Priddis 2014 broadband surface and walkaway VSP seismic experiment

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ABSTRACT

CREWES and INOVA conducted a high-resolution broadband multi-component seismic surface and borehole test survey at the Priddis Geophysical Observatory in late October and early November of 2014. Two types of sources were used: 0.125 kg of dynamite at 5 m depth with source points every 6 m, and an INOVA UNIVIB using a linear 1.5-150 Hz sweep with two sweeps per vibe point.

Four source and receiver lines were laid out in a star pattern centred on Testhole1, which is an instrumented borehole installed by CREWES in 2013. All four receiver lines had SM-7 10Hz three-component geophones at a 3 m receiver spacing. In addition, one of the receiver lines also had twelve SM-7 geophones in groundscrews as well as single-component SL11 accelerometers and SM24 10 Hz high-sensitivity geophones, all at a 6 m receiver spacing.

The forty-five three-component 28 Hz geophones permanently installed in Testhole1 at a nominal 3 m spacing were also used for this survey. Prior to beginning the seismic survey, natural gamma-ray and full waveform sonic logs were acquired in Testhole2, 50m away from Testhole1, which was then instrumented with a USSI retrievable clamping three-component fibre-optic system with six nodes spaced 20 m apart.

INTRODUCTION AND OBJECTIVES

CREWES and Inova conducted a high-resolution broadband multi-component seismic surface and borehole test survey at the Priddis Geophysical Observatory in late October and early November of 2014. Before beginning the seismic survey, natural gamma-ray logs and full waveform sonic logs were acquired in Testhole2. Testhole1 contains forty-five permanent three-component geophones, which were re-wired at the surface in order to place output traces in the correct order when plugged into our Aries recording system via adapter boards (Hall et al., 2013). A retrievable clamping three-component fibre-optic system (USSI OptiPhone) was deployed in Testhole2 at 20 m spacing.

The base layout for surface sensors consisted of four receiver and four source lines of 240 m length centered on Testhole1 in a star pattern. Receivers were three-component 10 Hz geophones spaced 3 m apart. In addition, the east-west line was extended to accommodate longer offsets for a receiver comparison test involving digital single-component receivers and high sensitivity 10 Hz single-component geophones at a 6 m spacing. At fifteen locations, three-component 10 Hz geophones placed within ground screws were co-located with the digital and high-sensitivity geophones.

Two sources were used: 1) 0.125 kg of dynamite at 5 m depth with source points every 6 m and, 2) an Inova Univibe was used on the extended east-west line at a 6 m vibe point spacing using a broadband linear sweep. Five non-linear broadband test sweeps were acquired at the end of the survey. All sensors recorded most of the shots.

Location

The Priddis Geophysical Observatory is located just south of Calgary on land owned by the University of Calgary. The legal description to staging is Rothney Astrophysical Observatory SW-13-22-3-W5M. The geophysical observatory consists of buried targets and three test holes numbered 1, 2 and 4, all of which are less than 150 m in depth (Hall et al, 2013). The land consists of two fields, where the south field is used to grow crops and the north field is used for cow pasture. Figure 1 shows the view looking southwest from Testhole2 across the fence into the south field.

Objectives

The 2014 field program had many objectives

- Obtain many closely spaced dynamite shots from many azimuths into the permanent geophones in Testhole1
- Hi-resolution 2D surface seismic lines at a variety of azimuths
- Deploy USSI fibre optic system in Testhole2. This is the first time we have deployed this system.
- Source tests (Dynamite vs. Vibe)
- Receiver tests (Geophone versus Accelerometer, planting methods).

FIG. 1. Dynamite shotholes being drilled and loaded.

