The pulse-probe experiment – a look at the Autoseis recording system

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ABSTRACT

The CREWES experiment at the Priddis test site in July 2012 was designed to test different acquisition methods and recording systems. The project was named Pulse-Probe to describe one of the source methods being tested. The equipment used were two Aries SPMLite recording systems, one with single SM7 3-component 10Hz geophones; the other with strings of 6 32CT 10Hz geophones podded and similar strings spread over 10 metres, an ION Scorpion with Vectorseis MEMS sensors, and Autoseis autonomous nodes each with 3 SM24 10Hz vertical geophones. Also tested were some GS-20DM 3-component geophones planted under sand bags instead of using spikes for coupling, and a single 3-component downhole geophone deployed in the well on the property. Sources for the survey were the University of Calgary Envirovibe, a Mertz M22 provided by Geokinetics, and dynamite shots of several charge sizes and depths. This paper makes some comparisons between the Aries and the Autoseis autonomous node recording systems.

INTRODUCTION

This experiment was acquired during the week of 9 July to 13 July 2012. Outsource Seismic provided all permitting and logistics; the layout and shooting personnel were provided by Geokinetics, with assistance from University of Calgary staff and students. Most of the equipment was deployed on Monday 9 July, with shooting starting on Tuesday with a first pass using the University of Calgary Envirovibe as a single source and a conventional linear sweep of 10-120Hz. On Wednesday morning the dynamite shots were acquired, followed by the Pulse-Probe experiment using two vibrators, the Envirovibe with a normal sweep and the Mertz M22 providing a mono-frequency output.

The receiver line layout is shown in Figure 1. Both the Sensor SM7 3-component geophones and the Vectorseis were laid out at 2m intervals from flag 101 to 493. The Autoseis nodes and the strings of 32CT geophones were laid out at 10m intervals from flag 101 to 491 (on every fifth flag). These strings of 6 x 32CT geophones in a 3 x 2 wiring configuration are part of a test to compare the same geophones laid out in a tight bunch (called “pods” in this paper) versus spread out over 10m (called “strings” in this paper). The 32CT 3-component coupling test geophones were laid at the center of the spread from flag 211 to 306 with 10m spacing.

The source line numbers for this project were 14 for the first pass with the Envirovibe alone, 2, 4, 6, 8, and 10 for the dynamite, and 16 for the second vibe pass with two vibes. Each dynamite line was a series of different charge sizes and depths along a short line perpendicular to the receiver line.

Part of the project was a test of operating the Autoseis nodes as autonomous units alongside the standard cabled system, both to investigate the system response of the Autoseis, and to become familiar with operation of this system which requires accurate timebreak information to be collected at the recorder for later data separation. A brief analysis of the Autoseis sytem and how it compares to the Aries acquisition system is the focus of this paper. Figure 2 shows the line, and the sensors used for this project.

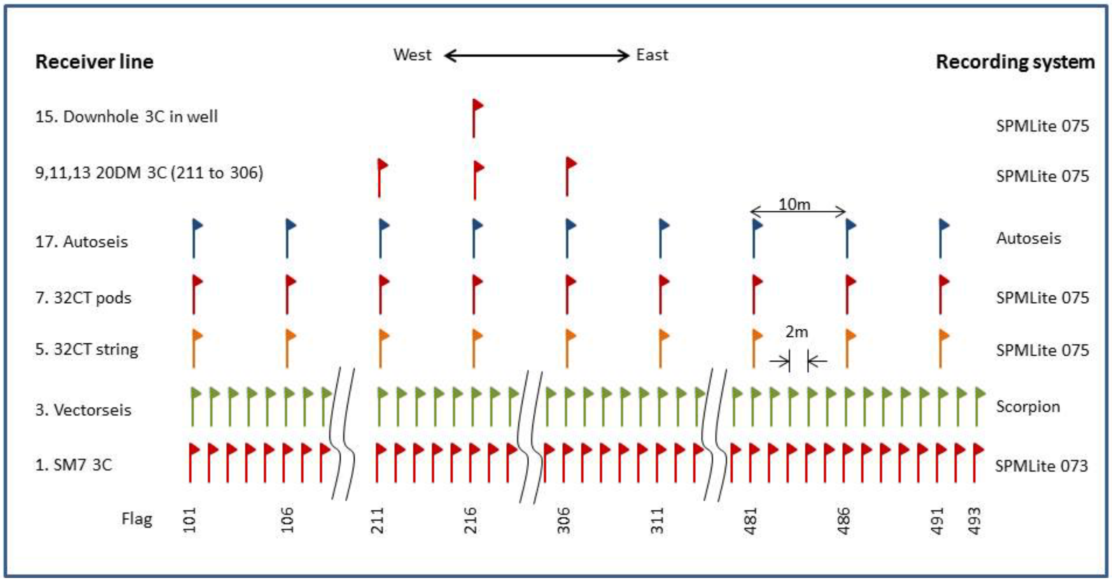

FIG. 1. The sensor layout for the acquisition of the Pulse-Probe experiment

FIG. 2. The receiver line looking west and the four sensors used. Top left: vectorseis, top right: SM7 3C, bottom left: GS-32CT pods, bottom right: Autoseis with SM24.

THE AUTOSEIS SYSTEM

The Autoseis nodes were loaned to the University of Calgary for this experiment by Autoseis Inc., who also provided the layout crew for these units. They were deployed at 10m intervals, with 79 units along the line. The geophone strings (3 x SM24) attached to the Autoseis were spread over 1 metre along the line. The Autoseis has an integrated GPS receiver that provides both position and time to the unit. Post-acquisition data separation uses a GPS time acquired by the Aries recording system for shot timebreak, accurate to microseconds, which provides the start time of the desired data window in the Autoseis memory. This was accomplished using a Verif-i GPS timing unit loaned to the University of Calgary by Inova. The Autoseis provides the seismic data in a SEGY REV-1 format with modified header to include all the required information. The data is recorded in 32 bit signed integer, with a maximum level of +/- 2.5 volts. Many of the Autoseis traces show a DC offset of up to +/- 100 microvolts, making it necessary to debias the data. The Aries recorder applies a mean correction to the traces before saving the data.

COMPARING TO ARIES DATA

To start the comparison between the two systems, the dynamite shot at location 10101 is used. This was 2 kg at 15 m depth. The shot gathers for the two systems are shown in Figures 3a and b, raw (with debias) and filtered 15-20-55-60 Hz. The data shows good energy to more than two seconds, with several shallower reflections also apparent. The Aries SM7 data is from the vertical component of the 3-component geophones, decimated to 10 m spacing to match the Autoseis locations, the Aries pods and strings are from the GS32CT geophones every 10m coincident with the Autoseis nodes. The line occupied by the Vectorseis and SM7 geophones was 2 meters south of the line occupied by the Autoseis and the GS32CT pods and strings.

