Recovery of low frequency data from 10Hz geophones

Malcolm B. Bertram and Gary F. Margrave

ABSTRACT

An analysis is made of the data from three different projects that provide the means to calibrate a method to recover low frequency data from 10Hz geophones. These surveys were selected because of the ability to directly compare the enhanced spectrum from the 10Hz geophones to that from 2Hz geophones, MEMs sensors, and/or seismometers, thereby providing a measure of the effectiveness of the method. The ability to recover usable data to two octaves below resonance is demonstrated.

INTRODUCTION

The three surveys used for this analysis are: a) the Blackfoot broadband survey recorded by CREWES in 1995 as a data set for analysis of acquisition parameters required for converted wave data, as well as providing a data set with frequencies down to 0.5Hz, b) the Spring Coulee survey in 2008 which compared MEMs sensors (Sercel DSU3) to three component geophones (Sensor SM7) over a 6.5 Km line, and c) the low frequency tests conducted at Priddis in 2009 to compare MEMS (Sercel DSU3 and ION Vectorseis) with geophones (SM24) and seismometers (Nanometrics Trillium 240). A description of the Blackfoot survey is available in CREWES Research Report Volume 7 (1995), the Spring Coulee survey is covered in CREWES Research Report Volume 20 (2009), and the Priddis seismometer tests in CREWES Research Report Volume 21 (2009).

THE BLACKFOOT DATA

The survey consisted of a 4 km line recorded east of Calgary at the Blackfoot field. Geophone stations were every 20m with four different sensor types at each station. These were a single 10Hz 3C geophone, a string of 1C vertical 10Hz geophones spread over 20m, a single 4.5Hz 3C geophone, and a 2Hz vertical geophone. There were also 60 2Hz horizontal geophones planted at the centre 60 stations of the receiver spread. Shot parameters were 6 kg of dynamite at 10m depth. Samples of the data from the vertical components of the single 3C receivers are shown in Figure 1, showing good data quality. There is an obvious difference in the low frequency content in these records, perhaps showing up best in the ground roll, and in the noise before the first breaks where the AGC has boosted the background. The analysis presented here is on Field Record 7, for no reason other than it was the first production record of the project. Only the vertical component is used.

A discussion of instrument efficiency in the 1995 CREWES Report (Bertram, 1995) investigated whether there was significant data loss due to clipping, with the conclusion that with the gain setting used there was some clipping on the traces within 50 m of the shot point, and within the first 100 msec. For this reason, the analysis presented here is restricted to offsets greater than 80m. Several different offset regions are compared to see if the results are consistent over all data signal levels.

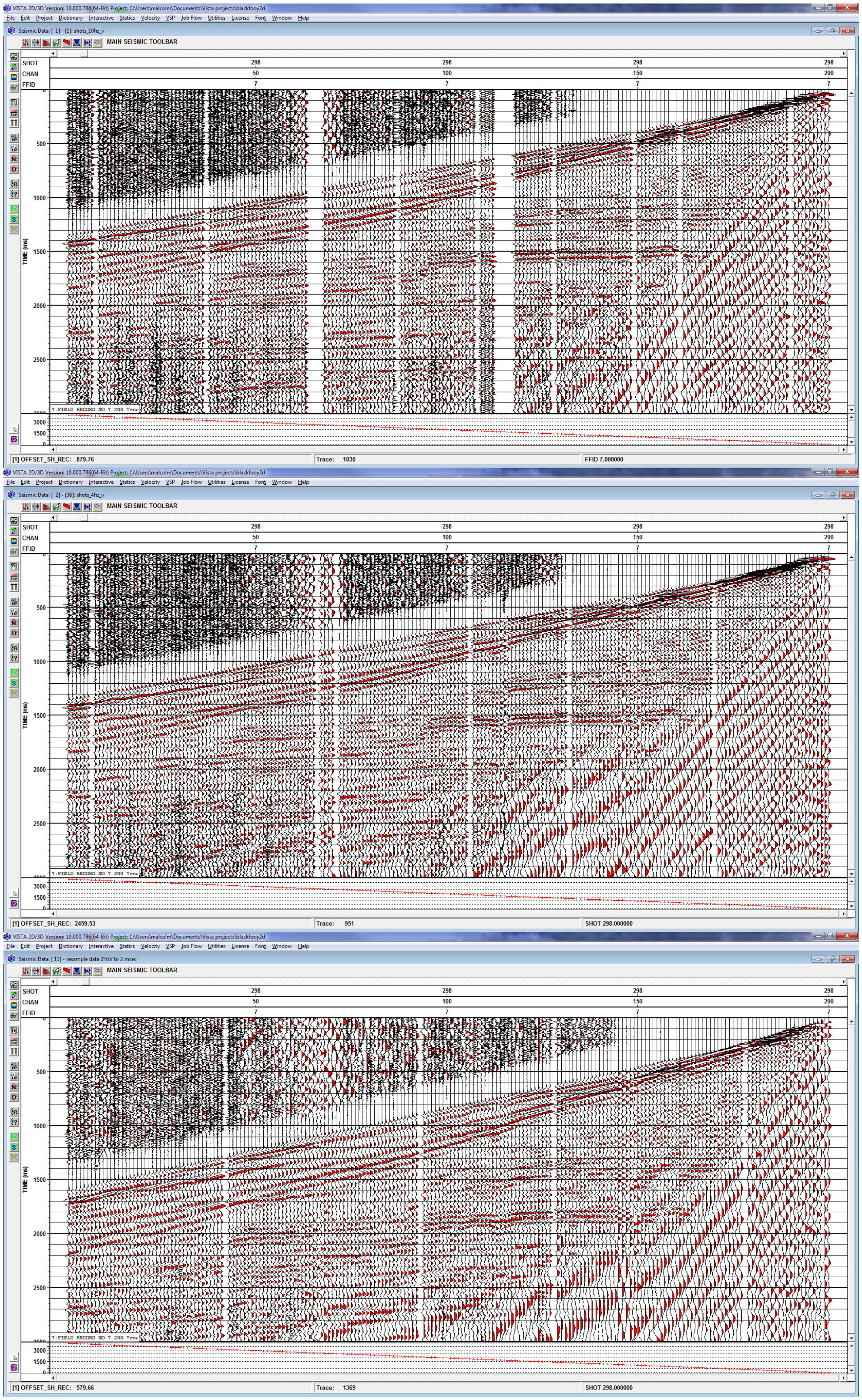

FIG. 1. A shot gather from the vertical geophone elements. 10Hz top, 4.5Hz centre, 2Hz bottom.

In this survey, after processing, the data from the 2 Hz geophones were found to contain useful information down to 0.5 Hz, providing excellent velocity information for inversion of the data (Ferguson and Margrave, 1996) Since most surveys are recorded with 10Hz geophones, having a response roll-off below 10Hz of about 12db/octave, this low frequency information is not normally available in the processing flow. To enhance the low frequency portion of the spectrum, an inverse filter, with a designed wavelet representing the inverse of the 10Hz geophone response, is convolved with the data. The results are compared to the 2Hz spectrum to assess the performance. For this paper, only the 10Hz data are enhanced and compared to the 2Hz data. A similar test will be conducted on the 4.5Hz data at a later date.

A LOOK AT SPECTRA

Shown in Figure 2 are the average amplitude spectra for the three gathers shown in Figure 1. Because of the higher sensitivity of the 2Hz geophones, the noise floor for these is 18db below the 4.5Hz geophones, which is then about 2db below the 10Hz geophones providing a significantly better signal resolution from the 2Hz geophones.

