Seismic acquisition projects 2009

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ABSTRACT

Since the CREWES meeting in November 2008, several acquisition projects have been undertaken. These include: a) a 9C VSP and 3C 2D line recorded in March 2009 at the Priddis observatory, the VSP to provide data for near surface attenuation studies and geophone orientation algorithm development, and the 2D line to evaluate the area for the proposed injection test site embedded array, as well as provide another data set for noise analysis; b) a set of evaluation records recording weight drop thumps and low frequency vibrator sweeps into comparison spreads of geophones, MEMs sensors, and seismometers acquired in August 2009 to evaluate the low frequency response of the seismic sensors compared to seismometers, and investigate surface propagation at low frequencies; c) the 2009 University of Calgary Geophysics Field School (GOPH549), this year recording a 3C 2D line in the Spring Coulee area.. Also, during the last year, a new small weight drop source using an elastic band for acceleration has been developed and constructed at the University of Calgary.

INTRODUCTION

The first project was the Priddis survey in March 2009. For this project, a shear wave MiniVibe was borrowed from the University of Alberta for use as a second source for the 9-C VSP investigating near surface properties, attenuation, and providing data for geophone orientation algorithm development. Following the downhole tests, a three component 2D line was acquired across the south paddock using the University of Calgary's Envirovibe as a source. This line was recorded using a high source effort to provide good spatial resolution for both noise analysis and detailed information for designing the proposed buried geophone array for this area.

The second survey was an evaluation test of three component MEMs sensors alongside seismometers, with a three component geophone line also recorded. This experiment was conducted with the assistance of ION and CGGVeritas who provided the MEMs sensors, recording equipment and personnel for the comparison study. A weight drop unit and the University of Calgary's Envirovibe were used at sources for this survey. Sweeps included 2-10 Hz and mono-frequencies of 3 Hz and 5 Hz. Some sweeps of 2-100 Hz were also recorded, but are not usable for comparisons since the seismometers were sampling at 10 msec.

The third survey was the 2009 Geophysics Field School, which was again based at Spring Coulee, acquiring an East-West three component line this year. This is the first time that Field School students have been exposed to full scale three component recording. The line intersects the 2008 Field School line 1 and passes the north end of the January 2008 Spring Coulee line shot by CREWES.

The new weight drop source was constructed on a small trailer, and consists of a 400 pound steel hammer hitting an aluminum base plate which is held down by the weight of the trailer to provide good ground coupling. The small mass size is an attempt to increase the velocity at impact for a higher frequency output, and the hammer weight can be changed easily in the field if desired. The design is intended for small engineering studies where higher frequency is an advantage for shallow event resolution.

PRIDDIS 9C VSP AND 3C-2D LINE, MARCH SURVEY

The intent for this project was to acquire data to evaluate the property for the proposed sequestration test site currently under review, while providing another dataset for noise attenuation studies. The first part of the project involved a 9C VSP survey using the University of Calgary Envirovibe as a P-wave source, and the University of Alberta MiniVibe as a shear-wave source. The two sources were parked side by side 10m south of the 130m test borehole. The University of Alberta MiniVibe is a truck mounted unit, shown in Figure 1. The vibrator mass on this unit can be rotated to provide either inline (SV) or crossline (SH) output. Data from the VSP will be used for near surface attenuation studies and provides a useful data set for downhole geophone orientation algorithm development.

The downhole tool used was the University of Calgary's Geostuff single 3C clamping geophone, attached to a Geode recording system. The survey was started with the 500m Geostuff cable, with the geophone at depths from 110-9m at 9m intervals. After some intermittent connection problems showed up in this cable, the shorter 100m cable was used for the second part of the VSP, with the geophone at 95, 90, 80, 70, 50, 30 and 10m depths.

FIG 1. The MiniVibe unit belonging to the University of Alberta set in SV mode.

For each tool level, recordings were made of several different sweeps in P, SH and SV modes using both vibrators. Firstly a 10-250 Hz (vertical) and 14-250 Hz (horizontal) linear sweep was recorded. The difference in the starting frequency is due to the University of Alberta MiniVibe only being able to operate down to 14 Hz safely, while the University of Calgary EnviroVibe is capable of 10 Hz. Following these sweeps, band-limited sweeps of 10-25 Hz (vertical) and 14-25 Hz (horizontal), 15-35 Hz, 25-50 Hz, 40-70 Hz, 60-105 Hz, 95-155 Hz and 145-250 Hz were recorded for near surface attenuation (Q) studies. All sweeps were 20 seconds in length. Figure 2 shows an example of the raw data from the 10-250 Hz vertical sweep.

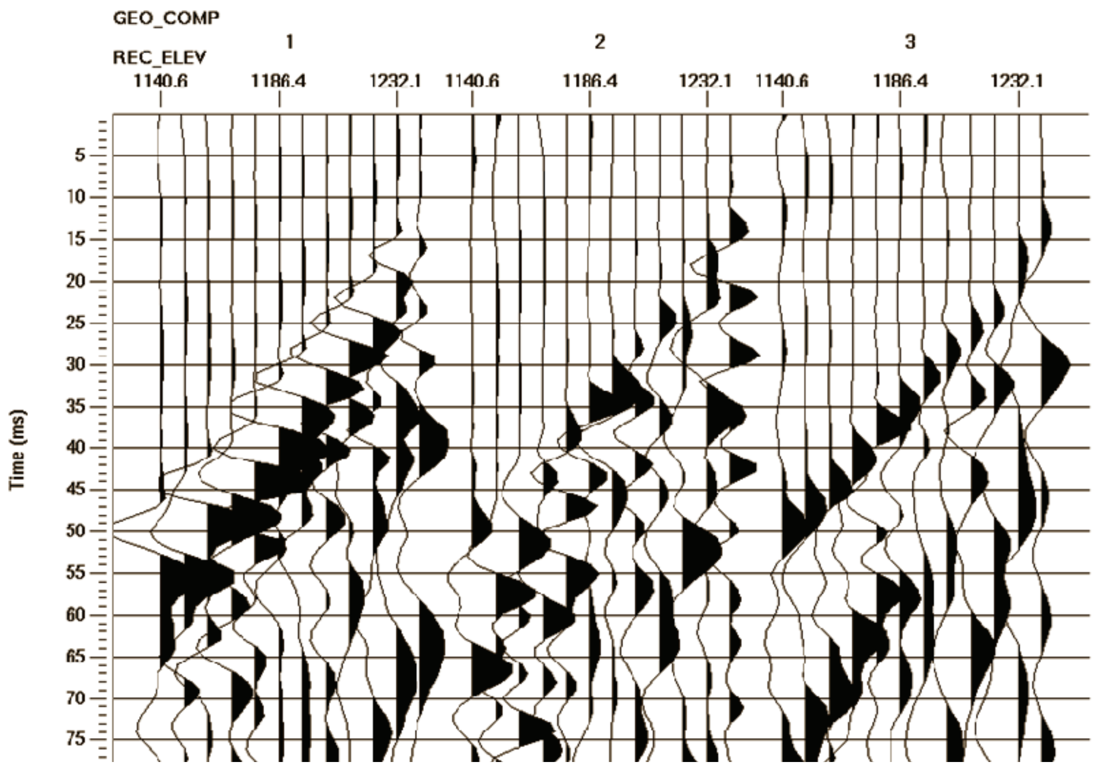

FIG. 2. University of Calgary vibe (P source) recorded by a 3C geophone in the borehole. Vertical component is on the left, and horizontal components are in the center and on the right. No component rotation has been applied.

As the second part of the project, a three component 2D line was shot across the south field. This line was 768 m in length at a bearing of about 70 degrees, approximately in the dip direction of the structure. Receiver spacing was 4m and shot spacing was 2m. Receivers were Sensor SM24 3C geophones in a plastic nail-style case belonging to the University of Calgary. At the time, snow depth varied from centimeters to almost a meter in drifts. In order to easily plant the geophones, and to have the vibe plate firmly on the ground, the source line was cleared by a Bobcat with a snow blower. The receiver line was deployed using two ATVs with chains pulling trailers over the snow. This was necessary due to warm temperatures during the days, which caused the source line to become very muddy, increasing the probability of damaging the field. Snow melt also pooled in the cleared line and froze overnight, giving excellent geophone coupling. When the line was picked up, some geophones were under several centimeters of ice, and a few cases were broken while being extracted. Figure 3 shows the line looking towards the west.