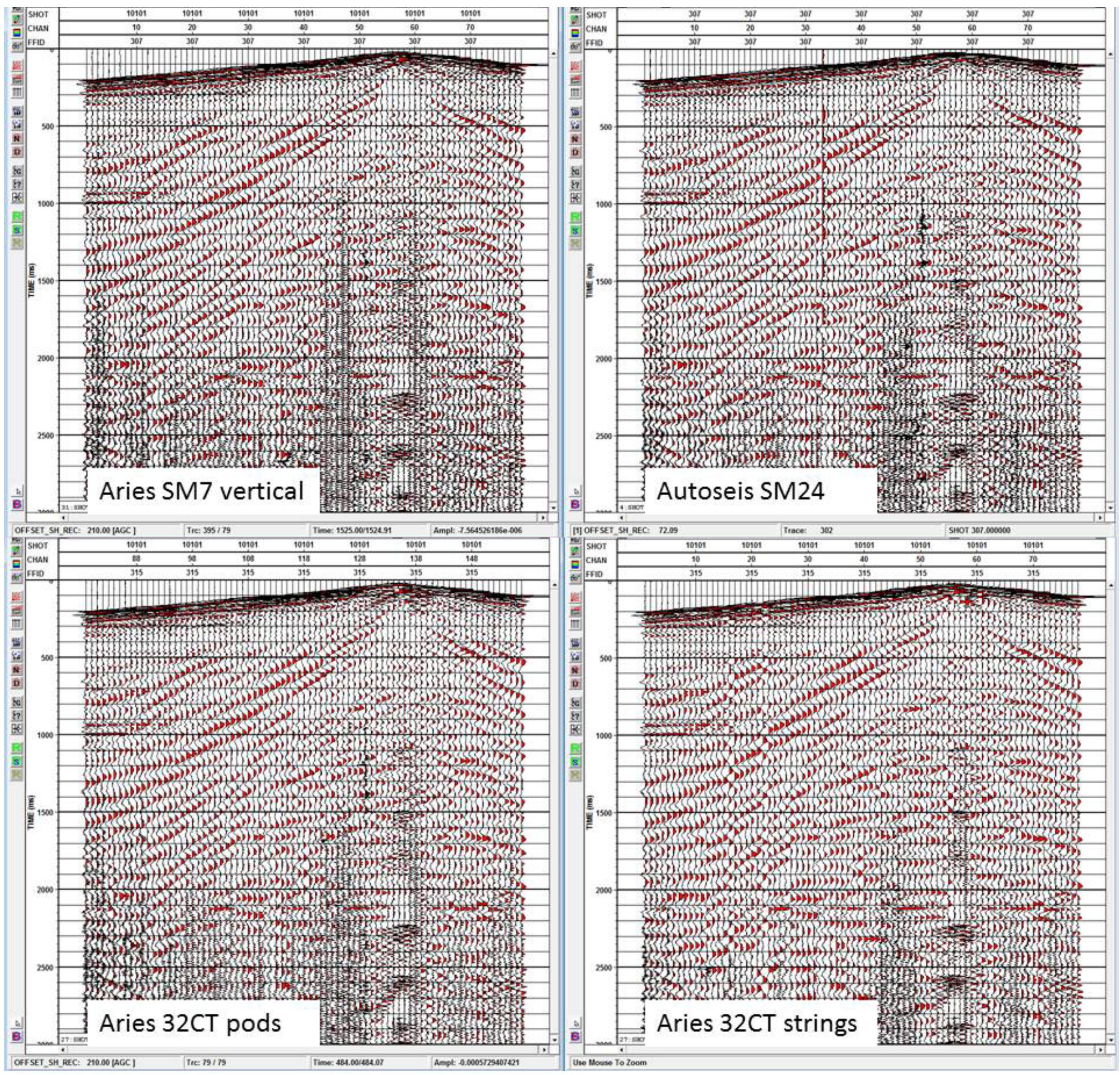

FIG. 3a. The raw shot gathers for dynamite shot 10101 after debias.

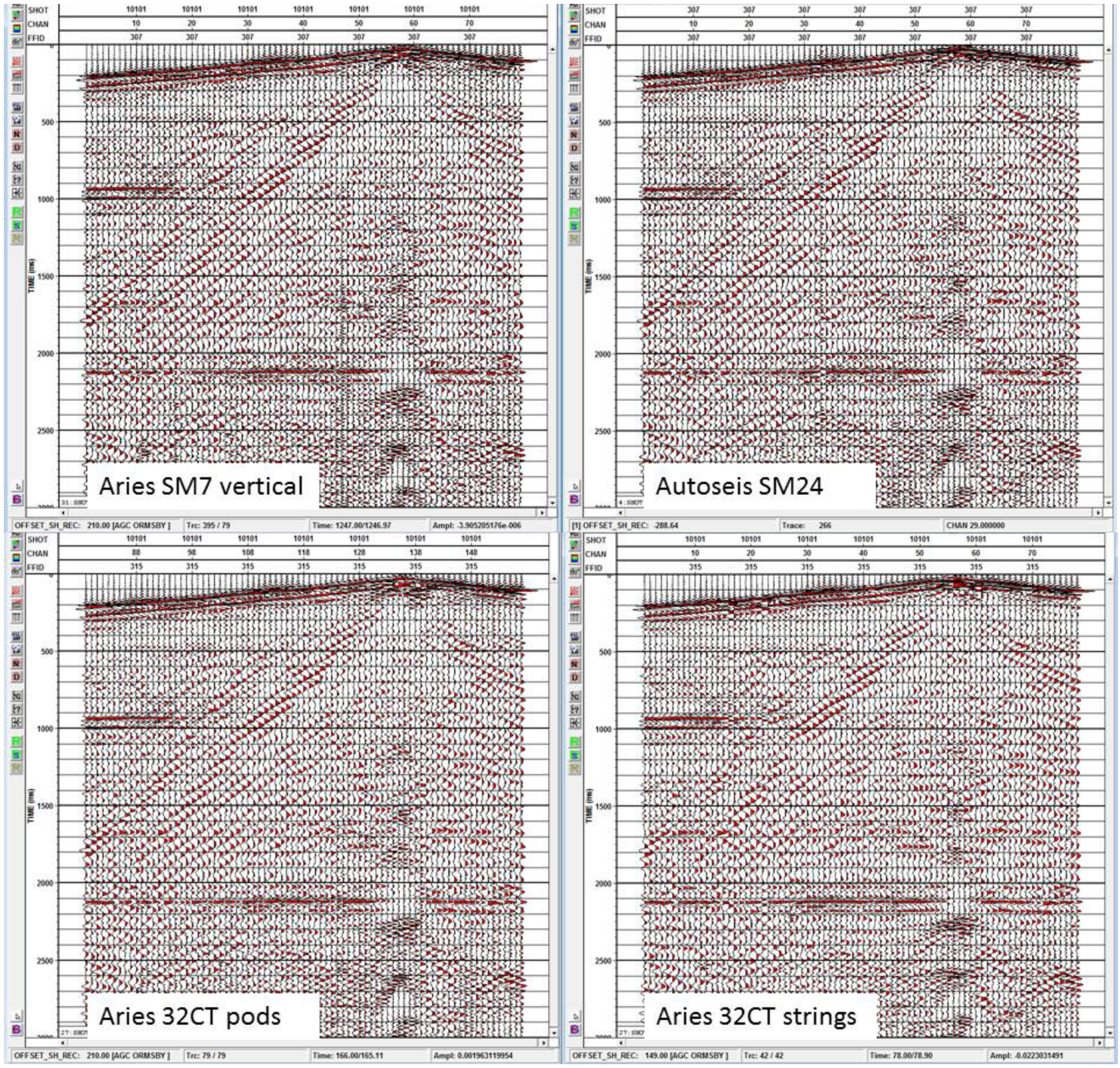

FIG. 3b. The filtered shot gathers (15-20-55-60Hz) for dynamite shot 10101.