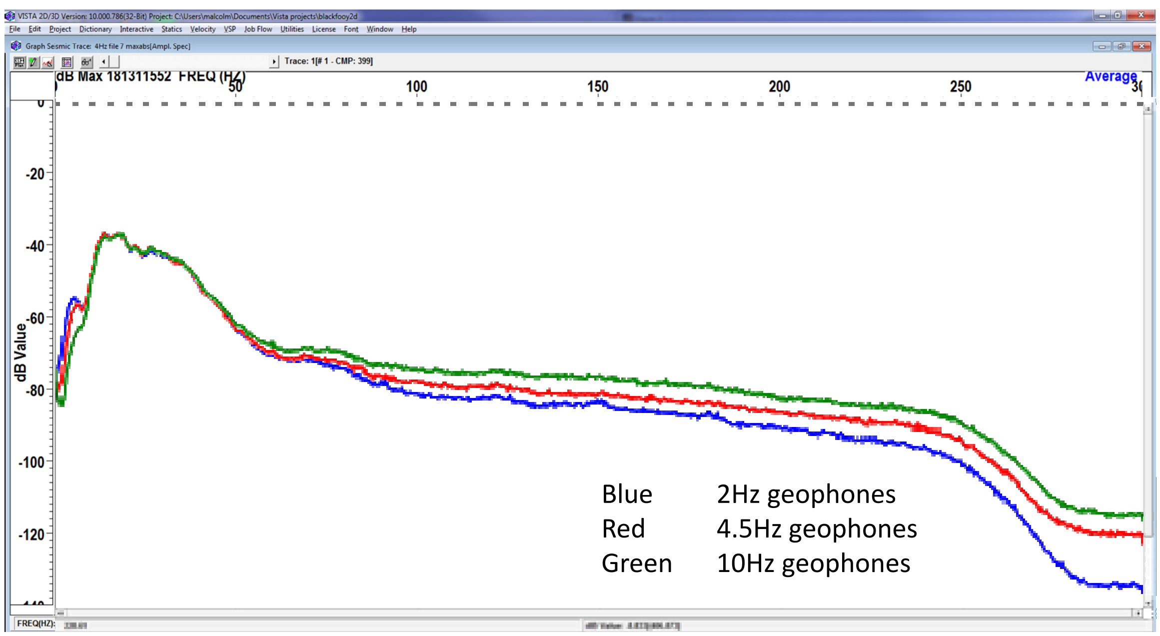

FIG. 2. The average amplitude spectra for the gathers of Figure 1.

A zoom of the spectra for detail of the low frequencies (up to 50Hz) is shown on Figure 3 for three different offset ranges. The divergence between the three responses is clear, with the 10Hz geophone showing a loss of output starting at about 15Hz.

An inspection of the last plot in Figure 3 seems to indicate that the point at which the geophone output devolves into noise at long offsets is at about 1.5Hz for the 10Hz geophone, 0.9Hz for the 4.5Hz geophone and 0.2Hz for the 2Hz geophone. Assuming the 2Hz geophone is reliably representing the signal linearly down to 4Hz (twice resonance), the difference between this and the 10Hz geophone at 5Hz (one octave below the 10Hz resonance) is approximately 14db. At 2.5Hz the difference is greater than 20db. This is close to that expected from the geophone response curves (Figure 6).

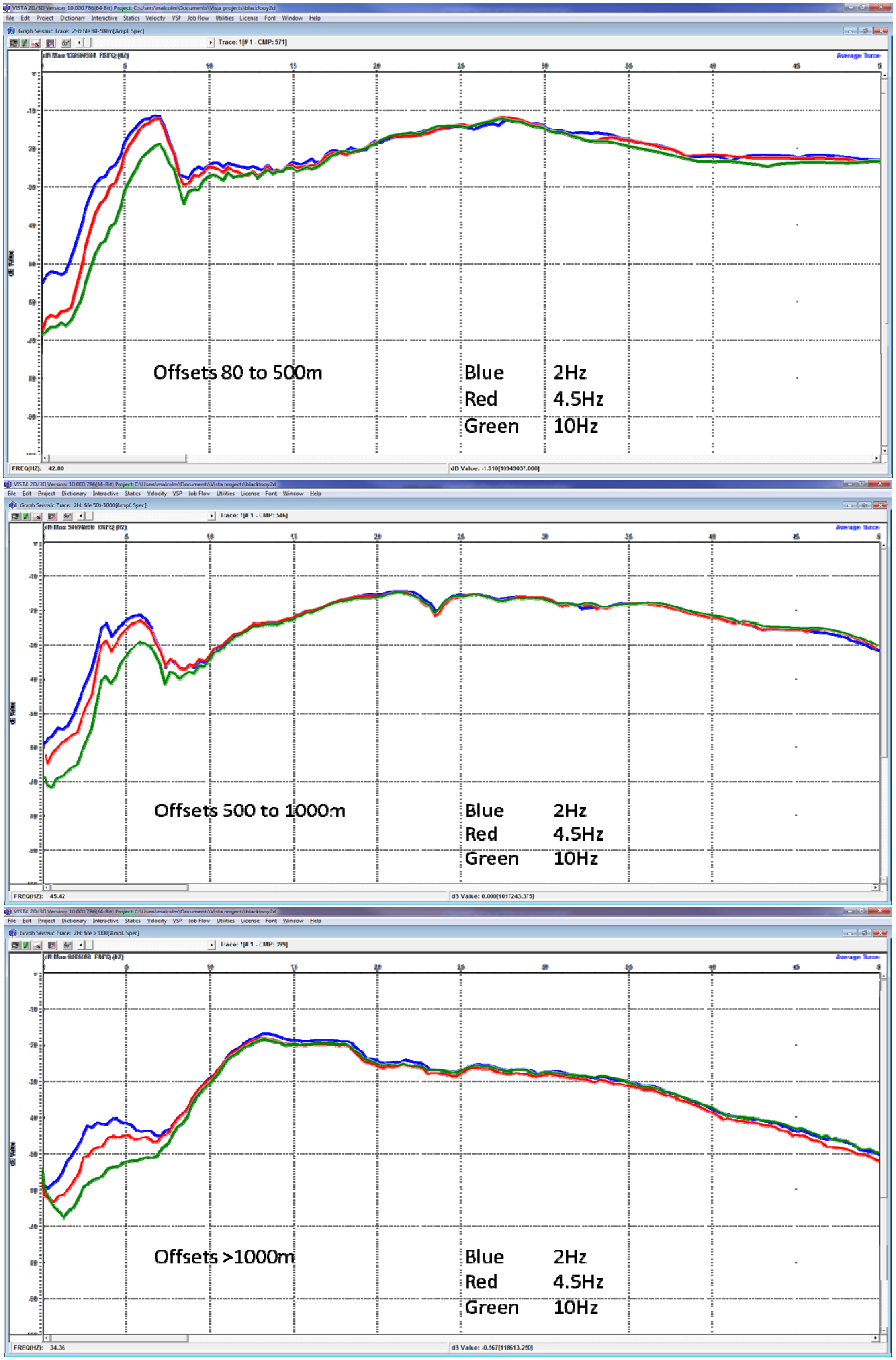

FIG. 3. A zoom of the average amplitude spectra (0 to 50 Hz) for limited offset ranges.

The plots in Figure 3 do suggest that there is recoverable data available from the 10Hz geophones down to about 2Hz, at which point the resolution of the data will be marginally above noise level. To check the presence of signal at these low frequencies, a filter of 1-2-4-8 Hz was applied to the records of Figure 1. The results are shown in Figure 4. As expected, there is some phase difference caused by the 10Hz geophone response. From this plot it is apparent that there is available low frequency data in the 10Hz output, but with the one octave roll-off on the filter the dominant frequency is about 5Hz in these plots.