FIG 3. The Priddis south field 3C-2D line looking west.

The line was shot using the University of Calgary EnviroVibe with a starting sweep of 8-150Hz over 20 seconds with 0.1 second tapers, four sweeps per Vibe Point. Acquisition was suspended for three days due to high winds and a problem with the vibe's hydraulics. The following day, flags were missing and geophone locations were drifted in making it difficult for the vibe operator to see receiver stations. After acquisition was re-started, the sweep was inadvertently changed to 10-150Hz during a system reset. This was not evident until the data was being processed some time later. Every uncorrelated sweep was recorded as a separate file, as well as the correlated sum. This provides a very complete data set for future analysis, in particular investigating the coupling change between the first sweep and the following ones after the plate has bedded in (the plate visibly sank during the first sweep). An offset-limited (0-120 m source-receiver offsets excluded) migrated section is shown in Figure 4. Shallow reflections dip to the east, in the opposite direction to local topography. As a comparison, the corresponding line extracted from the 3D survey shot by the University of Calgary Geophysics Field School over the same area in August 2007 is shown in Figure 5. There is a bulk time shift between the two sections due to different elevation datums being used.

An analysis of the data from the March 2009 line is presented elsewhere in this volume (Shaken, not stirred: Priddis 2009 3C-2D hi-res acquisition; Dave Henley et al).

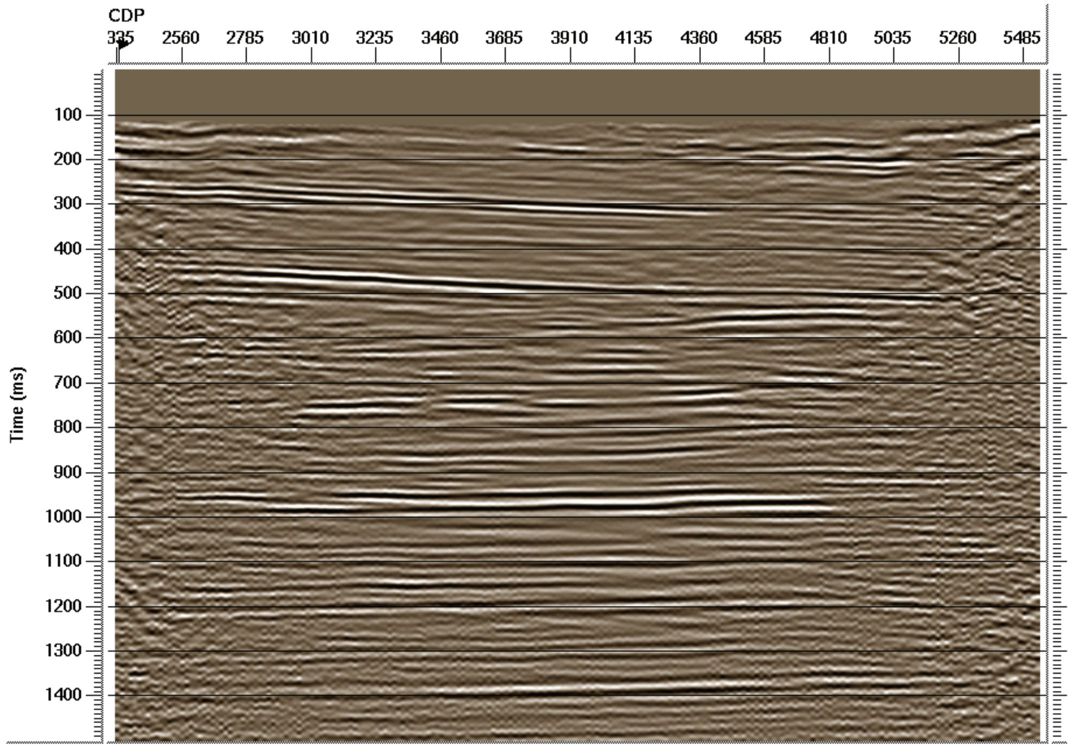

Fig 4. Offset limited migrated P-P section. West is to the left.

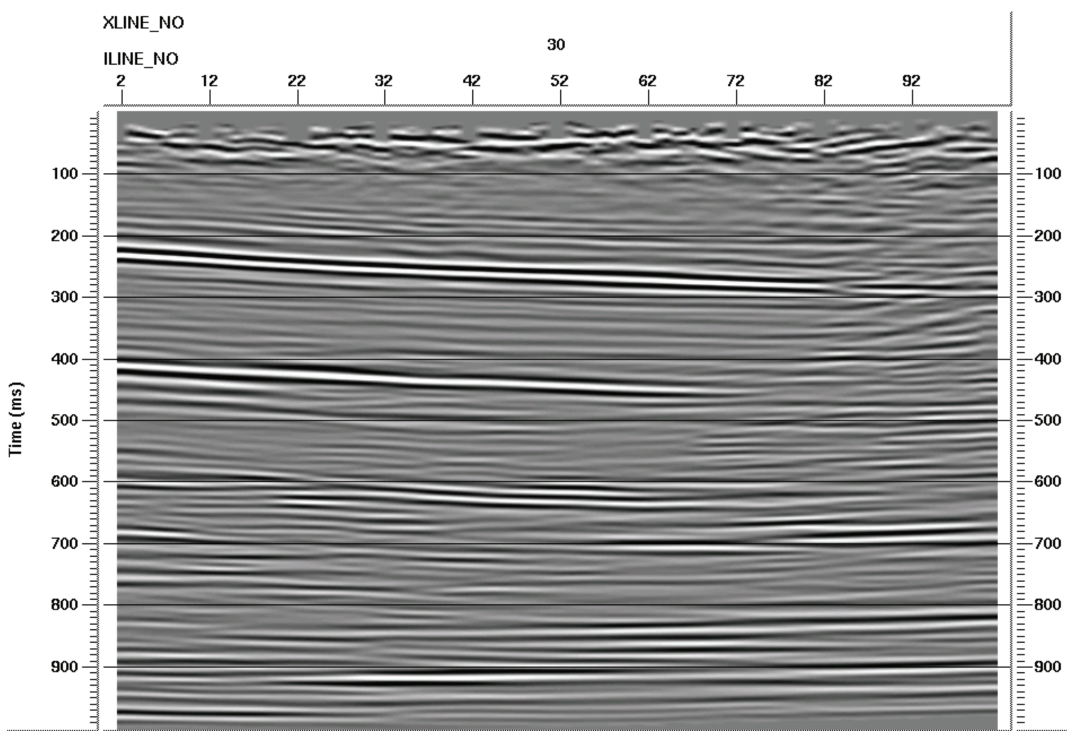

FIG 5. The corresponding line from the 3D survey acquired by the 2007 Geophysics Field School

PRIDDIS LOW FREQUENCY COMPARISON TEST

In August 2009 the University of Calgary had available 8 Nanometrics Trillium 240 seismometers which were to be deployed at temporary sites around Alberta as part of a monitoring project. While these units were still in Calgary, it was decided to attempt to compare the low frequency response of 10Hz geophones to these calibrated units. As an additional experiment, with the co-operation of ION and CGGVeritas, the tests included ION Vectorseis and Sercel DSU3 MEMs sensors. These solid state sensors were planted alongside the seismometers which were spaced at 10m as shown in the diagram below (Figure 6). The geophone spread was deployed as 80 geophones at 1m spacing to provide more detail of surface motion. The 8 seismometers were planted on flat paving stone pieces, which were placed in shallow holes and leveled before the seismometers were installed. These were set up alongside the geophones at stations 1, 11, 21, 31, 41, 51, 61 and 71 (10 m spacing). Both MEMs systems had sensors alongside the seismometers, and also had a 9th sensor beside the geophone at station 80. The ION spread used Vectorseis 3C units recorded on a Scorpion system, and the Sercel spread used DSU3 sensors recorded on a 428XL system. After attempts to run the Aries SPMLite recording system with the low cut filter set to 0 Hz failed (an entry of 0 caused a default to 3 Hz), the filter was set to 1 Hz. The four sensor units used for this experiment are shown in Figure 7.