WELL LOGGING

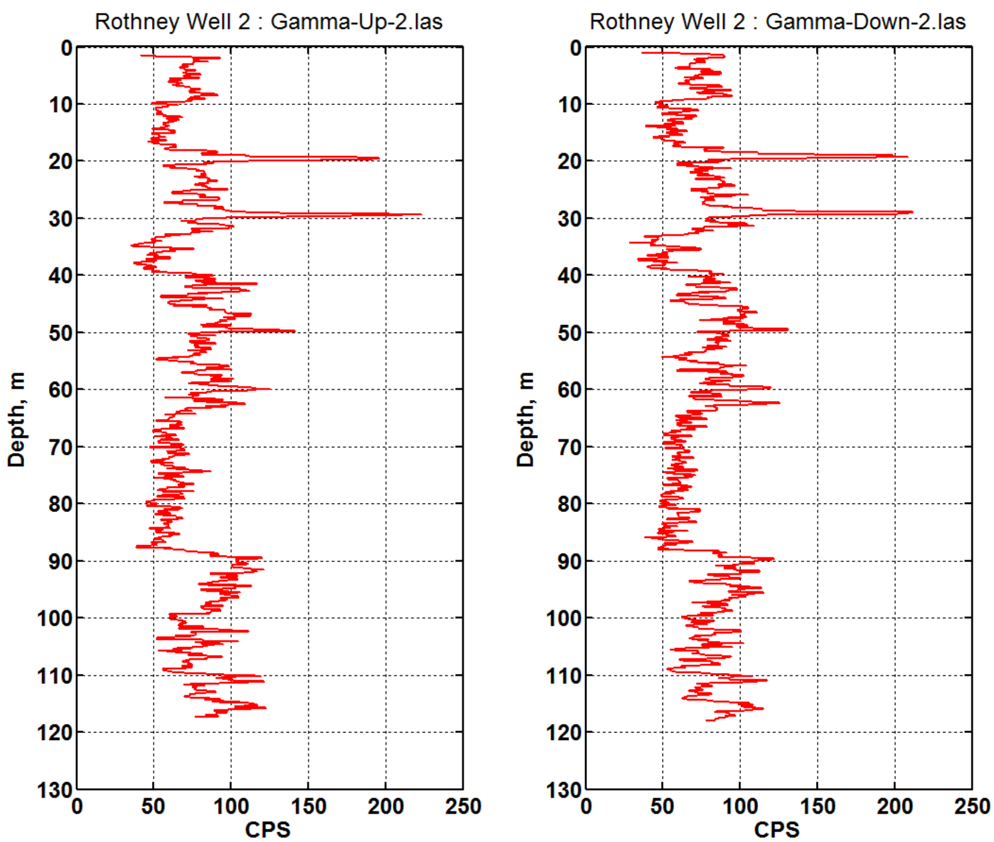
Natural gamma and full waveform sonic logs were acquired in Testhole2 on October 21 using a Mount Sopris Matrix II system as described by Han et al., 2008, Wong et al., 2007 and Wong et al., 2009.

Testhole2 is cased with polyvinyl chloride (PVC) casing that was cemented into the ground. It was known that the bottom of Testhole2 had cement inside the casing after completion, but the total usable depth inside the casing had only been estimated before this work (Hall et al., 2013). Upon insertion of the natural gamma-ray tool, it was found that the cable went slack at 117.43 m depth referenced to the top of the well casing, which is 0.875 m above ground level.

Natural gamma-ray logs were recorded with the tool moving at 8 m/s, both up and down-going (Figure 2). Note that the depths for the up and down-going logs do not match perfectly in this case because we lost depth calibration by 1.35 m when the cable went slack as the tool reached the bottom. The depth was re-calibrated at the top of the well before continuing.

Full waveform sonic logs sampled every 10 cm were then recorded with dominant source frequencies of 7, 10, 15, 20, and 30 kHz from 0 to 115 m depth (referenced to top of well casing) with the tool moving at a constant speed of either 4 or 5 m/s up and down the test hole. The 7 and 20 kHz results are shown in Figure 3. All data was recorded with a fixed gain of 8 and stored with no AGC. Processing has been thus far limited to high-pass filters and AGC for display. These data need to be further processed and have first-break picking performed in order to derive velocity logs. It may also be possible to use these data to image the borehole (eg. Chabot, 2003). Typically, this tool has been run at 15 kHz, so it will be interesting to see what effect varying source frequencies has on the final result. It is hoped that these sonic logs will also provide low-frequency information for future full-waveform seismic inversions.

a) 



b)

FIG. 2. Natural gamma-ray tool (a) and data (b) for the tool travelling up the test hole from the bottom (left) and travelling down the test hole from the top (right).