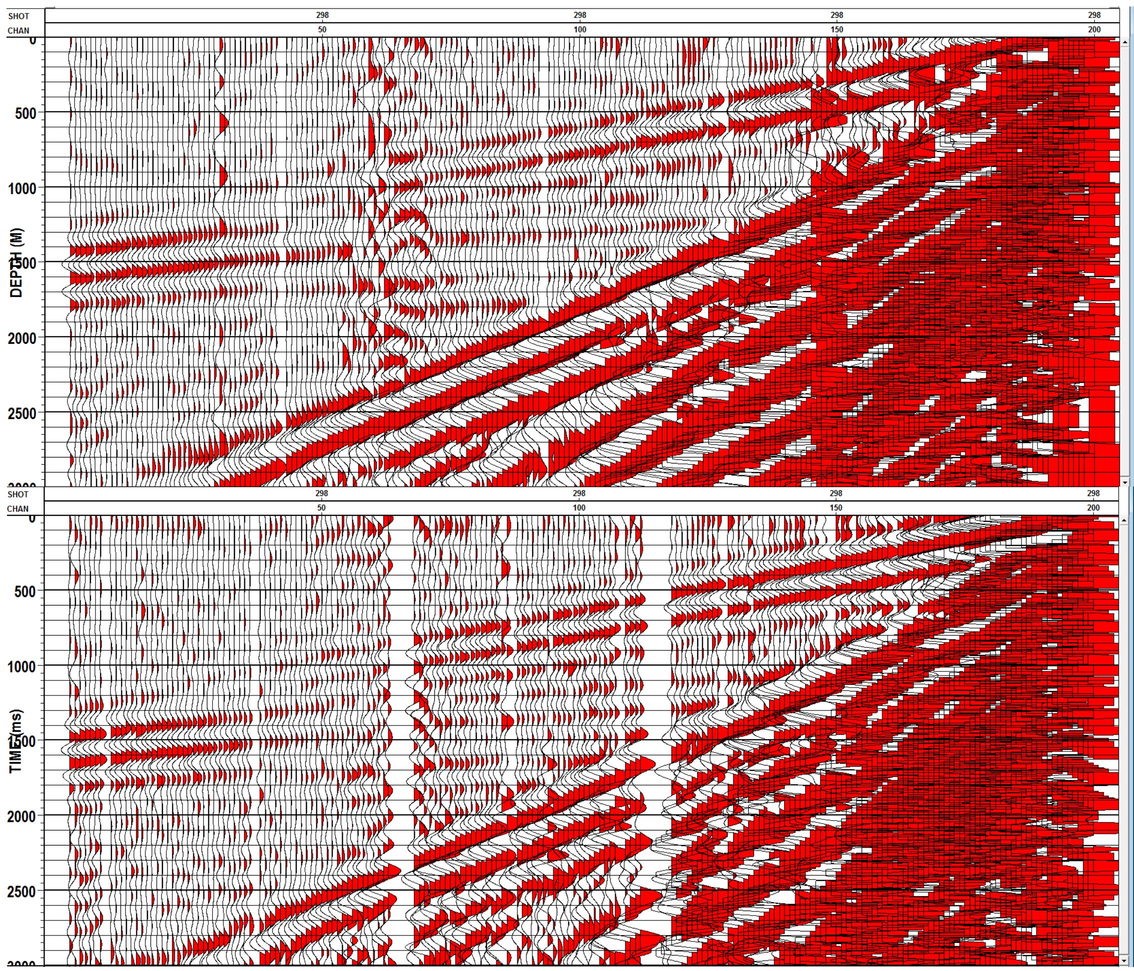

FIG. 4. The shot gathers with 1-2-4-8 Hz filter applied. 2Hz top, 10Hz bottom.

It is still necessary to establish the lowest frequency we can expect to recover from the 10Hz geophones for the purpose of designing the low cut to apply following the inverse filter, as the filter will boost the near DC levels substantially. The plots shown in Figure 5 are a series of low pass outputs, showing that we do have some data below 4Hz, but it is not until the 5Hz high cut that we see any energy appearing in the 10Hz geophone panel at the far offsets in the first breaks.

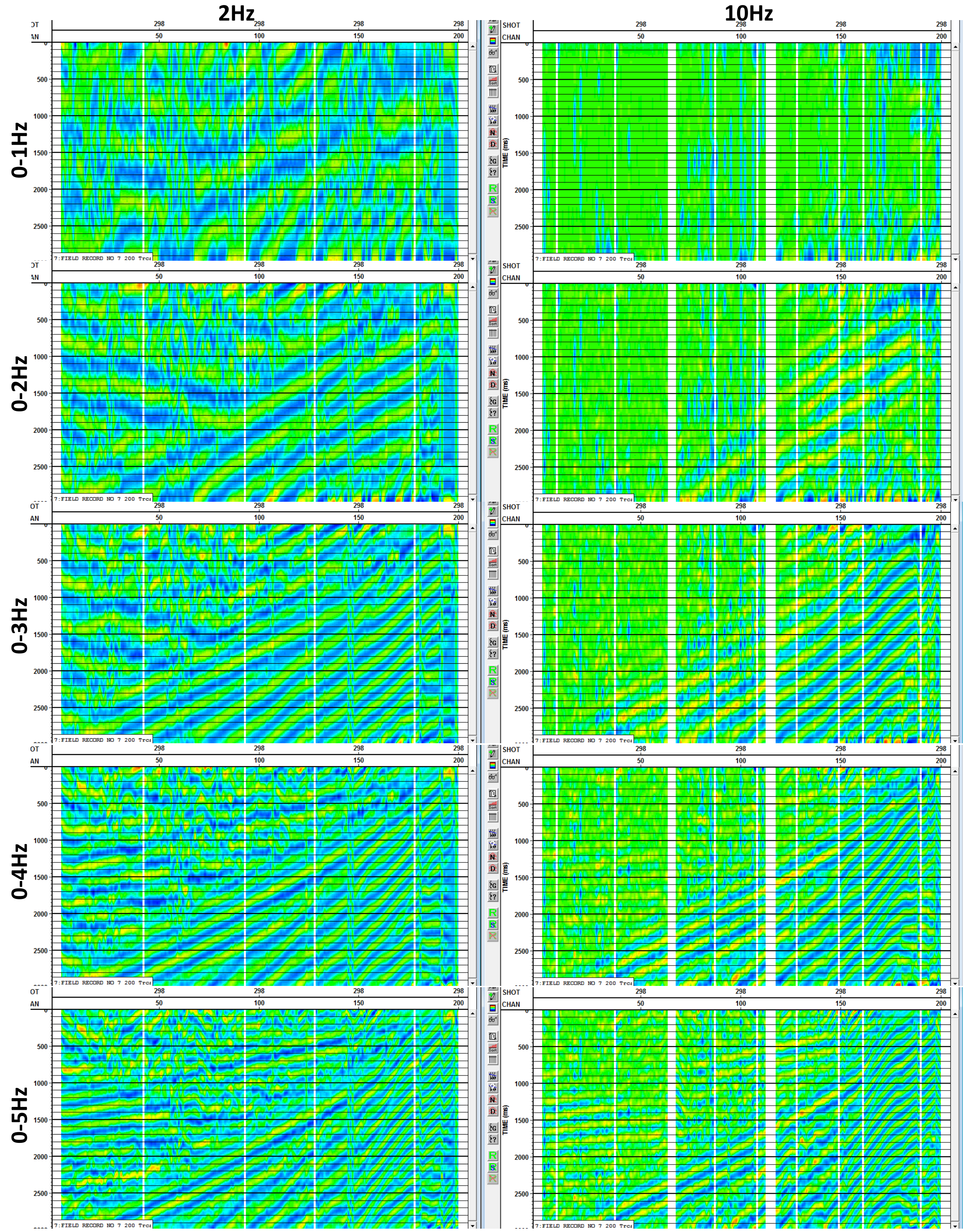

FIG. 5. The low frequency content of the gathers before processing. Left:2Hz geophones, right:10Hz geophones.

THE INVERSE FILTER

Assuming that the geophone response roll-off is 12db/octave, this can be approximated by a second order, minimum-phase, Butterworth filter. Such a filter was designed in Matlab, a time-domain wavelet created and inverted, then convolved with the data. A plot of the filter response as well as the geophone response curve is shown in Figure 6. Some questions regarding the phase have not yet been resolved.