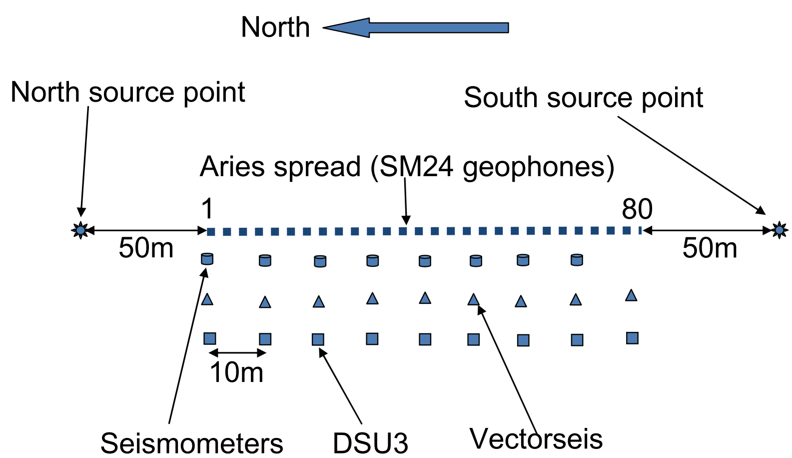

FIG 6. The layout of the sensors for the Priddis low frequency tests. The four sensor lines were spaced 1 m apart.

FIG 7. The four sensors used for the low frequency tests. From top left Sercel DSU3, Sensor SM24 three component geophone, ION Vectorseis, Nanometrics Trillium 240 seismometer.

Recording parameters for the four systems are given in Table 1:

Table 1. Recording parameters for the various systems.

Recording System	Sample Rate (Msec)	Record Length (Thumper)	Record Length (Vibroseis)	Low Frequency Filter (Hz)
Aries SPMLite	2	10	60	1
ION Scorpion	2	10	60	1.46
Sercel 428XL	2	10	60	0
Nanometrics	10	continuous	continuous	0.004

Note: the Nanometrics Trillium 240 seismometer is specified with a passband which is flat to velocity from a 240 second period to 35 Hz. These seismometers were recorded continuously on autonomous Taurus data recorders with data broken into discrete records using GPS as a time stamp. The output is in an ASCII format, requiring pre-processing to convert the data into SEG-Y for standard processing methods.

The sources for this survey were an accelerated weight drop unit deployed both with and without elastic tensioning bands, and the U of C EnviroVibe. The weight drop source is shown in Figure 8, and the Envirovibe in Figure 9. The Envirovibe has a hold down weight of 15,000 lb and is rated to operate from 10 Hz to 300 Hz. The reaction mass weight is 1750 lb and the baseplate 855 lb.

FIG 8. The weight drop source with elastic bands installed.

FIG 9. The University of Calgary Envirovibe at Priddis August 2009.

With the focus on low frequency, the EnviroVibe was operated well outside its designated specifications, with sweeps as low as a constant 3Hz over 30 seconds. Table 2 shows the sweeps used, and the power levels at which it was felt the vibe could operate safely at these frequencies.

Table 2. The sweep parameters for the low frequency comparison survey.

Sweep Number	Frequency Start-Stop	Length Seconds	Power %	Start Taper	Stop Taper
9	3 - 3	30	3	0.1	0.1
10	5 - 5	30	5	0.1	0.1
11	2 - 10	50	10	25	0.1
12	2 - 10	30	10	15	0.1
13	2 - 10	10	10	5	0.1
14	2 - 100	30	25	5	0.1
14	2 - 100	30	50	5	0.1
14	2 - 100	30	75	5	0.1

The deciding factor for safe operation was to restrict the reaction mass motion to half the maximum travel of 2 inches to allow for creep during the sweep. Some of the sweeps were run using several different power levels or sweep lengths, to provide some varying ground stimulation for analysis of near offset surface effects. The long start taper was to ensure mass travel was within the safe limit at the low frequencies.

The hope was that a substantial amount of information could be derived about surface waves at these low frequencies, and some comparative measure made of the actual sensor response compared to the seismometer data. All data was recorded uncorrelated, with the TREF sweep signal recorded on the Aries and Sercel systems for later correlation.

The acquisition systems were not all synchronized to a time break because of the short lead time for the experiment, and the non-standard triggering used by the weight drop source. All thumper records were acquired by manual start after a count down, with a time shift being applied after acquisition. The vibroseis records were acquired using the Aries as the control system, while the ION and Sercel systems were started manually on countdown. Cross correlation was used to determine the time shift to be applied to the different systems on a record-by-record basis before any comparisons were made.

A comparison of the thumper data provides some interesting results – firstly a check of repeatability of the source shows that there is virtually no difference between separate thumps. Figure 10 shows a shot gather of one thump recorded on the Aries / geophone system. The first break velocity is about 2200 m/s. and the ground roll shows a velocity of about 450 m/s. Figure 11 shows the spectrum comparison for four thumps recorded at the same source location into the 80 geophone Aries spread. There is very little difference between the four in the section of the spectrum from 0 to 50 Hz which contains nearly all the useful energy.

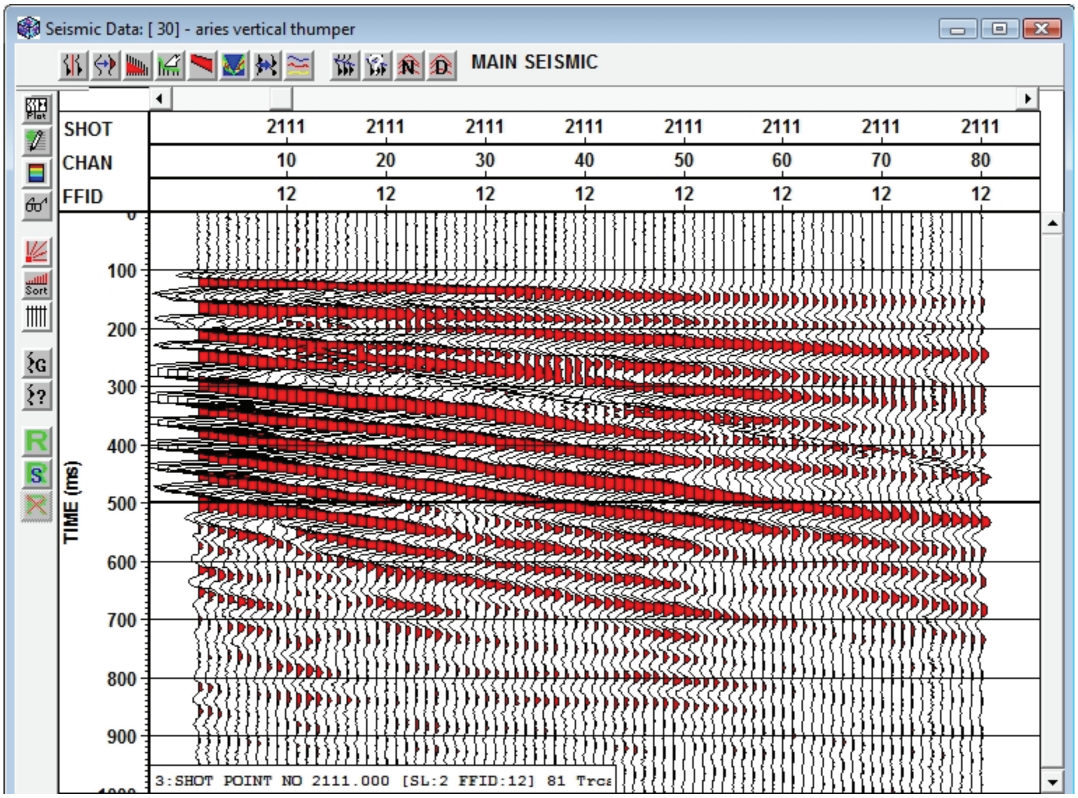

FIG 10. Example record for one thump recorded on the Aries system with SM24 geophones.