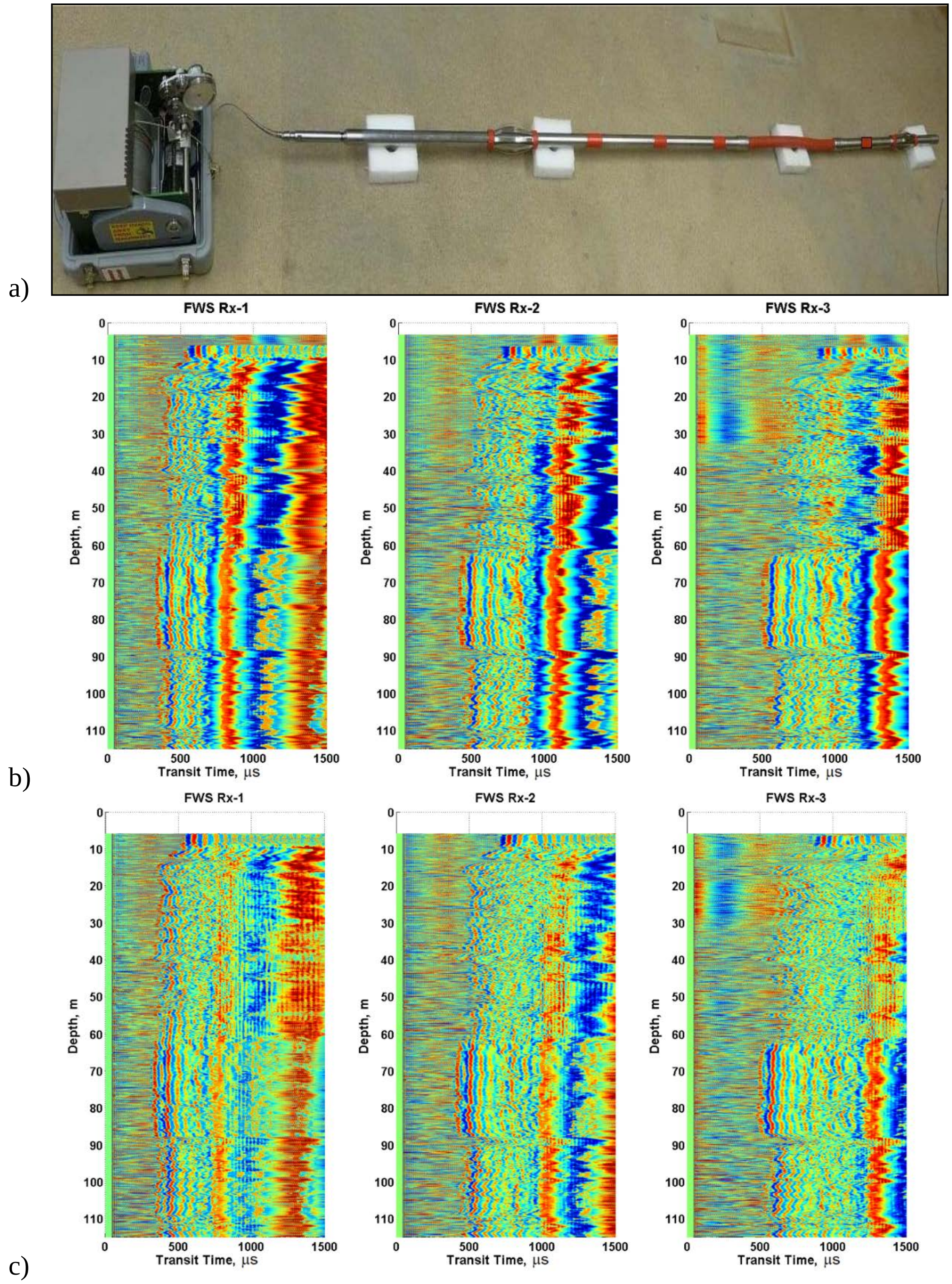


FIG. 3. Full waveform sonic tool (a), and logs for Testhole2 acquired at 7 kHz (b) and 20 kHz (c) sampled every 10 cm with the tool travelling down the test hole. Processed for display with high-pass filters and AGC.

LAYOUT

Chaining and GPS surveying were carried out October 20 and 21 (Figure 4). Various line locations have been permitted until 2020 with the Alberta government at the Priddis Geophysical Observatory. Four of the permitted lines (TH6, TH1-02, TH11-01 and TH1-04) were used for this program (Figure 4, Tables 1 and 2). These lines will be referred to as E-W, NE-SW, N-S and NW-SE for the remainder of this report. All four lines intersect at Testhole1. Testhole2 is located between the NE and E arms of the E-W and NE-SW lines (Figure 4) 50 m away from Testhole1. Layout was performed November 3-4, Dynamite and Vibe shots were acquired November 5-6, and pickup was completed November 7.