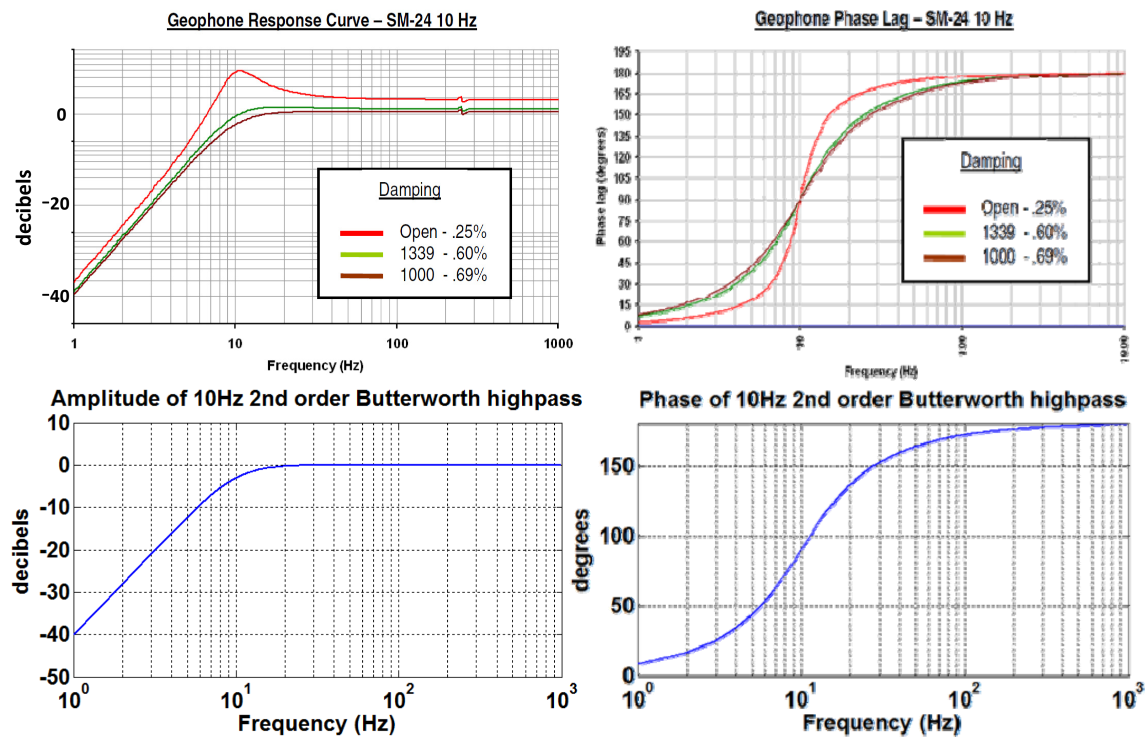

FIG. 6. The geophone response curve for the Sensor SM24 10Hz geophone, and the filter response curve from the second order Butterworth low cut filter derived from Matlab.

The 10Hz geophone average amplitude for the spectrum resulting from this inverse filtering is shown in Figure 7, compared to the 2 Hz average amplitude spectrum. As can be seen the data seems to be over-corrected below about 5Hz by this process. However, a look in detail at some different offsets shows that the correction is actually boosting the low frequency to close to the 2Hz levels, but on some traces is being overwhelmed by the low frequency noise, making the average amplitude plot unreliable. Figure 8 shows some amplitude spectrum plots from the boosted traces for different offset ranges. The noise close to DC is apparent in these plots, but the enhanced signal from the 10Hz geophones shows excellent correlation with the 2Hz data at offsets up to 1500m. For the 1500-2000m plot, the noise below 3Hz starts to dominate the data. At the far offsets not much energy below 5Hz can be recovered. This effect follows the noise floor expectations described by Maxwell (2010). This spectrum plot provides a means of QC on a trace by trace basis.

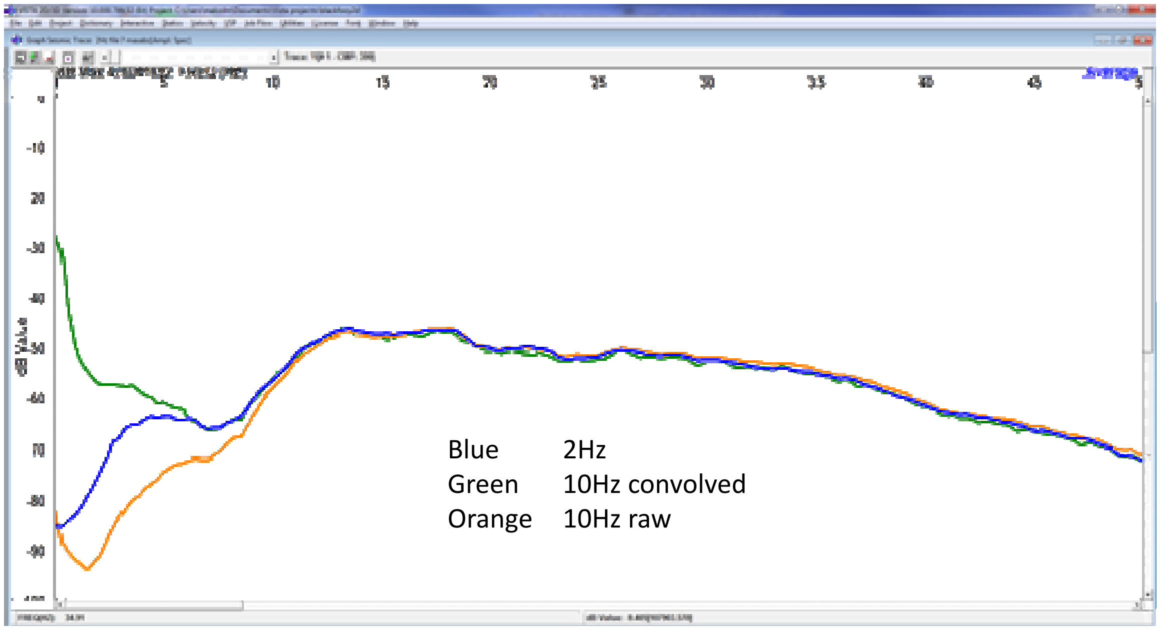

FIG. 7. Comparison of spectra (0 to 50Hz).

After inspecting the panels in Figure 5 showing the amount of energy at the low frequencies, and the spectrum plots in Figure 8, it is necessary to apply a low cut filter to this data after correction to remove the near DC component of the boosted noise. From the original processing of the 2Hz geophone data it is known that there is recoverable data to less than 1Hz as might be expected from Figure 5, but the 10Hz geophones probably will not contain any useful information below 2Hz . This is indicated by the amplitude spectrum in Figure 7 which shows the noise becoming dominant at this frequency (where both the 10Hz curves start climbing). A quick analysis of likely useful data suggests a low cut filter of 2Hz would be appropriate. This gives recovery of data to better than 2 full octaves below the 10Hz geophone resonance.

An analysis of the 4.5Hz geophone data will be carried out as the next stage in this work, to see if these geophones would provide data below 1Hz. A first look at this data suggests that there might be recoverable data down to 1Hz.

Also yet to be investigated are the horizontal components of this data set, and the re-processing of the vertical 10Hz to see if the quality of low frequency data has been significantly improved.