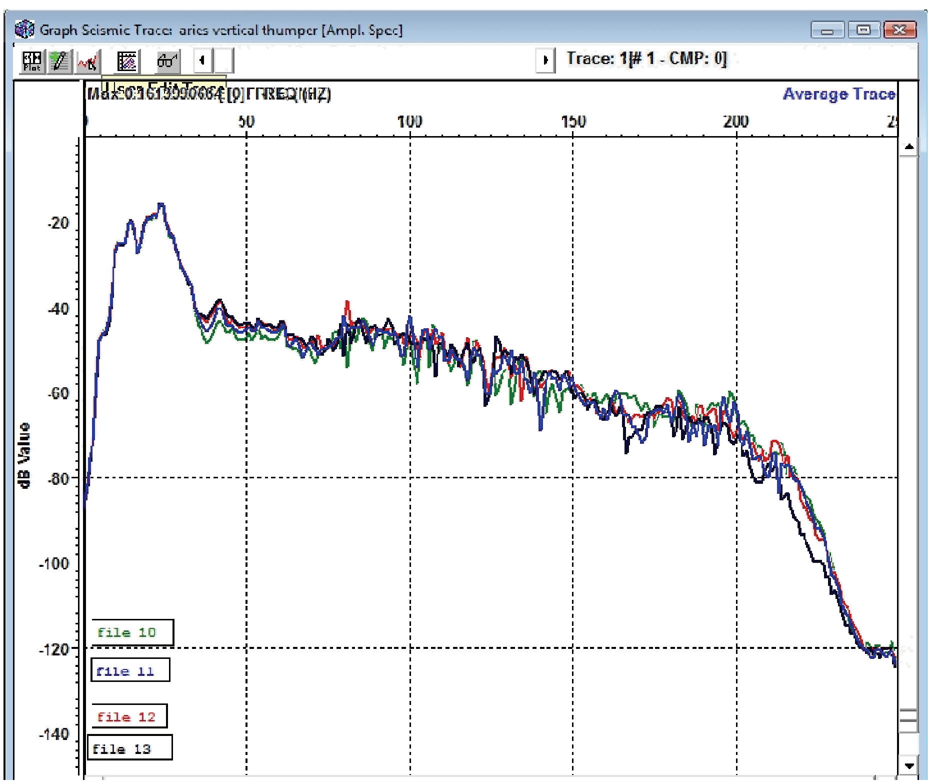

FIG 11. Comparison of four thumps at the same location. Aries records.

The most interesting result from this data was to find that the amplitude spectrum of the thumper records when the bands were not installed, and the spectrum when the bands were installed and tensioned are also almost identical. This is demonstrated in Figure 12, showing spectra from the thumper operating with and without bands at both ends of the spread (with a 50m offset to the nearest geophone). These spectra are derived from the full 80 geophone Aries spread. The conclusion here is that the velocity of the hammer is restricted by the poppet release valve flow rate, so the impact velocity is the same in both cases, although there is less bounce with the bands on and tensioned, and the thump sounds much firmer. The repeatability of the source signature at different locations is clearly shown to be excellent.

The next comparison is between the four sensors, showing the four records overlaid (Figure 13) and the spectra (Figure 14) from all four sensors for the same thump. The seismometer has a high cut of about 45 Hz due to the 10 msec sample rate. All the figures show raw data, with no scaling or filtering applied to any of the systems, and the Aries data decimated to those geophones that are coincident with the MEMs sensors. AGC has been applied to the plots for the overlay comparison. These results give confidence that we do have excellent similarity of coupling and response between the different sensors.

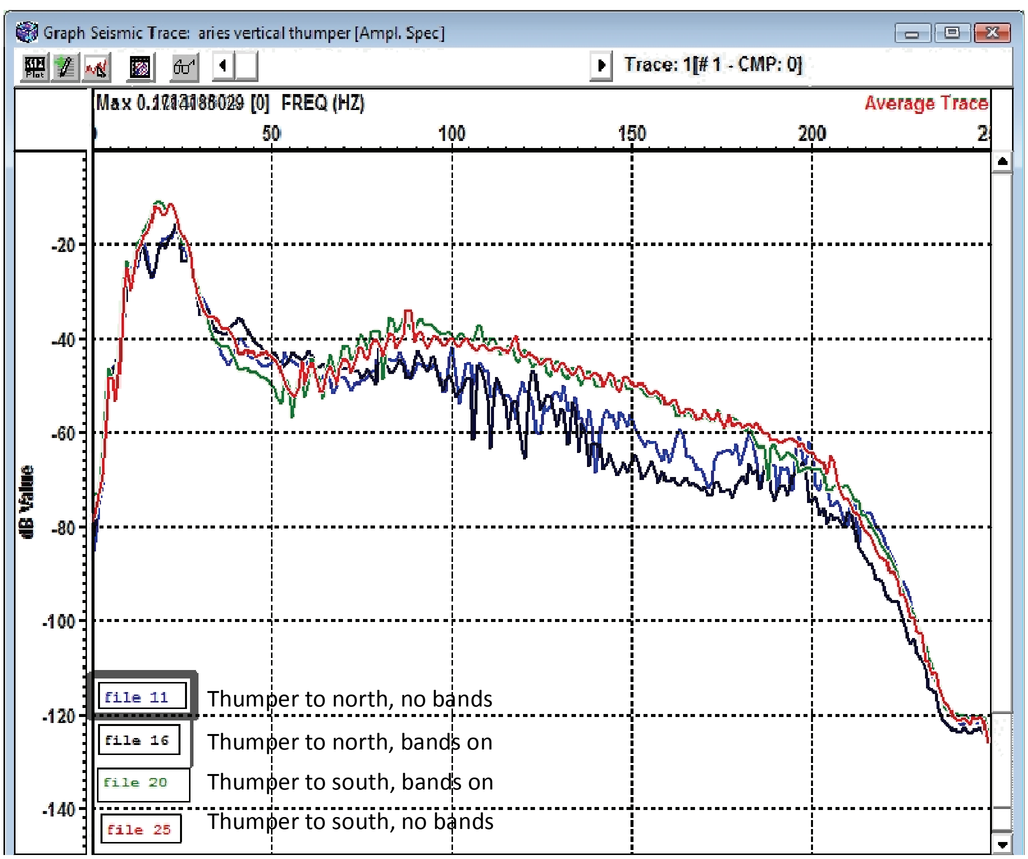

FIG 12. Comparison of four thumps, bands on and off at both ends of the spread.

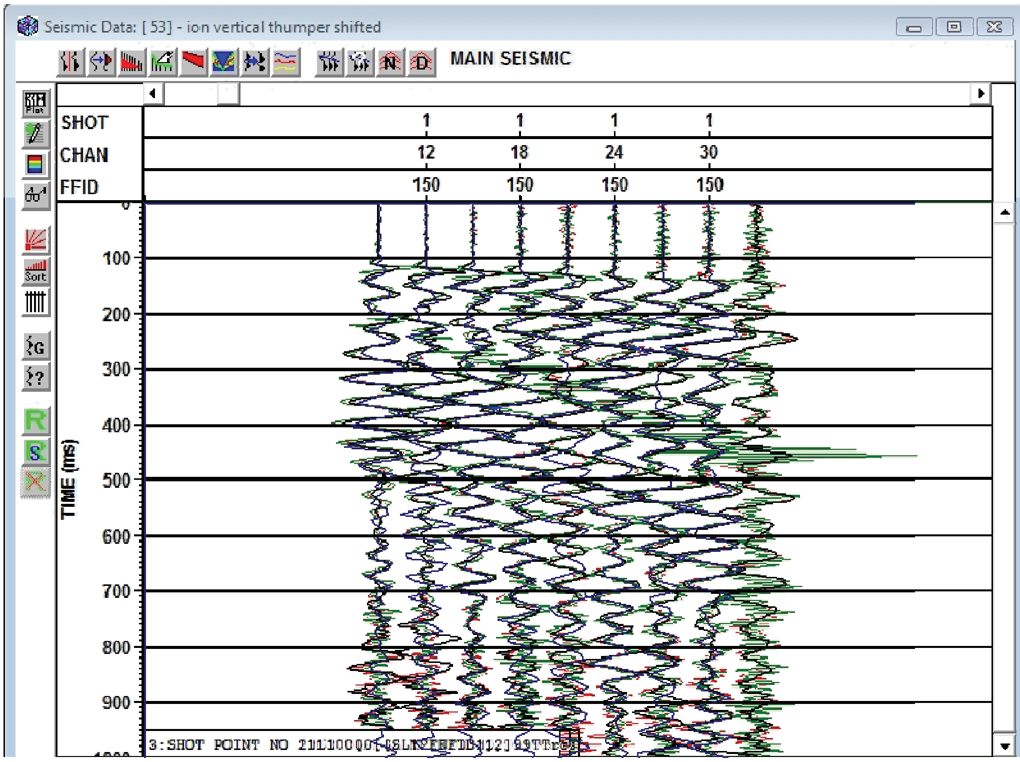

FIG 13. Comparison between the four recording systems for the same thump. Black=SM24, Green=DSU3, Red=Vectorseis, Blue=Trillium 240