Recording systems

Five separate recording systems were used for this survey. Four cabled systems (Two Aries SMP Lites, one G3i and one USSI) were trigged by Pelton VibePro's, and one nodal system (Hawk) recorded continuously. All systems sampled at 1 ms with the exception of the USSI recorder, which sampled at 0.25 ms.

Three recording trucks were used. Two of the trucks were seismic recorders with generators on board (Figure 5). These trucks were parked about 270 m away from the closest geophone, and were connected to the spread with long baseline cables. A rental cube van was used as a recorder for the USSI system (Figure 6), and was connected to the tool in Testhole2 with a short fibre optic cable. The length of this cable meant the truck had to be parked beside Testhole2, about 15 m away from the closest geophone. This system was powered by a small gas generator, and also used at least one battery charger. Unfortunately, this means generator noise (sound and electrical) is present to varying extents on the other seismic data (see below).

Sources

Two kinds of source were used, dynamite and Vibroseis. Dynamite shotholes were drilled and loaded October 24 at every second station from 101-181 of the E-W, NE-SW, N-S and NW-SE lines. There were a total of one hundred and fifty 0.125 kg dynamite shots spaced 6 m apart, with the charges placed 5 m below ground level (Figures 1 and 7). Six shotholes on the NW part of the NW-SE line were not drilled and loaded due to the shothole rig not being able to reach the planned locations within a patch of trees (Figure 4). The missing shots were not compensated for in any way. Shotpoints were also dropped to maintain at least 6 m between shotpoints where the lines intersect, as well as a minimum of 6 m from Testhole1.

An Inova Univib was operated by Geokinetics on the E-W line at every second station from 2084-2170 (Figure 8). This means the vibe points (VPs) were skidded 3 m to the west relative to the dynamite shot points (SPs). The vibe was not operated on the NE-SW, N-S or NW-SE lines. A series of test sweeps were recorded immediately to the east of Testhole2, consisting of linear 5-150, 5-200, 5-300 and 5-350 Hz sweeps of 10 s length at the same location.

Receivers

Testhole1 has 45 permanent GS-14-L9 28 Hz three-component geophones (Geospace Tech, 2014), strapped to the outside of the casing and cemented into the ground at a 3.06 m spacing (Table 2, Figure 9a). Geophone cables come up to the surface and can be plugged into our Aries SPM Lite recording system using adapter boards (Hall et al., 2013).

A six level three-component fibre-optic system from USSI that has nodes spaced 20 m apart was deployed in Testhole2 (Table 2, Figure 9b.) USSI (2014). A nitrogen powered clamping system provided by USSI was used to hold the nodes against the inside the casing from 15 to 115 m depth, with a node every 20 m. This is the first time we have deployed this system in a borehole.

Three kinds of receivers were deployed on the surface (Table 2, Figure 9c). These included SM-7 (Ion Geo, 2014a) three-component 10 Hz geophones in nail-type cases and within groundscrews (Manning et al., 2014), SM-24HS single-component high-sensitivity geophones (Ion Geo, 2014b), and AccuSeis single-component SL11 accelerometers (Inova Geo, 2014) on the surface. The SM-7 nail-type cases were planted in augered holes and were oriented to magnetic north with the pigtail pointing to the south. These geophones were planted on all four lines at every station from 101 to 180 at a 3 m geophone spacing. The SM-7 groundscrews were screwed into augered pilot holes from stations 143-165 at a 6 m spacing on the E-W line only. The SL11 and SM-24HS vertical component sensors were planted at stations 83 to 271 at a 6 m spacing on the E-W line only. These sensors were planted with just the sensor spike in the ground or with the entire case in the ground in an alternating pattern, so that a particular planting method had a 12 m spacing down the line.

While this survey was intended to be processed as four 2D lines, almost every shot was recorded by almost every receiver, which means that it may be possible to process the downhole and surface data as a 3D (eg. Figures 10 and 11), although the resulting azimuthal coverage in each bin may not be the best.

At the time this report was written we did not yet have copies of the SM-24HS and SL11 data.