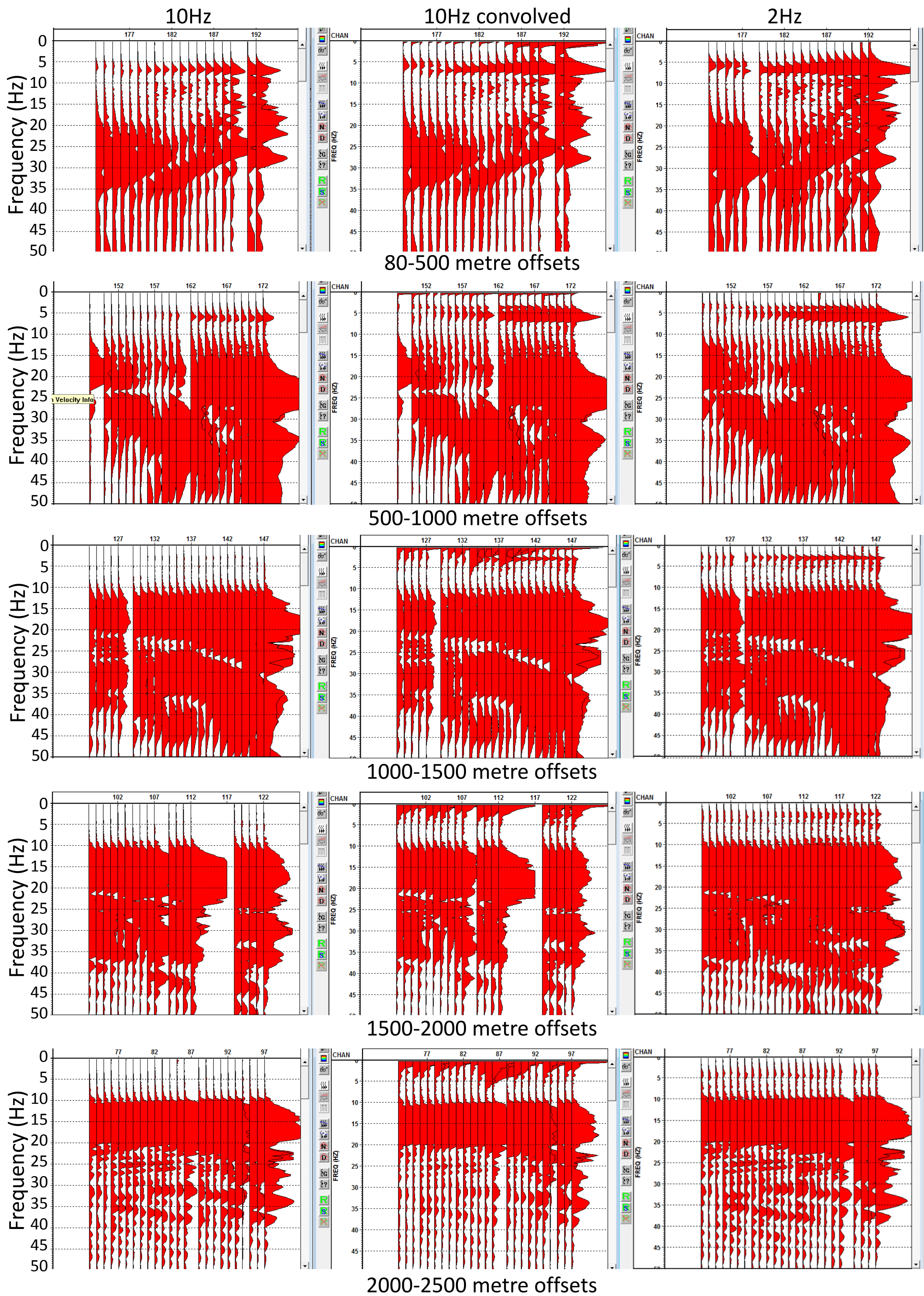

FIG. 8. Amplitude spectrum plots for some offset ranges (0-50Hz).

THE SPRING COULEE DATA

The Spring Coulee survey was shot in January 2008 over a property in southern Alberta where the University of Calgary has the mineral rights. The project compared 3C geophones to MEMs sensors over a 6.5 Km line with a group interval of 10m. The whole line was shot with two 60,000lb vibrators, and a section in the centre was shot with dynamite (CREWES Report 2008). Since the vibrator sweep started at 8Hz, the vibroseis records have no energy in the area of interest. However, the dynamite shots (2Kg at 18m) show good bandwidth, and are used here.

The shot selected for analysis here is at Shot Point 417. This is close to the centre of the spread. Figure 9 shows the raw vertical component of the Aries SM7 geophone gather and the Sercel DSU3 MEMs gather, and Figure 10 shows the two gathers after the geophone data has been convolved (with the inverse filter) and the DSU3 data integrated (to convert from acceleration to velocity). The increased low frequency content is clearly visible for both gathers; however, the dominant low frequency energy on the 10Hz gather seems to be coherent across the gather, suggesting it is an artefact from the filter application.

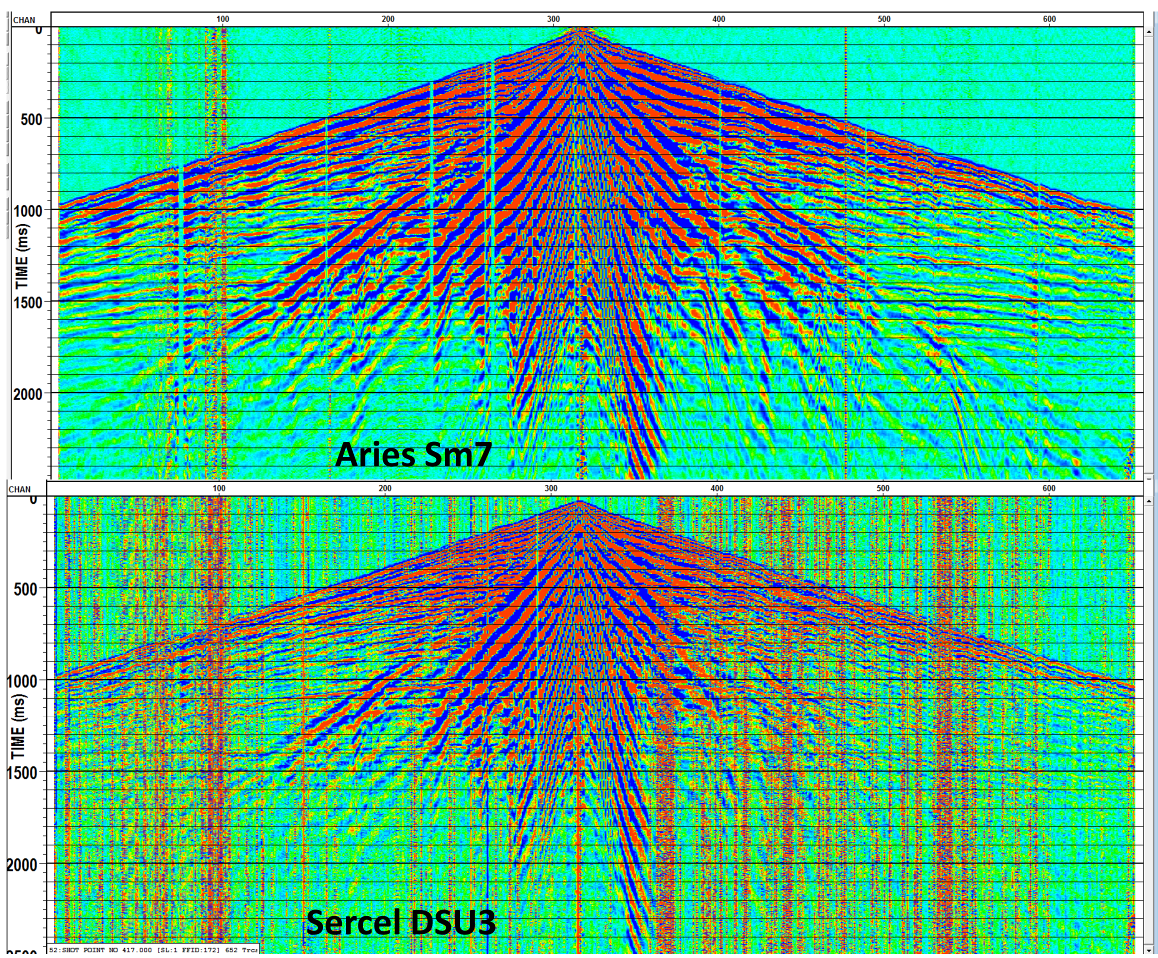

FIG. 9. The raw gathers from shot point 417. Top: Aries with SM7 geophones, Bottom Sercel DSU3 MEMs sensors.