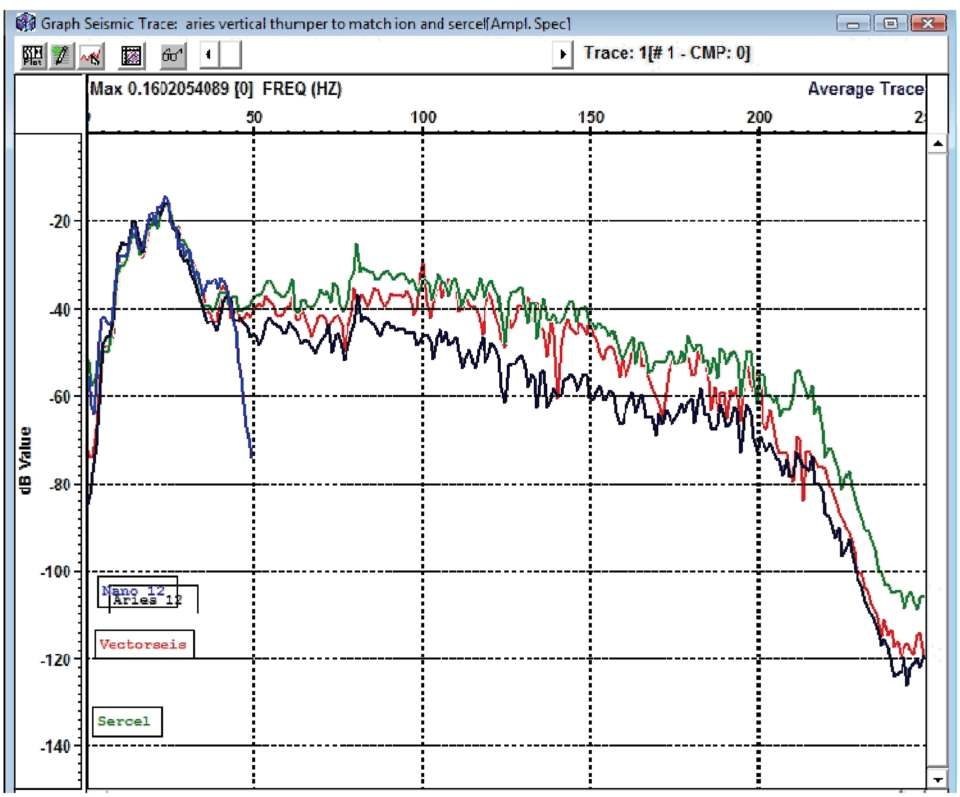

FIG 14. Comparison of the spectra for the four records in Figure 11. Black=SM24, Green=DSU3, Red=Vectorseis, Blue=Trillium 240

From the 5 Hz mono-frequency sweep data, it is necessary to look at an expanded section of the full 80 channel spread from the Aries system to be able to see the spatially un-aliased data (Figure 15). The 5 Hz TREF sweep is on the last channel on the right. While the 5 Hz is apparent in the data, the record is dominated by harmonics.

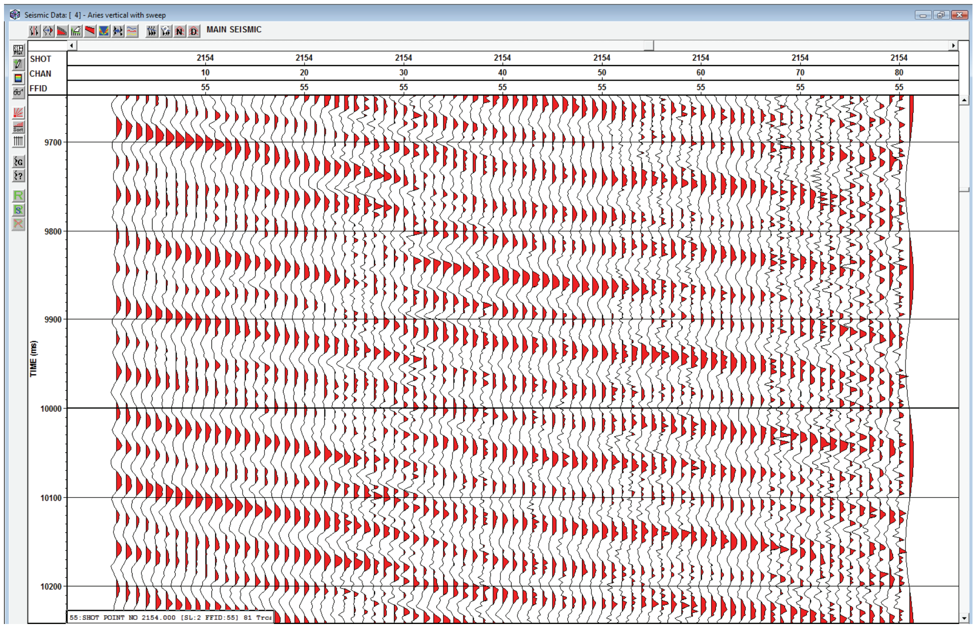

FIG 15. Part of the Aries record for the 5 Hz mono-frequency sweep. The sweep is on the right.

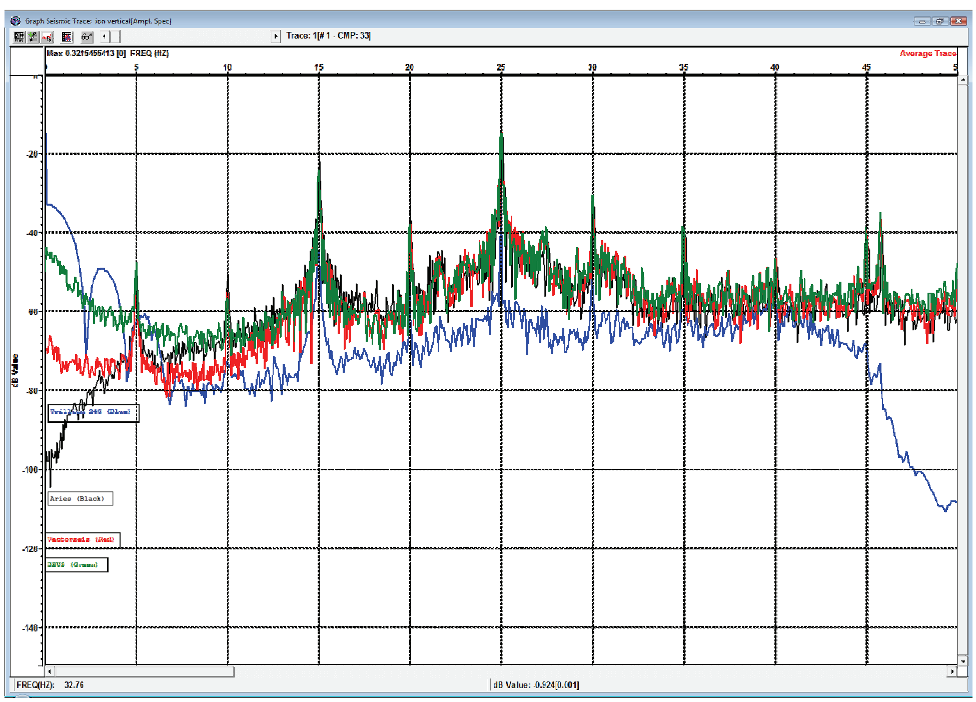

FIG 16. The spectra of the records from all four systems for the 5Hz mono-frequency sweep (0-50 Hz shown). Black=Aries, Green=DUS3, Red=Vectorseis, Blue=Trillium 240

Figure 16 shows the spectra of the four sensor systems, taking the centre part of the sweep (from 10 to 20 seconds during a 30 second sweep). By this time the ground motion is in a steady state of excitation from the source. The harmonics visible in Figure 15 are the dominant feature on all the systems. The frequency axis has been truncated to 50 Hz for this plot. The spike just above 45 Hz is noise from the generator on the Aries recorder.

Applying a bandpass filter of 3-4-6-8 Hz produces the output shown in Figure 17. The main difference between the systems appears to be the Sercel DSU3 and the Nanometrics Trillium 240 showing more low frequency data than the ION Vectorseis or the Sensor SM24 geophones. This is also evident in the spectra in Figure 16, and may be a result of the different low frequency acquisition filters.