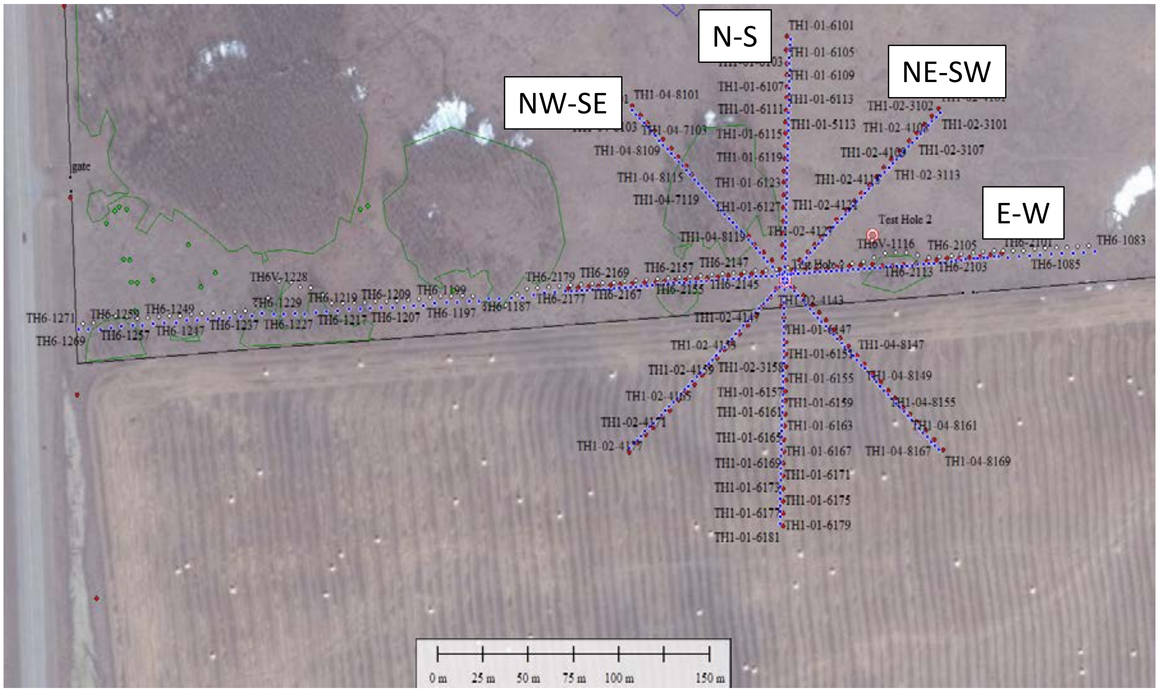


FIG. 4. Map of survey. Background image © 2012 DigitalGlobe, 2013 Microsoft Corporation (Bing Maps, 2013).

Table 1. Sources.

Line	Direction	Source	Stations	Spacing	Details
TH6	E->W	Dynamite	2101 - 2181 by twos	6 m	0.125 kg at 5 m depth
TH6	E->W	UNIVIB	2083.5 - 2169.5 by twos	6 m	Linear 1.5-180.0 Hz 16 s sweep
TH1-02	NE->SW	Dynamite	2101 - 2181 by twos	6 m	0.125 kg at 5 m depth
TH1-01	N->S	Dynamite	2101 - 2181 by twos	6 m	0.125 kg at 5 m depth
TH1-04	NW->SE	Dynamite	2101 - 2181 by twos	6 m	0.125 kg at 5 m depth

Table 2. Receivers.