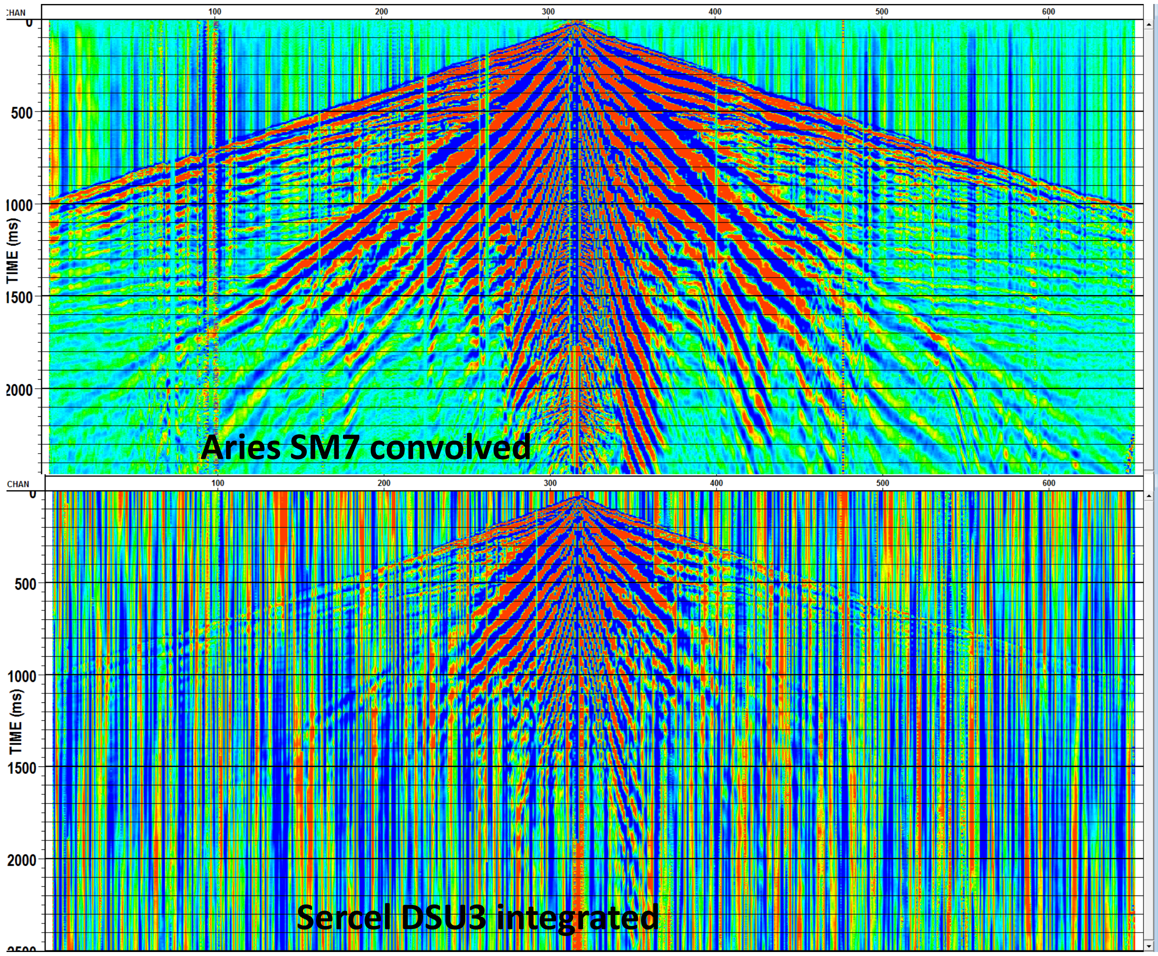

FIG. 10. The shot gathers form SP417. Top: Aries SM7 geophone data after convolving, Bottom: Sercel DSU MEMs data after integration.

Unfortunately this survey was shot with a 3Hz low cut on the Aries recording system which effectively eliminates any chance of recovering the very low frequencies from the 10Hz data. This also means that most of the low frequency appearing in the SM7 data after convolving is just enhanced noise. A plot of the average amplitude spectra of the gathers for all traces with offsets greater than 100m is shown in Figure 11. This shows clearly the effect of the low cut acquisition filter on the geophone data after convolving. Spectrum recovery is good however down to about 4Hz. Above 10Hz, the DSU3 integrated spectrum falls almost exactly on the geophone spectrum. Inspecting the blue trace (geophone data convolved) it is apparent that, as in the Blackfoot data, the noise becomes the dominant feature below 2Hz, where the trace turns up.

Looking at some offset ranges, as for the Blackfoot data, Figure 12 shows the traces from 600m to 1100m on the north side of the shot point. The 3Hz acquisition filter effect on the Aries data is clearly visible, with the boosted noise showing up below 1Hz.

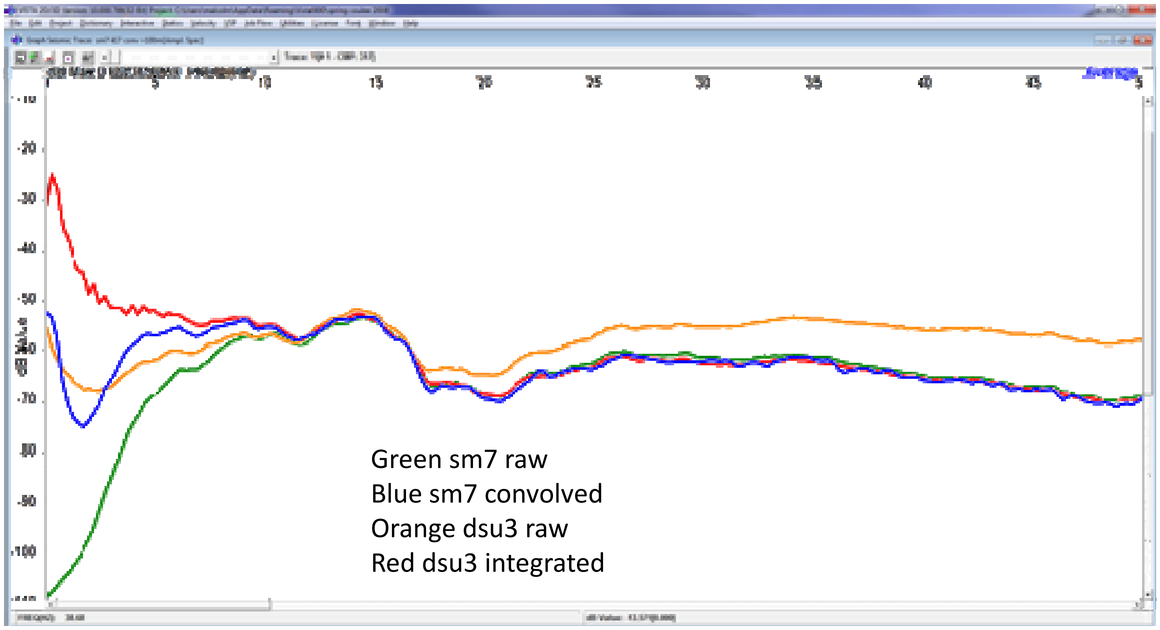

FIG. 11. Spectra of the gathers. Orange: DSU3 raw, Red: DSU3 integrated, Green: SM7 raw, Blue: SM7 convolved.