A similar result is obtained from the 3 Hz mono-frequency sweep, with the third, fifth and seventh harmonics predominant (Figures 18 and 19). From these results, it appears that the Envirovibe has trouble generating true ground motion at the 3 Hz and 5 Hz frequencies, and most of the transmitted energy is contained in the odd harmonics. Some tests to determine true ground motion beneath the vibe baseplate are proposed to develop some parameters for this sort of experiment. Since most of the airborne noise from the Envirovibe is engine related and can be seen at just over 60 Hz (about 1800 rpm), it is easily removed from the low frequency data by filtering. The same applies to the generators on the recorders (45 and 60 Hz).

An analysis of some of the results from the other sweeps is given elsewhere in this volume (Priddis geophone vs. seismometer; Kevin Hall et al).

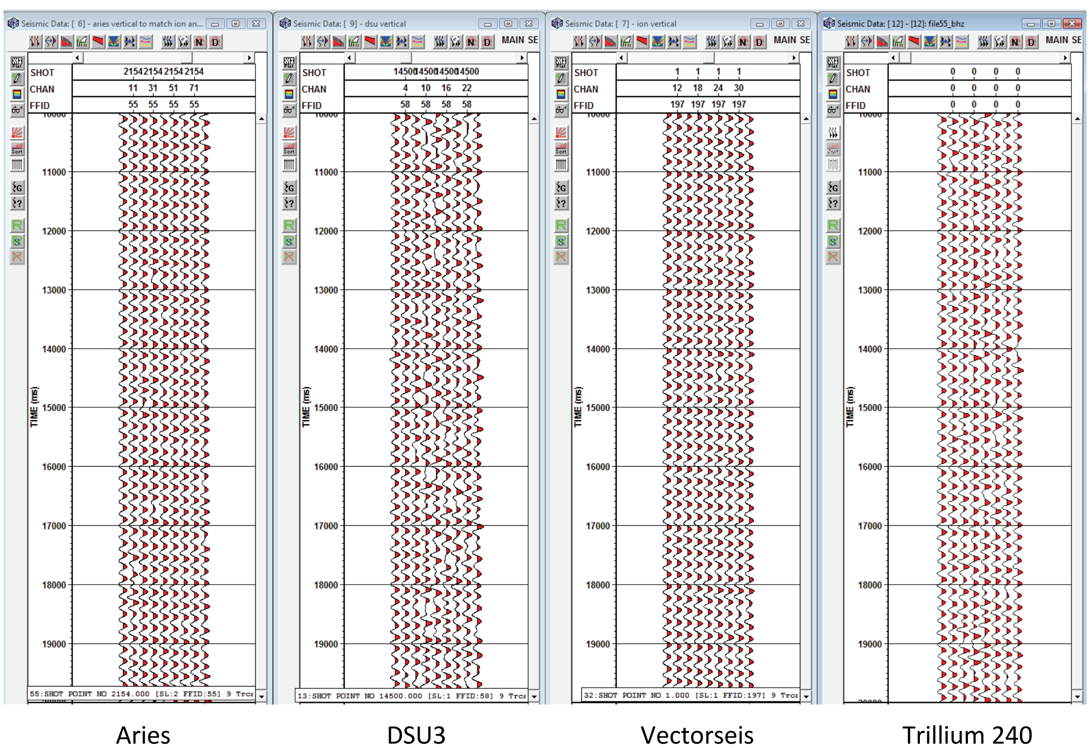

FIG 17. The four recording systems with a 3-4-6-8 Hz filter applied to the same 5 Hz mono-frequency sweep.

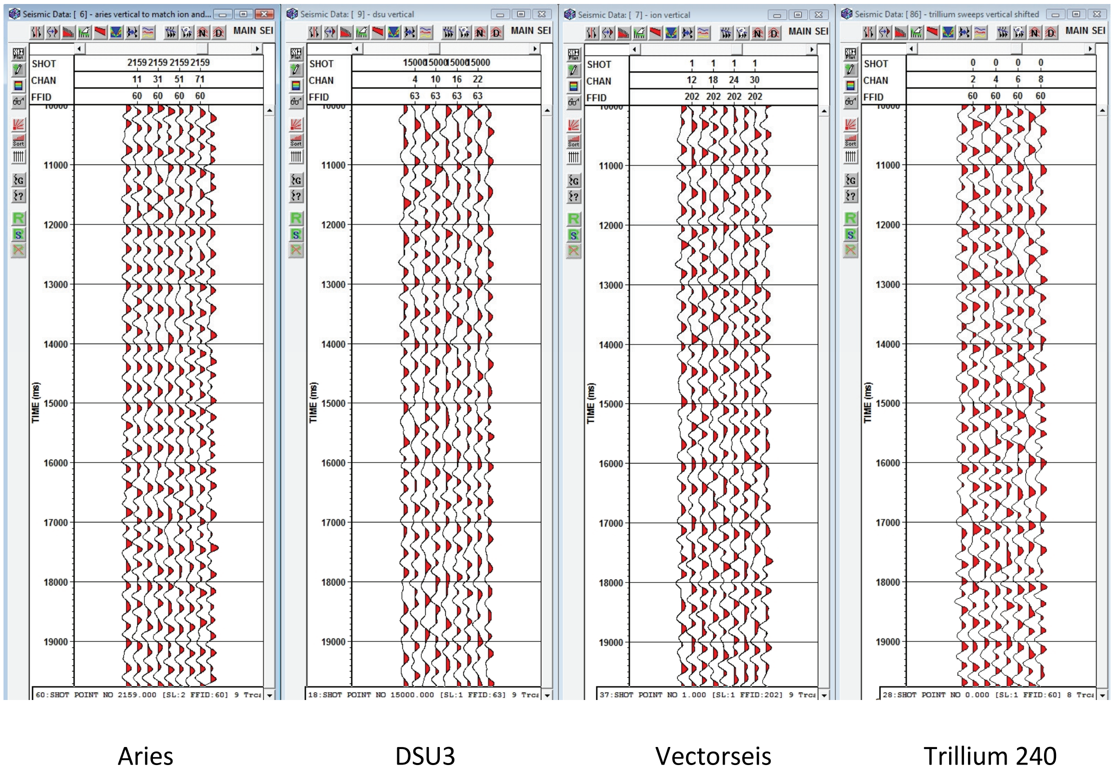

FIG 18. The four sensors at 3 Hz with a 1-2-4-5 Hz filter applied.

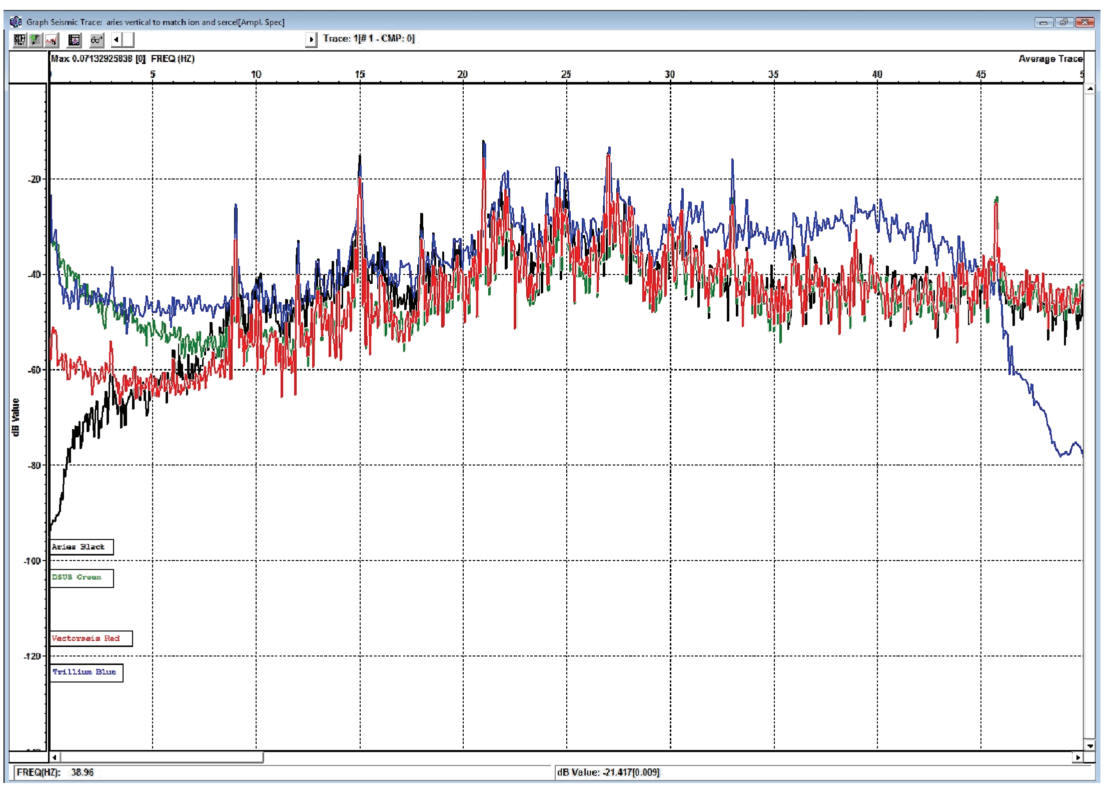

FIG 19. The spectra of the records in Figure 16 for the 3Hz mono-frequency sweep (0-50 Hz shown). Black=Aries, Green=DUS3, Red=Vectorseis, Blue=Trillium 240