Since the Autoseis data is in a 32 bit signed integer format, there is an inherent possibility of better data resolution over a 24 bit recording systems, such as the Aries. A comparison of the two systems shows that the first specification difference is the full scale recording level. For the Aries running at 30 dB preamp gain (the gain normally used on this system) the maximum is specified as 0.122 volts RMS, which is 0.173 volts peak, while the Autoseis is 2.5 volts. The maximum observed voltage on the Aries is about 0.223 volts in areas of clipping close to the shot. The reason for this is that the converter in the Aries will allow over-scaled inputs, but does not guarantee accuracy of these numbers. The observed maximum in the Autoseis data is 2.5 volts in the clipped areas, which corresponds to a full 32 bit word. This observation of the clipped maxima is used to generate some information about occupied bit level of the different converters.

Figure 4 shows a sample of the clipped areas of these gathers. There is a difference in the way the two converters handle an over-range signal. The Aries clips the output data, while the Autoseis filter can apparently roll over in error. Discussion with Autoseis revealed that this was due to a firmware error in the Autoseis unit which has since been corrected. To avoid problems in applying debias to the Autoseis traces the process is windowed to later than first breaks. Both converters recover quickly from a clipped signal so there is no further data loss as a result.

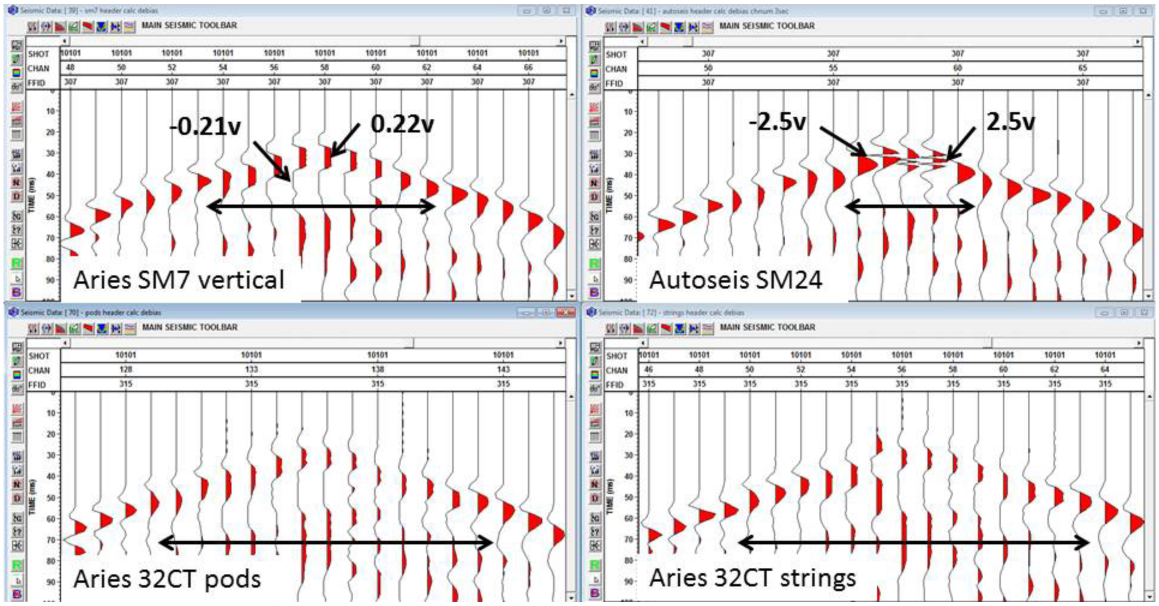

FIG. 4. Area of first break clipping on shot 10101 (indicated by arrow). The filter rollover is apparent on the Autoseis traces as single sample values of -2.5 volts.

Table 1. Bit value comparison. Values are volts.

Bit	**Autoseis**	**Aries**	Bit
32	2.50000E+00		
31	1.25000E+00		
30	6.25000E-01		
29	3.12500E-01		
28	1.56250E-01	2.20000E-01	24
27	7.81250E-02	1.10000E-01	23
26	3.90625E-02	5.50000E-02	22
25	1.95313E-02	2.75000E-02	21
24	9.76563E-03	1.37500E-02	20
23	4.88281E-03	6.87500E-03	19
22	2.44141E-03	3.43750E-03	18
21	1.22070E-03	1.71875E-03	17
20	6.10352E-04	8.59375E-04	16
19	3.05176E-04	4.29688E-04	15
18	1.52588E-04	2.14844E-04	14
17	7.62939E-05	1.07422E-04	13
16	3.81470E-05	5.37109E-05	12
15	1.90735E-05	2.68555E-05	11
14	9.53674E-06	1.34277E-05	10
13	4.76837E-06	6.71387E-06	9
12	2.38419E-06	3.35693E-06	8
11	1.19209E-06	1.67847E-06	7
10	5.96046E-07	8.39233E-07	6
9	2.98023E-07	4.19617E-07	5
8	1.49012E-07	2.09808E-07	4
7	7.45058E-08	1.04904E-07	3
6	3.72529E-08	5.24521E-08	2
5	1.86265E-08	2.62260E-08	1
4	9.31323E-09		
3	4.65661E-09		
2	2.32831E-09		
1	1.16415E-09		

Table 1 shows the bit value for the two systems. The pods and strings show clipping to a larger offset as expected from the parallel / series connections of the array causing an increase in input voltage of three times the output of a single geophone. The pods are noisier than the strings which is surprising, since they use the same geophones and the same acquisition system. There are fewer clipped traces close to the shot in the Autoseis data than in the Aries data, showing there is a better dynamic range in the upwards direction as expected by the higher maximum input.

The difference in the maximum input voltage between the Aries and the Autoseis is 20 dB. Although this sounds significant, it really only has meaning close to the shot. As is evident from the gather plots above (Figure 4), the clipping occurs on the Aries trace within 40m of the shot for the single SM7 geophone, up to 70m for the 32CT strings, and only in the first 100 milliseconds. For the Autoseis, the clipping is only on traces within 20m of the shot, and also only in the first 100 ms. These offsets and times are often lost in trace editing and muting during processing. Figure 5 is an attempt to quantify the actual converter use by bits occupied, a method first shown by Bertram (1995). The Matlab code used to generate these plots is given in Appendix A. The images are scaled to the maximum clipped level, with the clip voltage for each system plotted in dark red. Because the least significant bit of the Aries is about equal to bit 5 of the Autoseis, there is a colour difference in the low signal regions. This also means there are another 4.5 bits available for signal resolution in the Autoseis (actually 26 dB when calculated).