Line	Direction	Recorder	Receivers	Receiver Type	Components	Stations	Orientation	Spacing	Details
TH6	E->W	Aries SPML (1)	SM-7	10 Hz geophone	V,H1,H2	1101 - 1180 by ones	Vertical, Magnetic North	3 m	Nail type casing in augered hole, pigtails to the South
		Aries SPML (2)	SM-7	10 Hz geophone	V,H1,H2	1143 - 1165 by twos	Vertical, Crossline North	6 m	Groundscrews screwed into augered pilot hole
		G3i	SM-24HS	10 Hz high-sensitivity geophone	V	1083 - 1271 by twos	Vertical	6 m	Marsh case, alternating spike in ground and whole case in ground
		Hawk	SL11	accelerometer	V	1083 - 1271 by twos	Vertical	6 m	Alternating spike in ground and whole case in ground
TH1-02	NE->SW	Aries SPML (1)	SM-7	10 Hz geophone	V,H1,H2	3101 - 3180 by ones	Vertical, Magnetic North	3 m	Nail type casing in augered hole
TH1-01	N->S	Aries SPML (1)	SM-7	10 Hz geophone	V,H1,H2	5101 - 5180 by ones	Vertical, Magnetic North	3 m	Nail type casing in augered hole
TH1-04	NW->SE	Aries SPML (1)	SM-7	10 Hz geophone	V,H1,H2	7101 - 7180 by ones	Vertical, Magnetic North	3 m	Nail type casing in augered hole
Testhole1	Vertical	Aries SPML (2)	GS-14-L9	28 Hz geophone	V,H1,H2	1 - 45	Unknown	3.06 m	Strapped to outside of casing, depth range 6.77 to 141.41 m, cemented. Two elements per axis
Testhole2	Vertical	USSI	Optiphone	accelerometer	V,H1,H2	1 - 6	Unknown	20 m	Clamped to inside of casing, depth range 15 to 115 m, cemented.

FIG. 5. G3i recording truck (left), UNIVIB, and Aries recording truck (right) parked 270 m from the closest geophone.

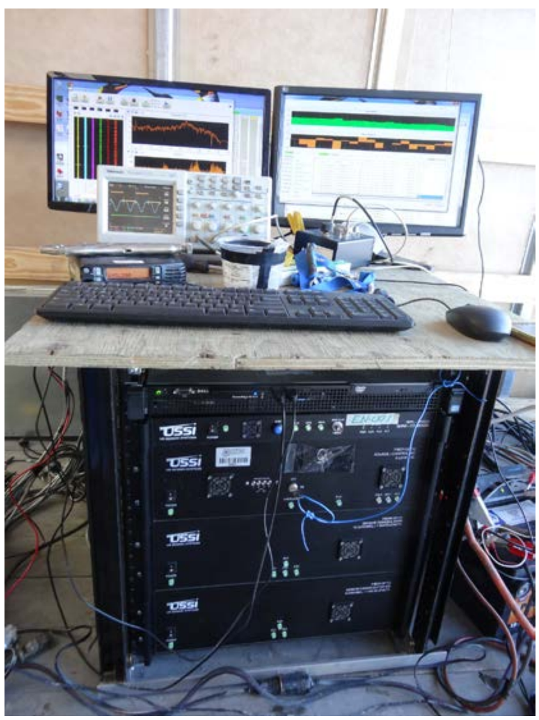


FIG. 6. USSI recorder setup inside a rental cube van with fiberglass walls. Truck was parked 15 m from the closest geophone.

FIG. 7. One hundred and fifty 0.125 kg dynamite charges.

FIG. 8. UNIVIB with USSI recorder in background.