2009 FIELD SCHOOL

In August 2009 the main component of the seismic section of the University of Calgary Geophysics Field School was again held in the Spring Coulee area, recording lines in the same area as the 2008 Field School, just north of the two sections on which the University of Calgary holds the mineral rights. This year the main reflection line was in an east-west direction, intersecting the north-south line from Field School 2008, and passing the north end of the line shot by CREWES in January 2008. The location is shown in Figure 20. This year, for the first time, the main Field School line was recorded using 3C geophones. Because of the limited number of 3C geophones available for the survey, and the necessity of optimizing for converted wave recording and processing, it was decided to shoot the line asymmetrically twice, once from west to east (Line 1), and then from east to west (Line 2), both times with the shot trailing the spread. By combining the two lines, a better offset range and subsurface coverage is achieved. The University of Calgary's EnviroVibe was the source for this survey. Figure 21 shows a typical shot gather (0 to 2.5 seconds shown) from Line 1 (shooting west to east). Recording parameters for this survey were 1 ms sample rate, 4 second record length, sweep from 10 – 150 Hz over 20 seconds, 4 sweeps per vibe point.

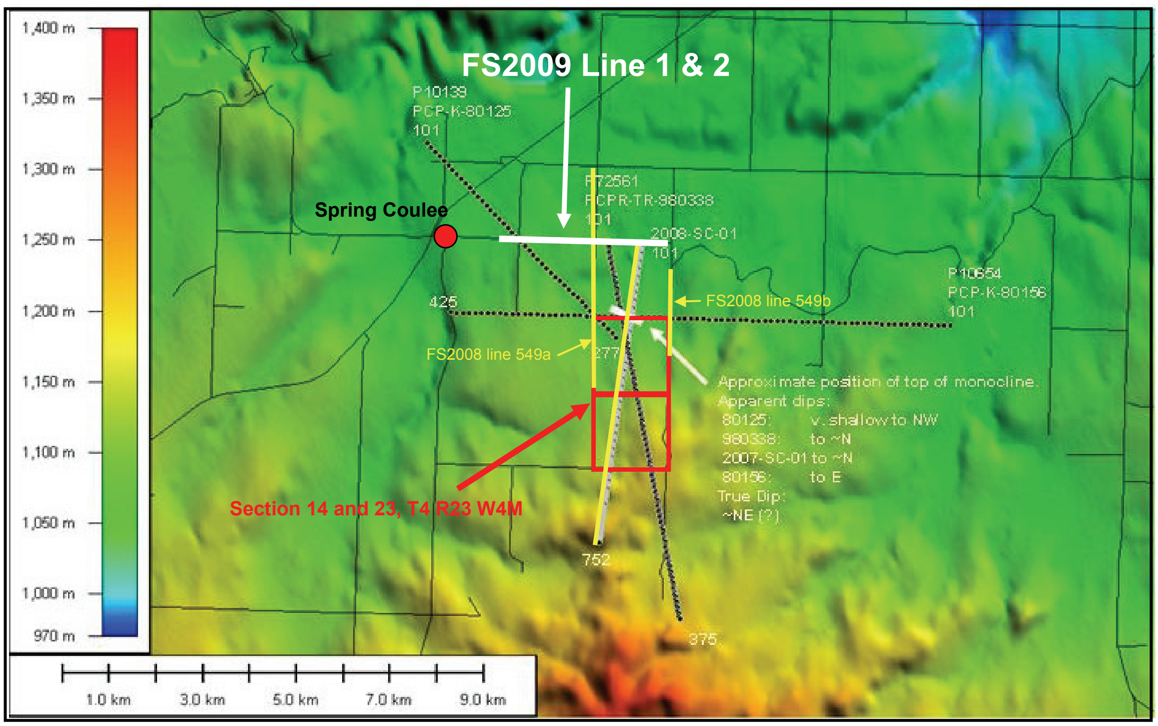

FIG 20. The location of the 2009 Field School 3C line

Excellent data were obtained, with several reflections evident. A migrated section from the vertical component for the first group (Line 1 - shooting from west to east) is shown in Figure 22. A comparison study between the two passes along this line is presented elsewhere in this volume (Multicomponent seismic survey at Spring Coulee, Alberta; Don Lawton et al).

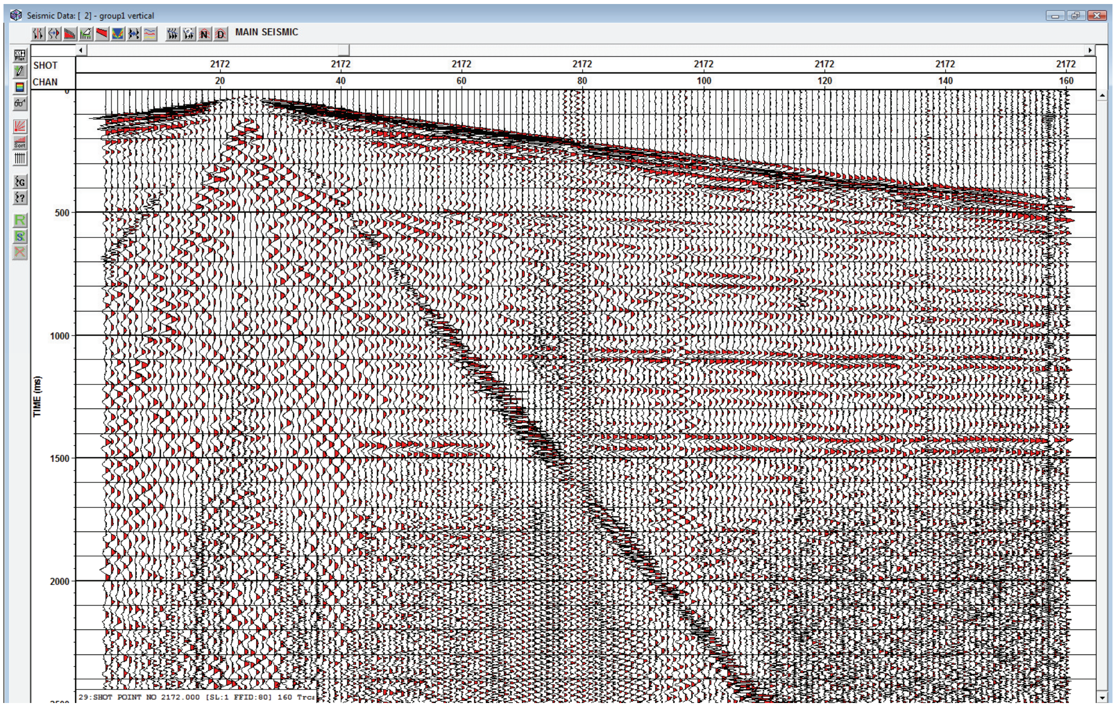

FIG 21. Shot gather from 2009 U of C Field School Line 1. AGC applied.