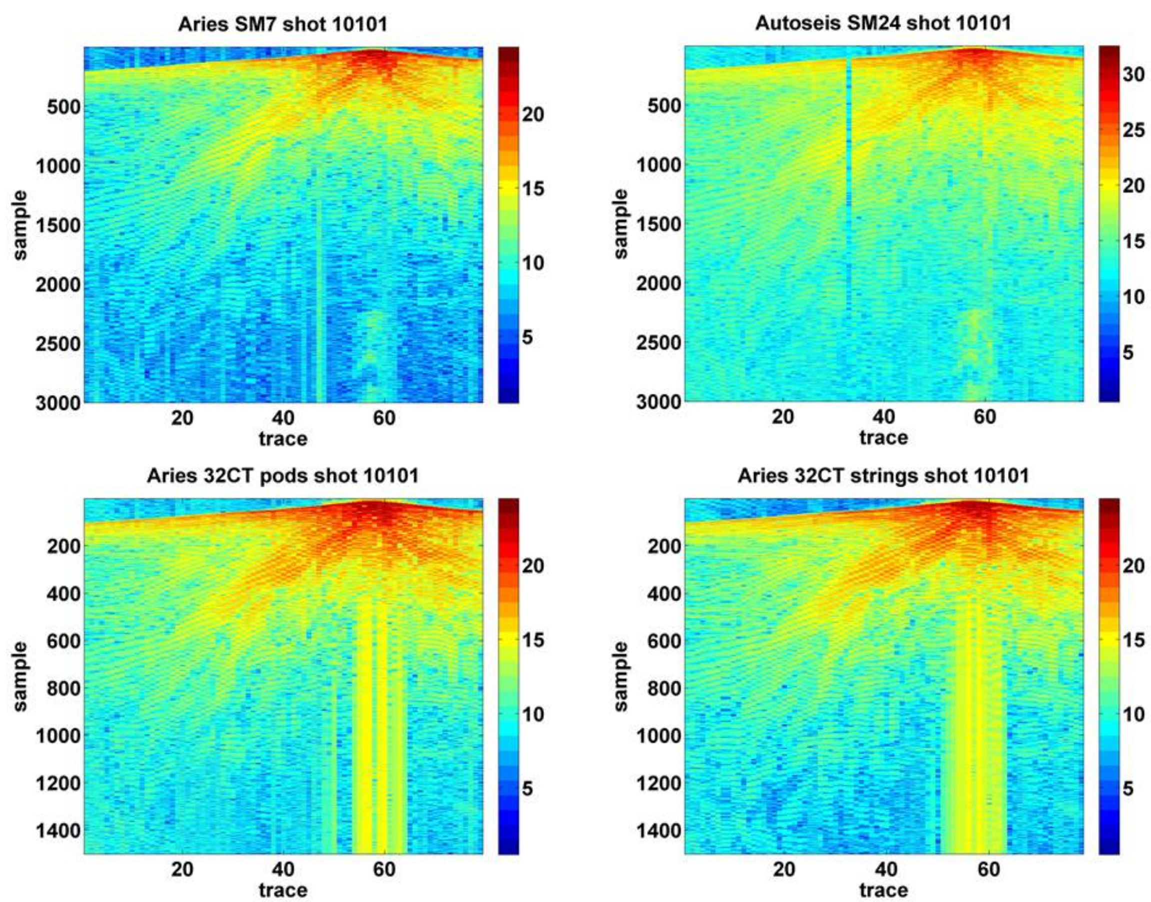

FIG. 5. Bit use plot.

From the two data sets, Figure 6a shows the ratio between the Autoseis SM24 and Aries 32CT pods peak to peak values for each trace for the shot gathers for shot 10101. The values are close to one for most traces, except for the traces near the shot, where the Aries and Autoseis have clipped, and the ratio rises to 11 (= 2.5 V / 0.22 V). Figure 6b shows the same plot for the shot at 10103, which was only 0.125 kg and caused clipping on the nearest two traces of the Aries but not the Autoseis. There is one dead trace on the Autoseis data which gives a zero. There is good correlation between the plots in Figures 6a and 6b showing that the ratio is the same for two separate shots for most traces. This suggests that the geophone plant or coupling is the most likely explanation for any differences. The two systems provide about equal quality data for the conditions at this location for these dynamite shots.

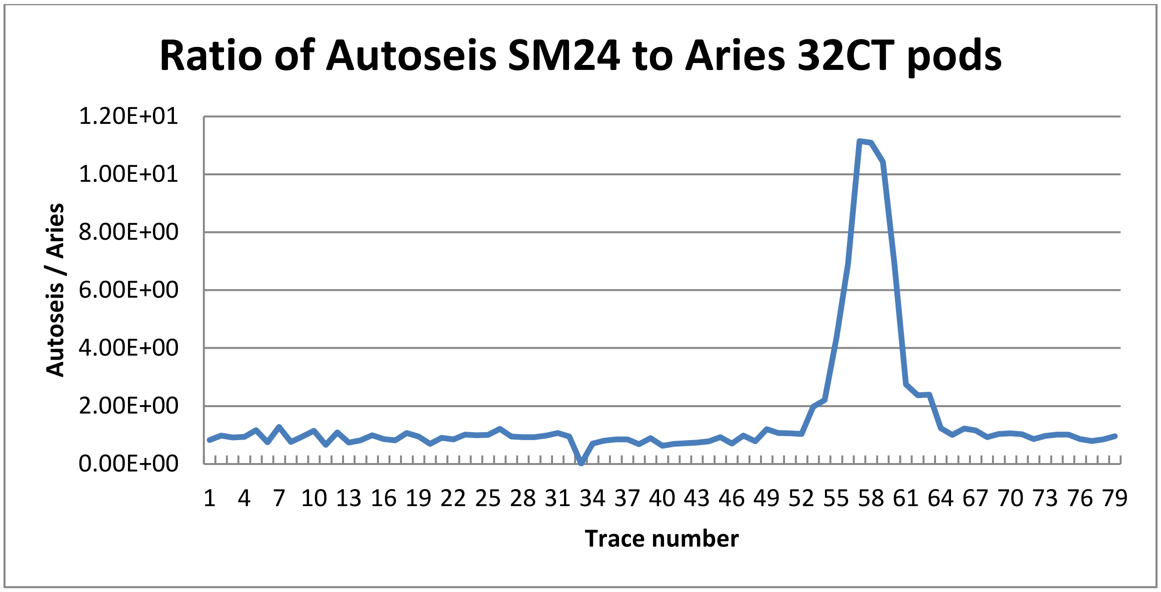

FIG. 6a. Data value ratios for shot 10101.

