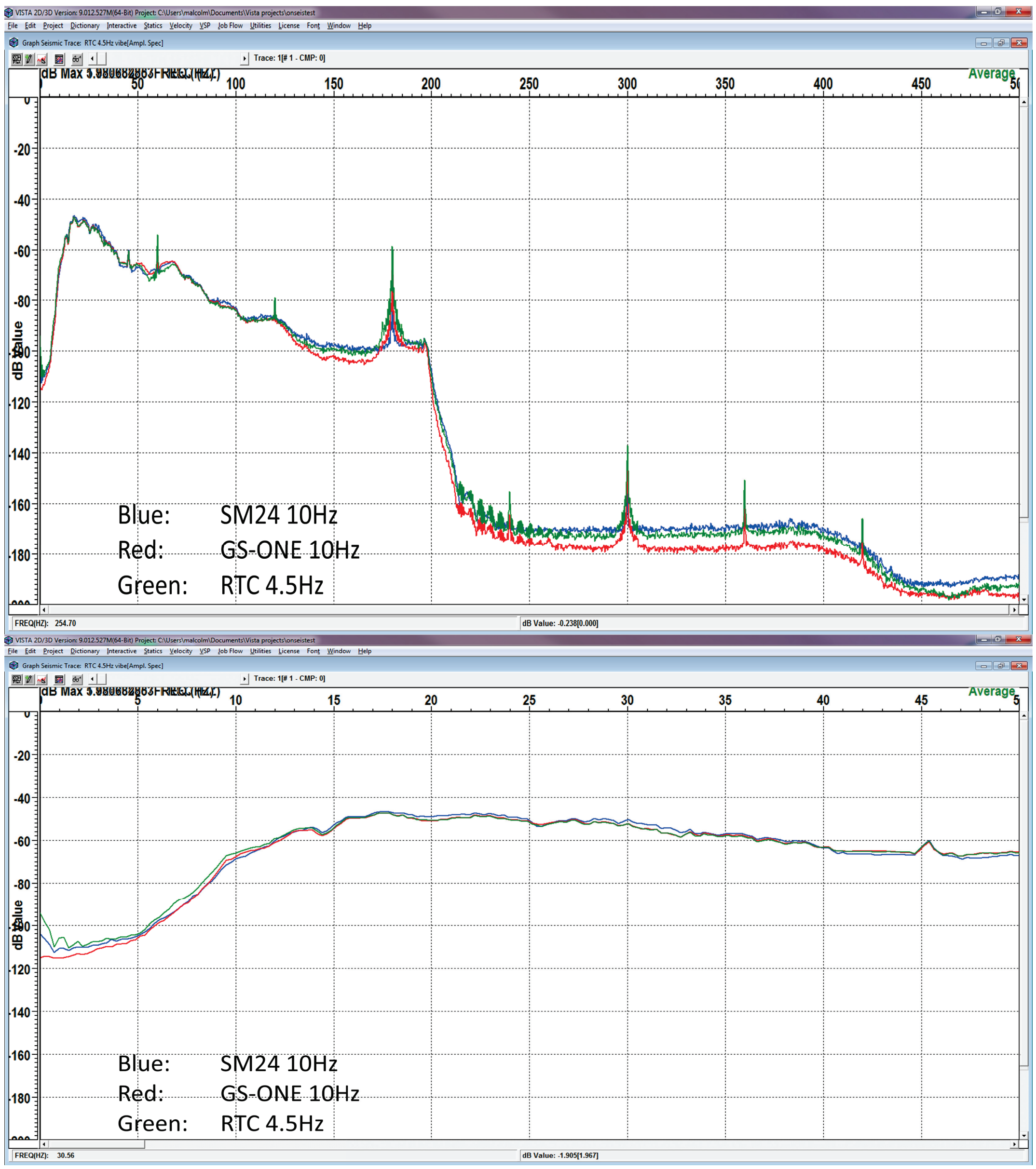

FIG. 25. The spectra for the receiver gathers at flag 109 for vibe shots from flag 112 to 180.

CONCLUSION ON THE GEOPHONE COMPARISON

The comparison of the three geophone types using the onSEIS source shows that the output of the onSEIS does continue down to at least 4 Hz, and probably lower. It appears that the improved sensitivity of the GS-One geophone does provide an improved signal, not only in the improved signal to noise ratio evident in the spectrum plots, but also for extracting more low frequency information from the data using the correction filter demonstrated at the CREWES 2010 meeting than would be possible from the SM24 geophones. As expected, the RTC4.5 geophones do demonstrate considerably more low frequency data than the 10 Hz geophones, and would be a preferable choice if the focus of the survey were at this end of the spectrum. However, application of the low frequency recovery technique shows that the GS-One is comparable to the RTC4.5 for this particular survey when using the onSEIS source, and since it demonstrates the higher signal to noise ratio at higher frequencies, may be the preferable choice.

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