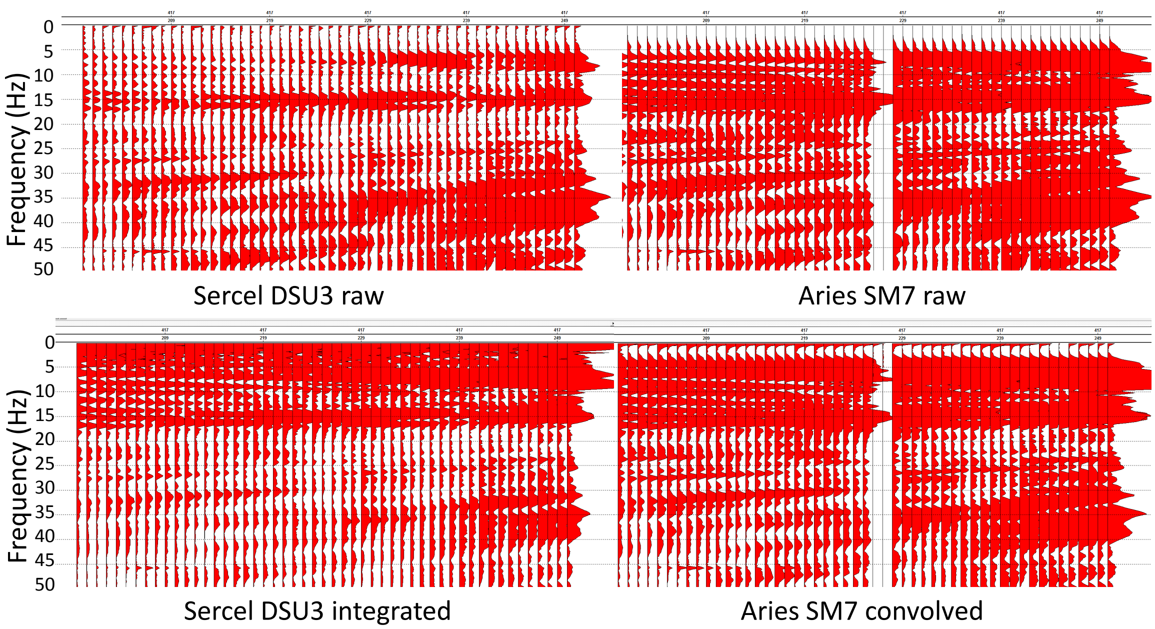

FIG. 12. A sample of offset traces from 600 to 1100m. Data from 0 – 50 Hz.

In this case, from the data in Figures 11 and 12, it is apparent that the recovery has worked quite will, and the application of a 2Hz filter to remove noise would be the next stage in processing. For this project, because of the low cut acquisition filter, just over one full octave of recovery is likely.

THE PRIDDIS LOW FREQUENCY TEST

This survey was conducted at the University of Calgary test site at the Rothney Astrophysical Observatory located south of Calgary near Priddis. The impetus for the test was the availability of 8 Nanometrics Trillium 240 seismometers to provide a calibrated low frequency detector. With the co-operation of CGGVeritas and ION the test included both Vectorseis and DSU3 MEMs 3C sensors as well as 3C SM24 geophones belonging to the University of Calgary. Sources for the test were the U of C EnviroVibe and a weight drop mounted on a trailer. The project was covered in the 2009 CREWES Report, and some data analysis presented at the CSEG and SEG in 2010 (Hall, 2010). The SM24 sensors were planted in a north-south direction, 1m apart over 80 m, with the Trillium 240 seismometers, Vectorseis and DSU3 sensors at every 10th station. Two shot points were located north and south of the ends of the spread at a 50m offset. Gathers from one shot are shown in Figure 13.

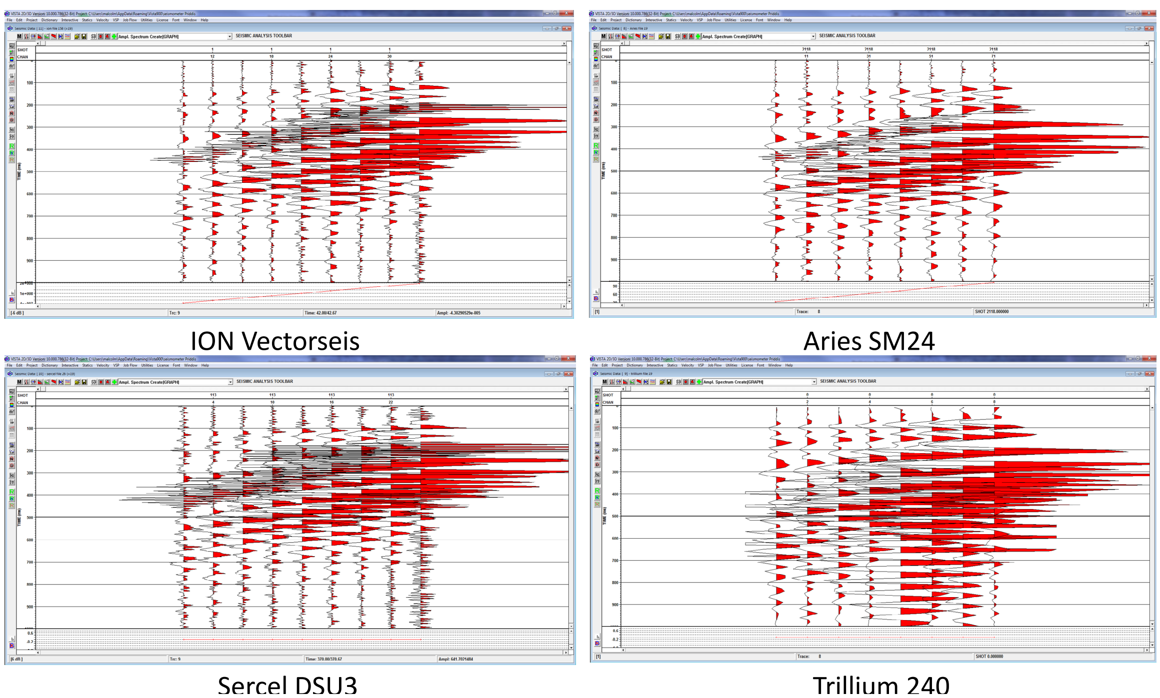

FIG. 13. The gathers from one thumper shot. The Aries data has been decimated to match the other sensors.

The average amplitude spectra from these four gathers are shown in Figure 14. The two MEMs sensors and the seismometer show very similar curves, with the geophone dropping off below 5Hz. For this survey, the low cut filters were set to 1Hz on the Aries system – the desired setting was no low cut, but a software problem did not allow the entry of a value of 0. As well as this low cut filter on the Aries system, the ION system had a 1.46Hz low cut applied, which is apparent in Figures 14, 15 & 16 where the Vectorseis response closely overlies the geophone response. From Figure 15 it is apparent that most of the energy from the thumper is in the area below 50Hz. After integrating the MEMs data and convolving the geophone data, the average amplitude spectrum plot of Figure 15 is produced. There is a good line up from all sensors up to 150Hz.