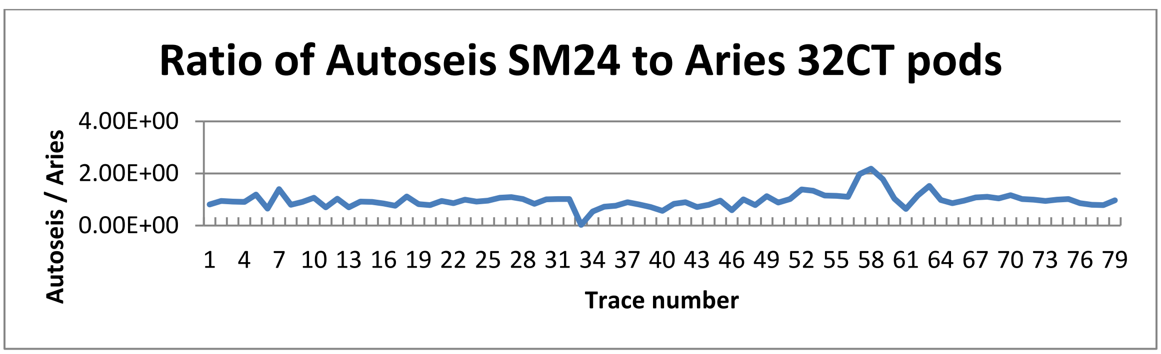

FIG. 6b. Data value ratio for shot 10103.

The data before the first breaks gives some idea of the ambient noise in the area, and shows that it is going to be difficult to get a comparison of the two systems at very low signal levels. Most of the noise visible here is from traffic on an adjacent highway. The limiting noise here is environmental rather than electronic. Further investigation is required at a quieter site to really quantify any benefits from the extra dynamic range available in the Autoseis.

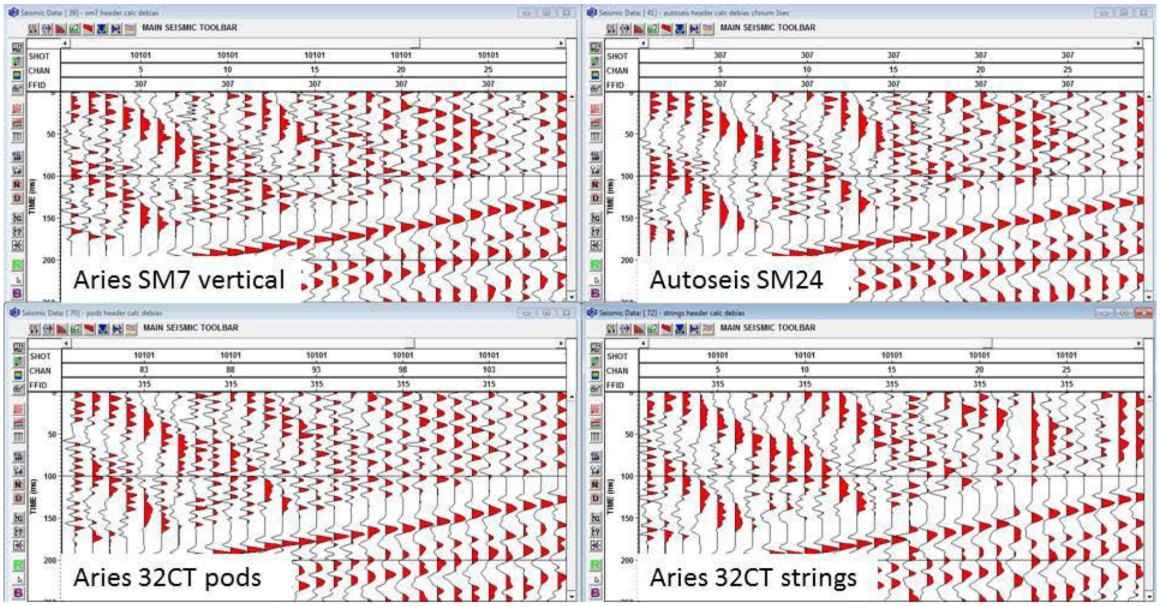

FIG. 7. The first few traces of the shot gathers for shot 10101 showing the noise before first breaks. AGC window 50 msec.

A look at the spectra of the two systems also indicates they are about equal in data quality. Figure 8 shows the spectra for the whole gather for the Aries SM7 and the Autoseis, including the clipped first breaks after debias of the data. The 26 dB available at the lower end of the Autoseis converter is evident at 500 Hz.

FIG. 8. Spectra of the two systems for the shot gather 10101.

At very low frequencies the two systems seem to have nearly identical response, suggesting there will be little to gain from low frequency recovery on the Autoseis data as compared to the Aries. Figure 9 shows the same shot gather spectra for all four data sets for channels 1-50 with the low frequency recovery also applied and plotted. The reason for windowing the data was to eliminate the clipped traces near the shot from the spectra. There appears to be very little difference between the two systems at the very low frequencies, and applying the low frequency recovery technique shows no obvious advantage of one system over the other.

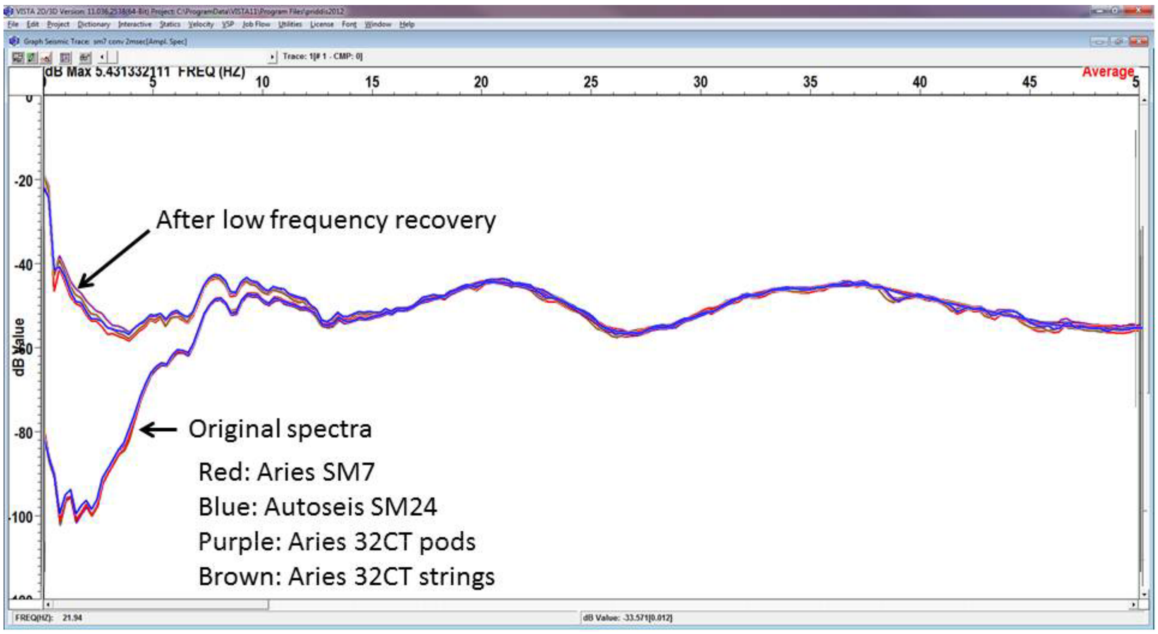

FIG. 9. Spectra of shot 10101 from channels 1-50 with low frequency recovery applied.