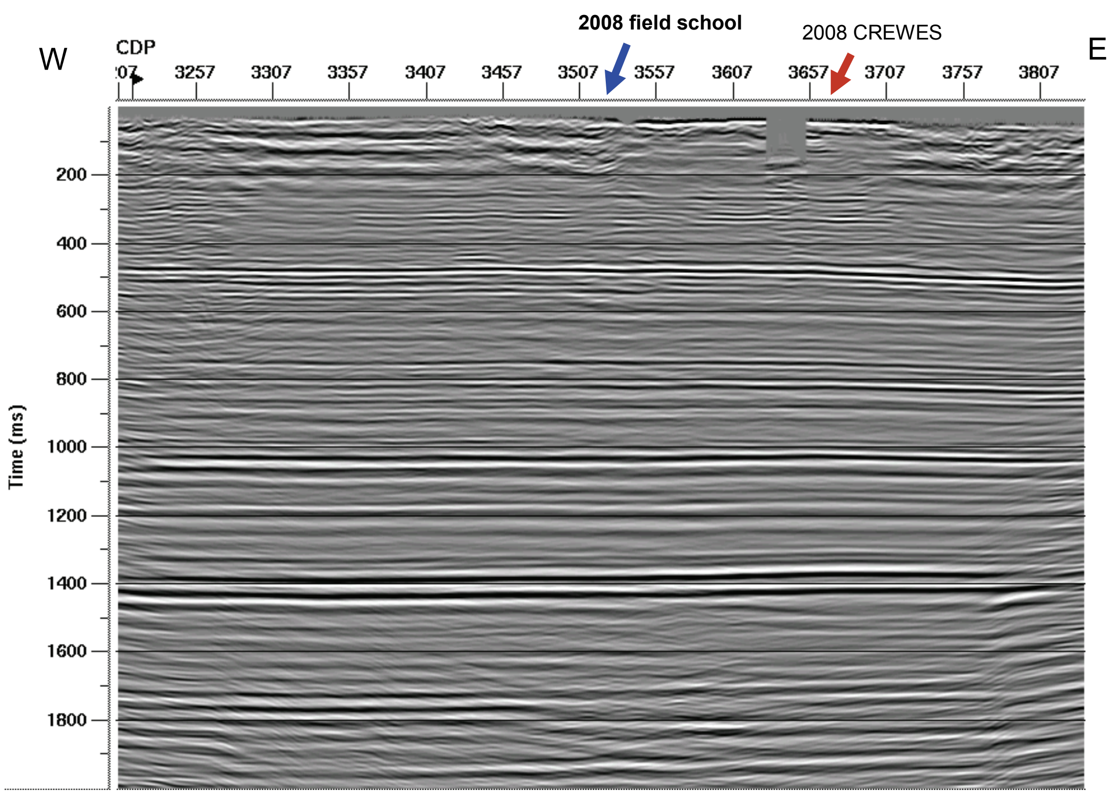

FIG 22. The migrated section for Line 1 from Field School 2009 (shooting from west to east).

ACCELERATED WEIGHT DROP SOURCE

After many years experience with accelerated weight drop seismic sources, it was decided that some re-design was warranted to try to correct some of the problems inherent with them. The U of C purchased a Bison EWG for seismic work in 1990, and had high hopes for good shallow data. However, the unit showed poor data quality mainly as a result of the geometry of the elastic band system and the excessive weight of the hammer itself. The U of C was also donated a second unit by Polaris – this time a slightly heavier unit with a different release mechanism. This unit also showed problems due to the hammer being too heavy, and from the low frequency study carried out in August 2009 (above), the hammer descent is apparently throttled by the hydraulic release poppet valve.

It was decided to modify the original Bison unit to try to provide a higher velocity impact with less recoil of the support trailer and reduced tendency to bounce, while retaining the necessary source energy. One of the main features of the design is a controlled elastic tension mechanism that allows the tension to be increased to both increase acceleration over the entire hammer travel and to reduce or eliminate hammer bounce by forcible restraint (i.e. tension is still high after the hammer has impacted the anvil). This controlled tension system allows for repeatable shots by setting the tension pressure as well as the lift pressure for the hammer. Another modification was to use a plate as an anvil for the hammer to impact instead of the hammer striking the ground directly or simply hitting a plate resting on the ground. The anvil / plate is forced into solid contact with the ground using hydraulics to lift the trailer so that the entire trailer weight is carried by the anvil. This hold-down pressure is adjustable and again can be set to provide repeatable shots. When the hammer was released in the original design, the trailer rebounded quite substantially, reducing the energy supplied to the hammer, and creating a large amount of low frequency surface noise as the trailer settled after the shot. The new design removes this problem and the trailer is quite stable during a shot. The hammer of the original unit was another problem – the elastics could not accelerate it to a sufficiently high velocity before impact. The new design has a hammer of 400lb which can be easily changed in the field to a different weight depending on survey requirements. At the moment the unit is still in trial with a number of design improvements already being implemented. The prototype shown in Figure 23 was used for the U of C Geophysics field school in August 2009 and survived two weeks of punishment. Figure 24 shows a typical record from this source recorded on the Geode system with a geophone interval of 2.5 m. Analysis of these records shows there is still a problem with this source – the same hydraulic poppet valve release mechanism was used as is on the heavier thumper used for the August low frequency tests. As a result, the hammer impact velocity is limited, producing less high frequency content than expected in the data. A different release mechanism is being designed and will be tested soon. With the improvement to the source in terms of reliability, ground input energy and repeatability, a similar unit to be used for shallow shear wave surveys is currently being designed, with the mass being driven at a angle to impact the anvil.

FIG 23. The new accelerated weight drop source in use at the 2009 Geophysics Field School.

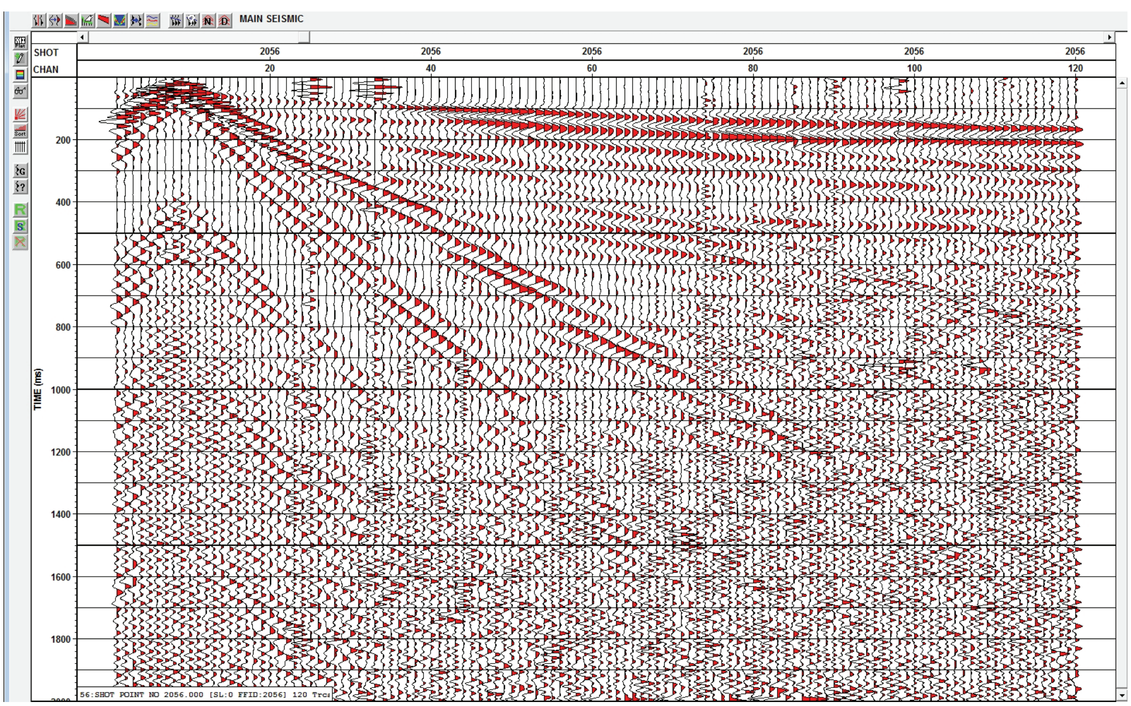

FIG 24. An example of data from the thumper source recorded on a Geode spread (2.5 m group interval). Filter of 10-20-50-80 Hz applied.

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CGGVeritas for providing the DSU3 units and the 428XL recording system

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For the 2009 Field School:

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Andrew Gorman from the University of Otago, New Zealand

For all the above:

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