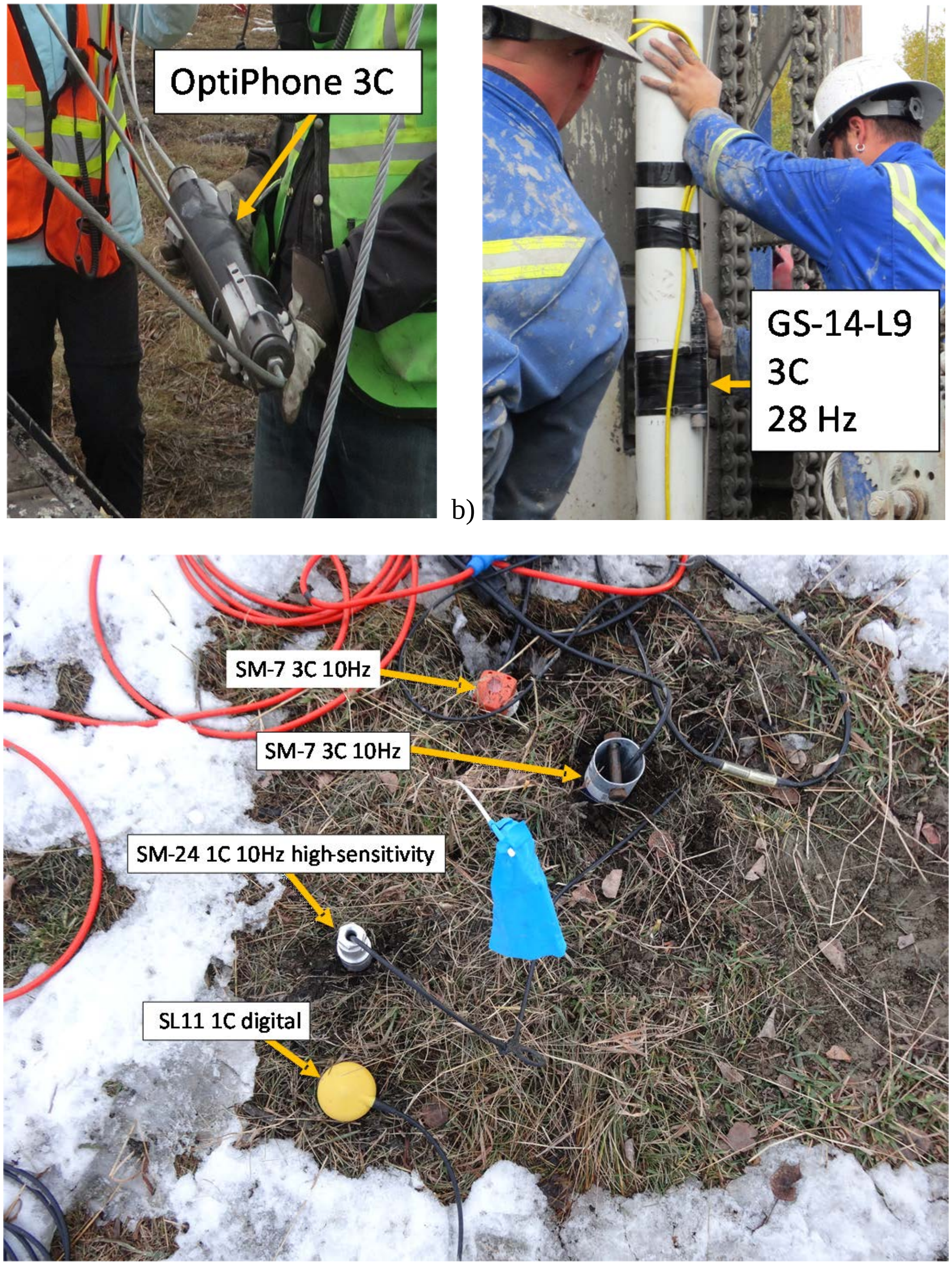


FIG. 9. Testhole1 GS-14-L9 (a), Testhole2 OptiPhone (b) and SM-7 in nail-type case, SM-7 in groundscrew, SM-24HS and SL11 on the surface (c).