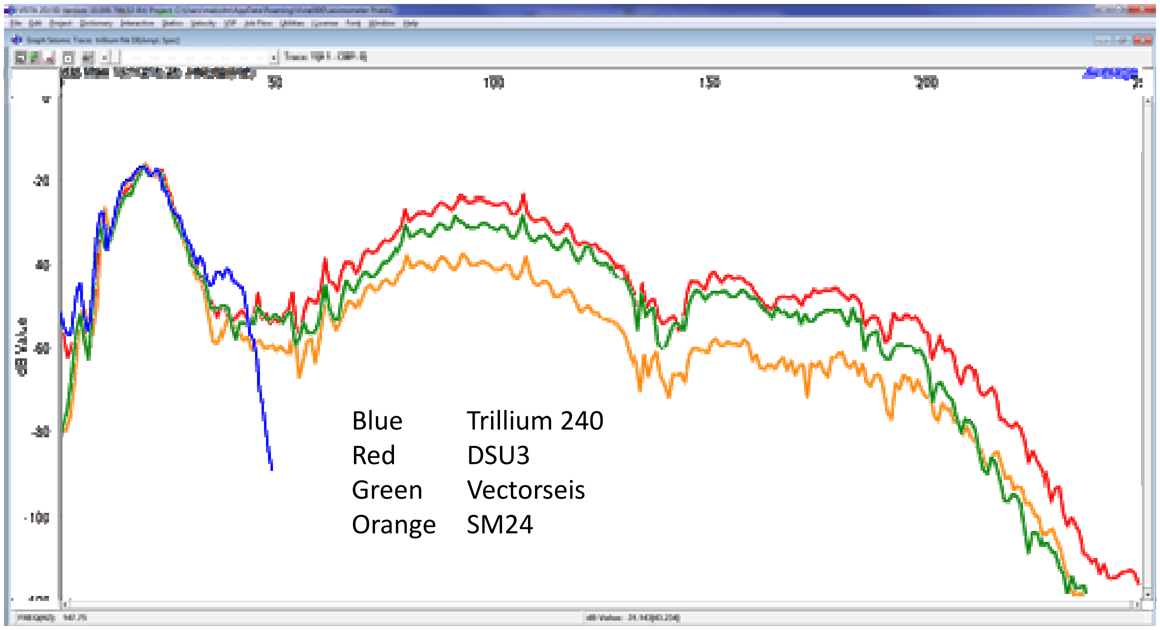

FIG. 14. The spectra from the gathers.

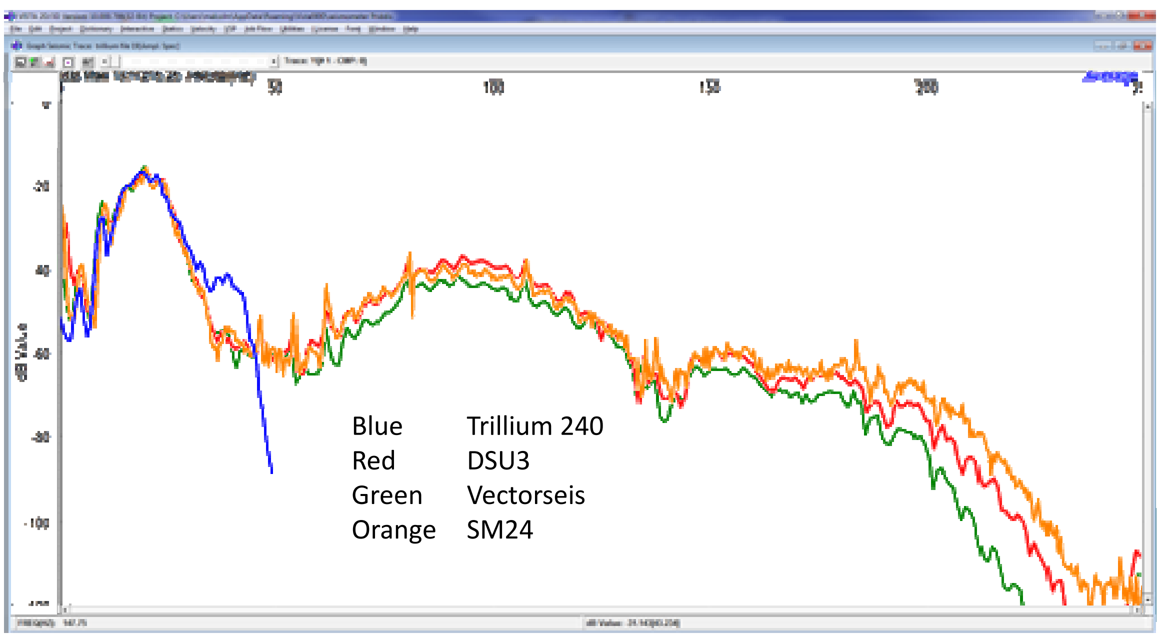

FIG. 15. The spectra after correction. The geophone data has been convolved, and the MEMs data integrated.

A zoom of the spectra to the range 0-50Hz in Figure 16 shows very good spectral matching between 5 and 50Hz, with only the seismometer diverging above 25Hz. This behavior is expected, and is covered in the Trillium 240 manual. Below 5Hz, all devices show data down to 2Hz, below which the noise appears to be dominant. So the inverse filter method of data enhancement for low frequency recovery from 10Hz geophones again seems to function down to about 2Hz, at which point a filter could again remove the lower frequency noise.

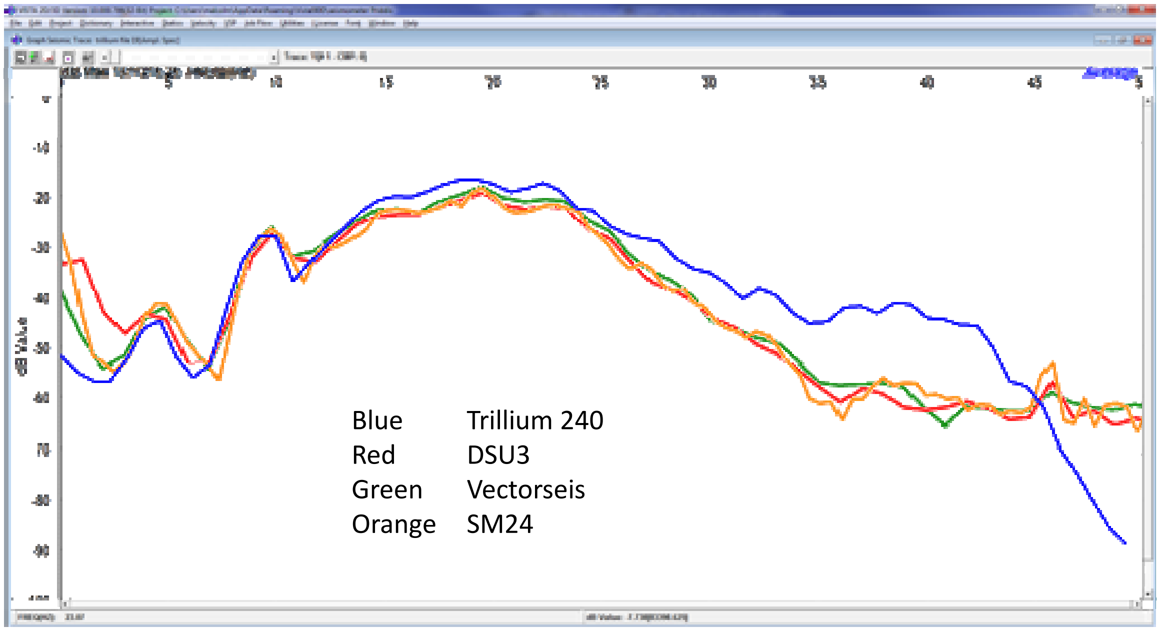

FIG. 16. A zoom to the 0-50Hz range of the corrected spectra in Figure 15.

CONCLUSIONS

All three cases presented here indicate that using this method of data enhancement shows a great deal of promise, as long as care is taken to establish if there is data to recover by inspecting the low frequency content, and being careful to take signal-to-noise decrease due to offset into consideration. The ability to compare the inverse filtered spectrum directly to another data set from either the 2Hz geophones or the MEMs sensors provides a high level of confidence in the application of this filter as an accurate method of data recovery in the area below geophone resonance. However, care is required, since many acquisition systems apply a 3Hz low cut filter by default, meaning that recovery of data below this is unlikely.

Some more quantitative analysis of the "head room" (i.e. how many bits of signal resolution we have or can recover) will be undertaken as part of the continuation of this study, as well as reprocessing of the data to investigate the overall spectral improvement.

ACKNOWLEDGEMENTS

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