The low frequency recovery technique documented by Bertram and Margrave (2010), has been shown to work very well on the data from the 2011 Hussar project (Margrave et al., 2011) and the 2010 Priddis onSeis comparison test data (Bertram et al., 2010). In these cases the data sets were from different geophones types – 4.5 Hz, 10 Hz and MEMS. The 10 Hz geophone comparisons were between standard SM7 and high sensitivity (high resistance and high output; either GS-One (2010) or SM-24-1K8 (2011)) which showed a slight separation between the spectra curves at very low frequencies. In this case all the geophones are of similar types – all have the same resistance, sensitivity, and response curves and all show the same low frequency recovery response. This result does provide some confidence that the new high sensitivity geophones actually do have a slight advantage at these frequencies, and that the low frequency response is geophone driven, not instrument. The conclusion here is that the 32 bit Autoseis system does not appear to have any advantage at these low frequencies for a survey of this type.

All the results so far are taken from shot 10101 – 2 kg at 15 metres. To investigate a shot with lower signal level, one of the cap only charges was chosen. Shot 4104 seems to have the lowest coherent low frequency noise caused by traffic, and the bit use plot for this shot is shown in Figure 10. The most significant bits occupied for these gathers is bit

19 for the Aries SM7, bit 20 for the 32CT strings, and bit 25 for the Autoseis. There is more visual difference between these plots than was seen in the previous bit plot (Figure 5), in particular the unexpected higher bit number in the pods plot. Inspection of these plots again shows about 4 to 5 bits advantage of the Autoseis over the Aries SM7. This is the same as before, indicating that the true signal level is being given by all systems.

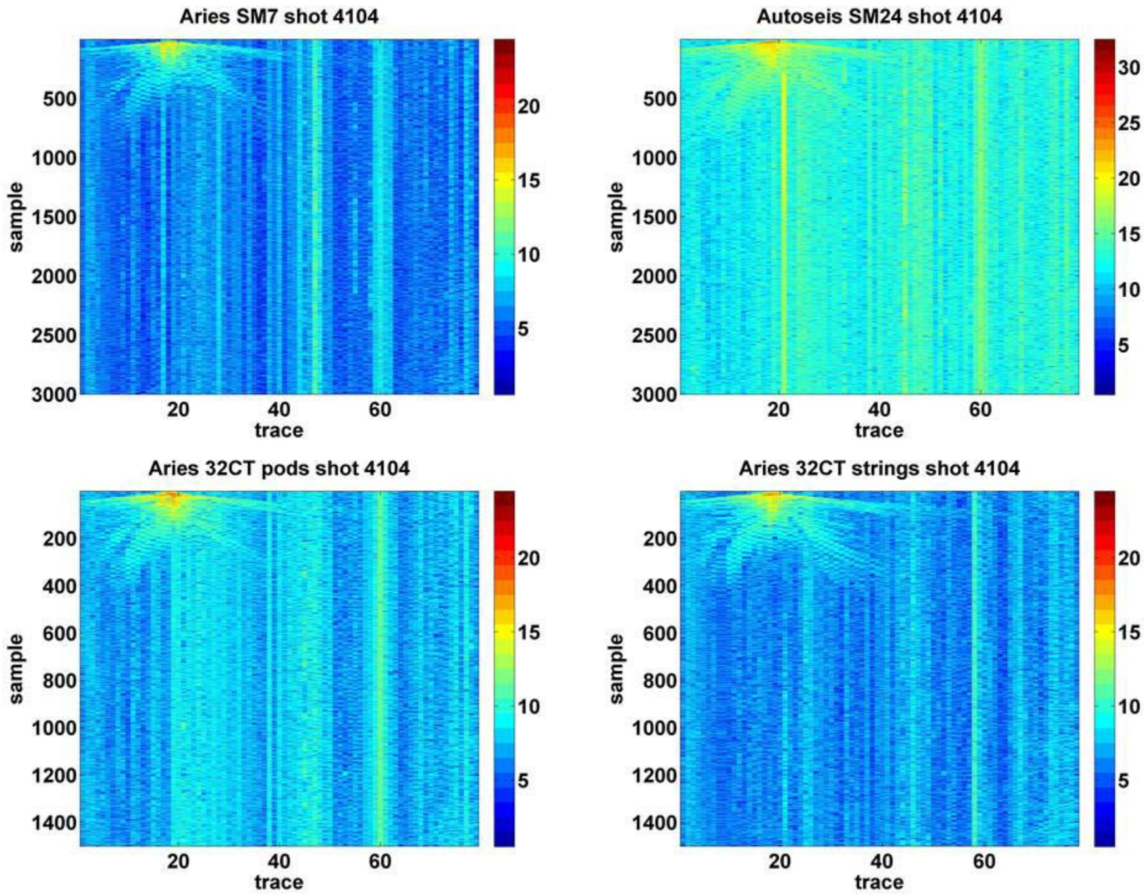

FIG. 10. Bit levels for shot 4101 (cap only)

Figure 11 shows the gathers for the four data sets for shot 4104. Only the first 300 ms of the gather are shown, with a filter of 70-90-150-200 Hz applied to try and extract some of the very shallow data that we know exists in this area. From the four plots, it appears that the Autoseis provides the best coherent energy along the first breaks, with data to the far offsets. The best display of the events at 100 ms and at about 220 ms is on the plot of the 32CT strings. There is little difference between the plots, with the Aries SM7 perhaps being weakest in high frequency energy. Actual signal levels in the coherent event at 220 ms are about +/- 2 microvolts for the Aries SM7, +/- 3 microvolts for the Autoseis, +/- 4 microvolts for the pods and strings. These values are about the level of bit 7-8 in the Aries converter, and about bit 12-13 for the Autoseis. This does suggest the possibility of being able to extract more from the Autoseis data through techniques such as very high stacking, or CMP, fold numbers. Further work is required to quantify any benefits of this system. A comparison with a slightly larger shot size is shown in Figure 12. This is shot 4106 which is 0.25 kg. The plot is filtered and gained the same as Figure 11. In this case, there is quite good continuity of the event just below 200 ms on all four gathers, with none standing out as superior. There is energy visible to about 120 Hz on these dynamite shots, which provides confidence that the vibe sweep chosen of 10-120 Hz is optimal for the area. This focus on the very shallow section and high frequency is to assist in generating an understanding of the top 200 m in the area, in preparation for the installation of a 150 m deep well on the property with several instruments installed which will be running continuous monitoring to test parameters for the future CO2 sequestration project sponsored by Carbon Management Canada (CMC). These instruments will include 40 levels of 3C geophones, a distributed acoustic optical fiber and possibly other sensors.

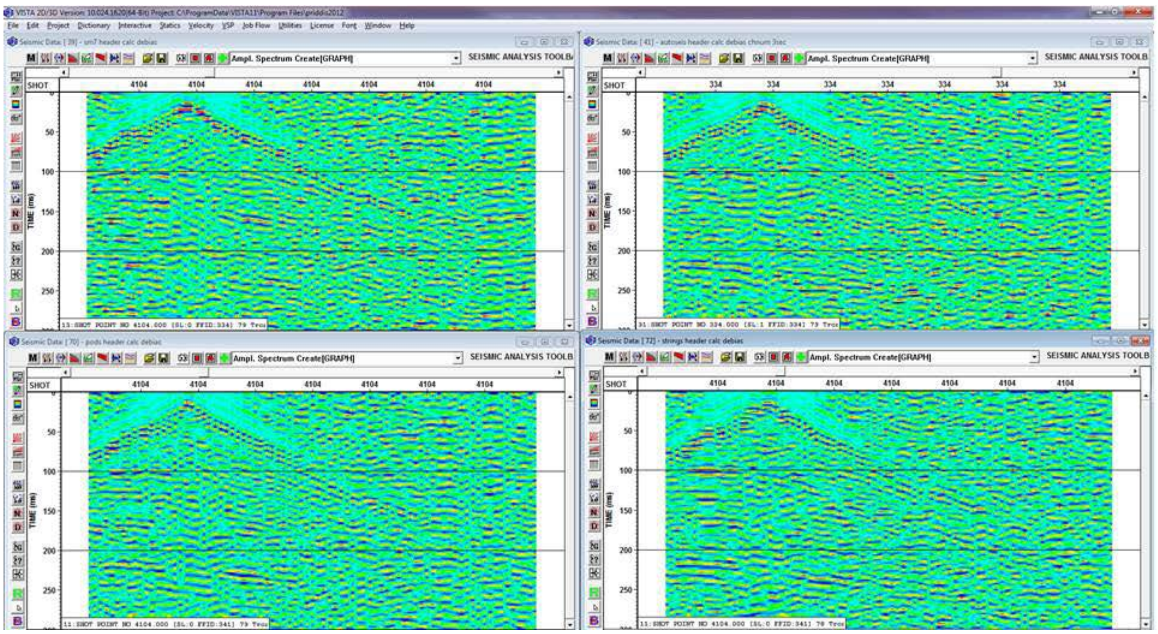

FIG. 11. Gathers for shot 4104 filtered 70-90-150-200 Hz. First 300 ms shown.

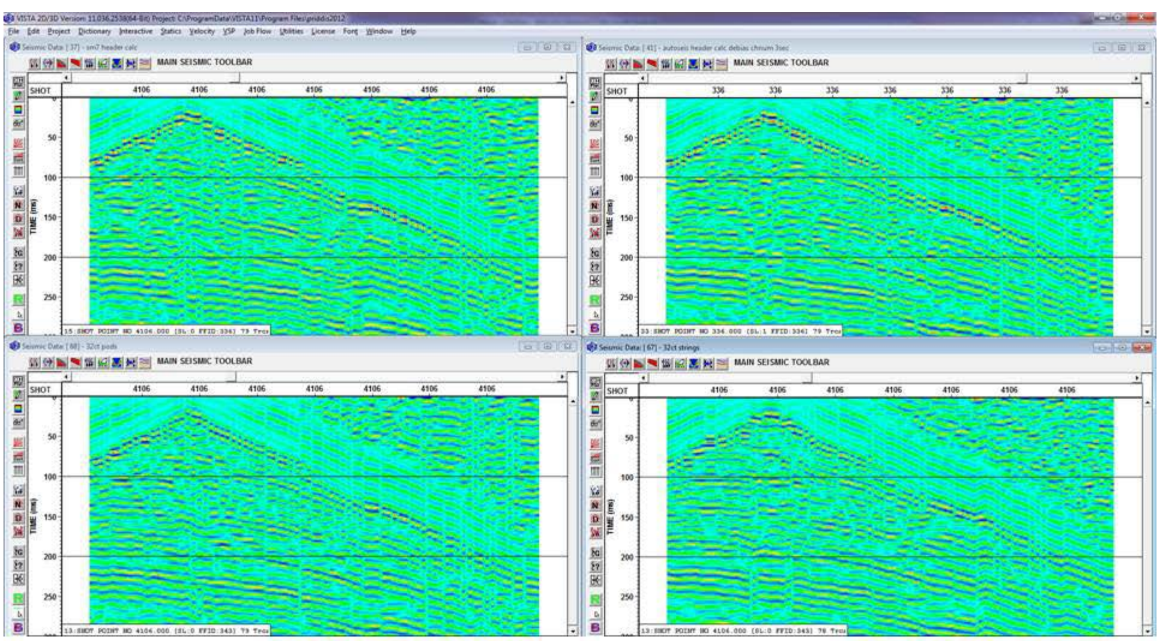

FIG. 12. Gathers for shot 4106 filtered 70-90-150-200 Hz. First 300 ms shown.

To this point only a few of the dynamite shots have been shown. The same results can be obtained from any of the shot groups, but there is considerable variation in the ambient noise, depending on the traffic at the time.

Most of the project involved vibrator acquisition, in all cases with the EnviroVibe operating along a source line about 2 m north of the receiver line that includes the Autoseis SM24 and the 32CT pods and strings. The SM7 and Vectorseis lines were another 2 m further south, away from the source line. Figure 13 shows the bit level plot for the four receiver spreads for an uncorrelated sweep from the first pass when the Envirovibe was operating as a single source at source location 467, near the east end of the line. The 32CT pods seem to be the noisiest of the Aries receivers, as was shown on the small charge size plot (Figure 10). One reason for the higher noise on the pods might be due to wind catching the looped cable from the geophone pod. Within 20 m of the vibe, the Aries channels are clipped with 23 bits occupied, while the Autoseis manages to just cope with the signal level, with a maximum of 30 bits occupied (0.6 volts).

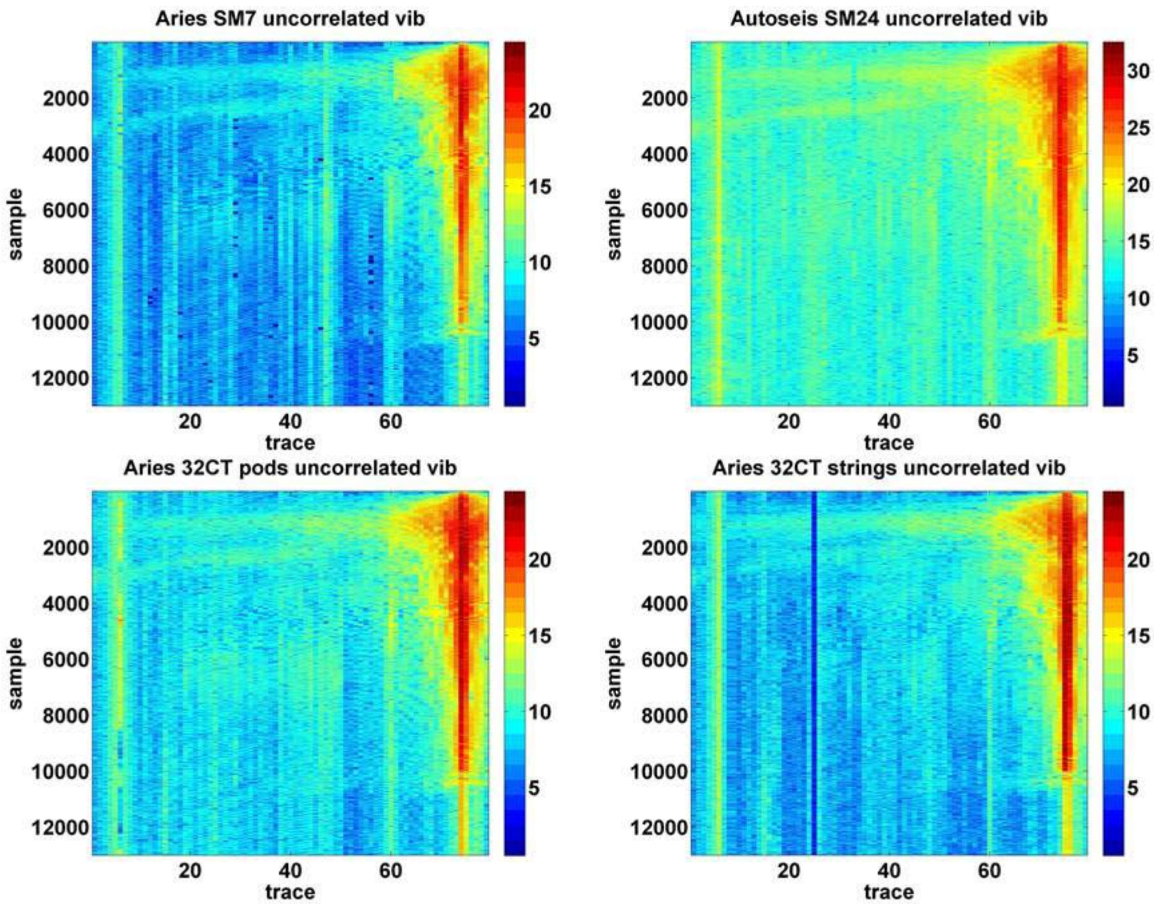

FIG. 13. Bit level plots for one uncorrelated sweep for single vibe at 467.

The second part of the vibe acquisition involved a monofrequency signal of 25 Hz produced by the M22 while the EnviroVibe ran the same sweep as before (linear 10-120 Hz). Figure 14 shows the bit level plot for one of these sweeps at source location 279, near the centre of the spread. The monofrequency 25 Hz is very evident here, showing up as the band across the entire spread on all the gathers, starting at 1 second and stopping coincident with the linear sweep. In the case of the Autoseis, the band is not quite as clear, but this is simply due to the colour bar values. For this shot the M22 was offset 100 m north of the receiver line. The maximum bit occupied is 23 for the pods and strings, indicating again a clipped input, 22 for the SM7 and 29 for the Autoseis, showing these two did not clip on this shot. A discussion of some of the results from this part of the project is given by Innanen et al. (2012).

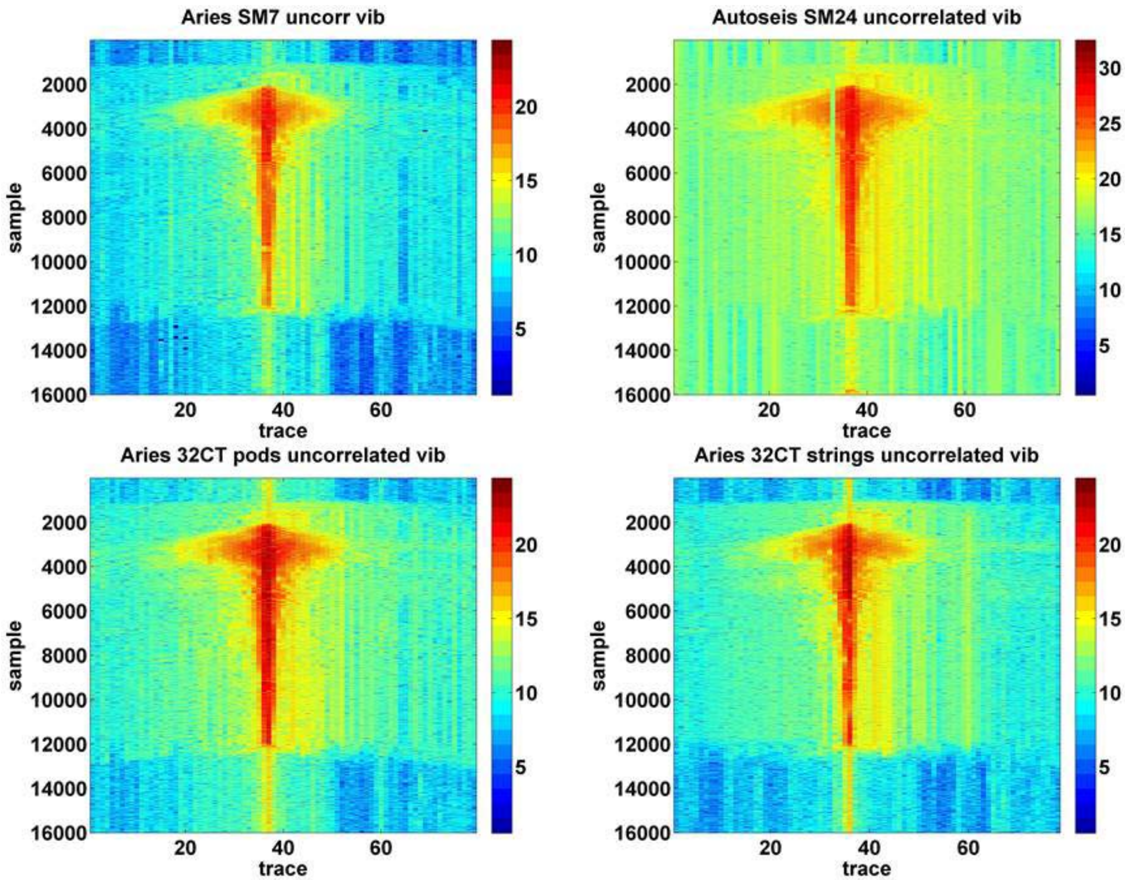

FIG. 14. Bit levels for one uncorrelated sweep for dual vibe source at 279.

CONCLUSIONS

The Autoseis system performs at least as well as the Aries system for this field work. There is no obvious benefit to either system from the point of view of shot gather data quality. However, this location has very high ambient noise, and this survey was a small effort with few shots and only 79 receiver locations for the Autoseis. The benefits of using a 32-bit recording system are expected to become more apparent after stacking.

Low frequency data recovery is dependent on the sensor much more than the recording system. Both Aries and Autoseis show exactly the same spectra after low frequency recovery when using similar geophones.

The Vibroseis data has not been investigated in any depth as yet: this will be part of the ongoing work.

ACKNOWLEDGEMENTS

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APPENDIX A

Matlab code used to generate the bit level plot from the shot gather.

```
%% bit level plot - this example displays the Aries data
trace_data = altreadsegy('input.sgy'); % input shot gather
trace_max = 0.223; % set max value when clipped (30db preamp gain)
trace_norm = (trace_data / trace_max) * 2^23; % normalise and convert
trace_log = log2(abs(trace_norm)); % take log2 value
trace_bit = trace_log.*(trace_log > 0); % positive only values
image (trace_bit) % plot
colormap(jet(24)) %set colours
colorbar % display colorbar
```

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