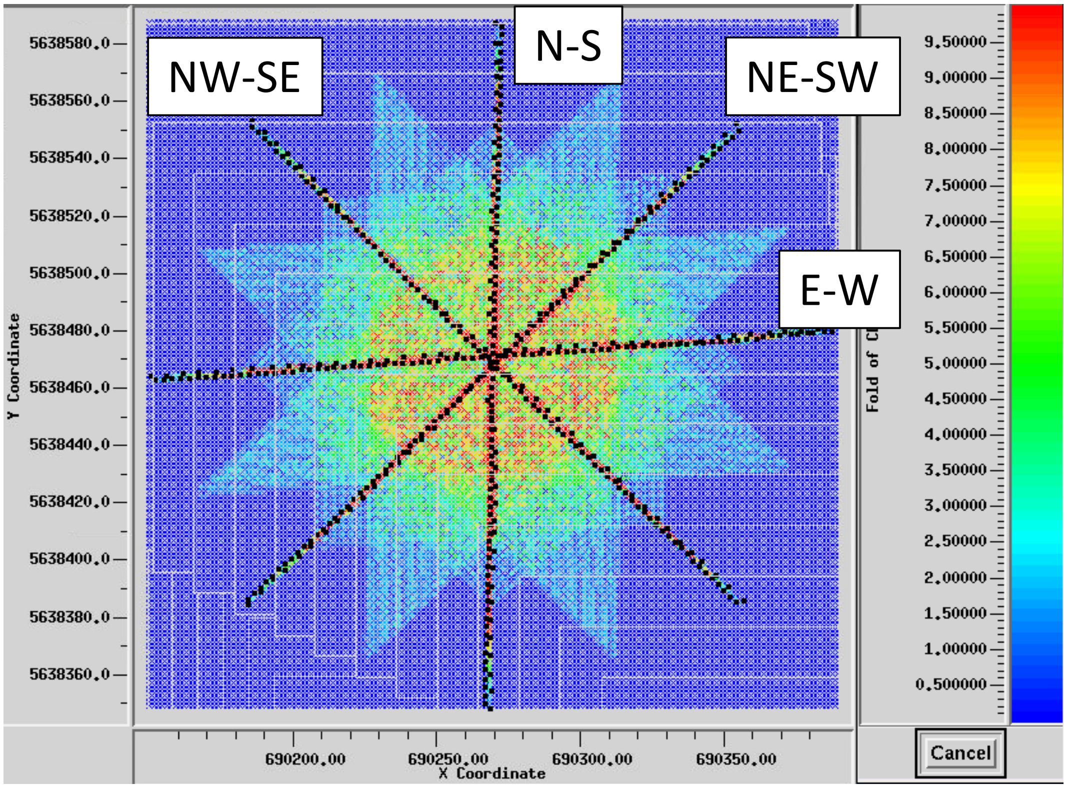


FIG. 10. Dynamite CMP fold for SM-7 geophones binned with 1.5x1.5 m bins. Colour bar extent has limited to a maximum of 10 fold.

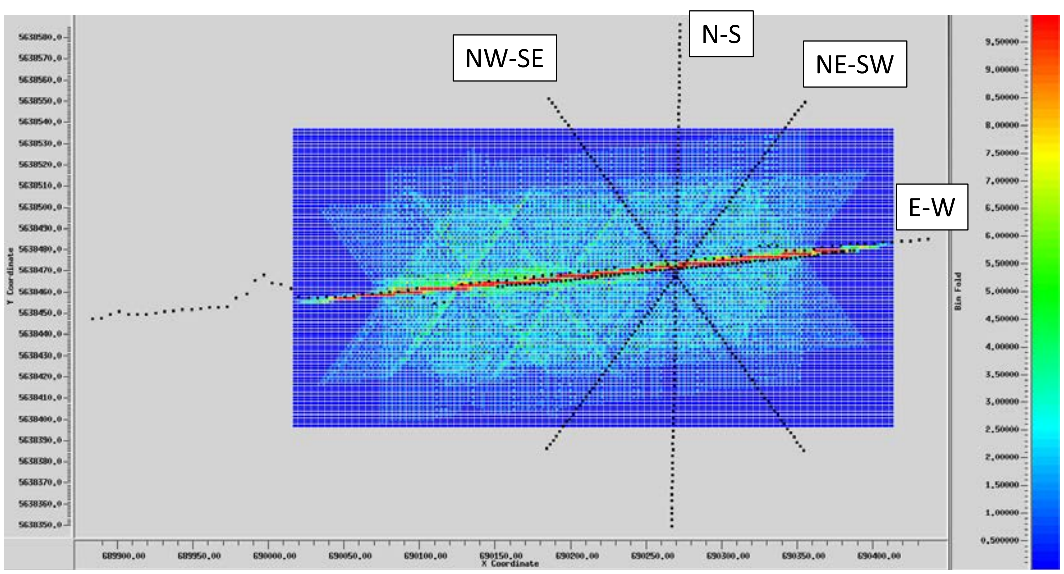


FIG. 11. Vibe CMP fold for SM-7 geophones binned with 1.5x1.5 m bins. Colour bar extent has been limited to a maximum of 10 fold.

INITIAL RESULTS

Figures 12 and 13 show the vertical and radial component data from the SM-7 geophones in nail-type cases for dynamite SP 2101 on the E-W line. Figures 14 and 15 show the same results for VP 2102 on the same line.

Processing for Figure 12 (dynamite) and Figure 14 (vibe) has been limited to a horizontal component rotation from horizontal 1 (H1) and horizontal 2 (H2) to radial (R) and transverse (T) components and a 500 ms automatic gain control (AGC) for display. The component rotation was a purely geometric one, assuming that all of the geophones were planted perfectly with H1 oriented towards magnetic north. The transverse component is not shown. Figures 13 and 15 show the same data, but with a correction for the 10 Hz geophone response from 0-10 Hz applied, as described by Bertram and Margrave (2010). This brought up a lot of very low frequency noise (less than 1 Hz), which has been removed by applying a 1-2-180-200 Hz Ormsby bandpass filter. It is visually apparent that the geophone correction has enhanced data below 10 Hz.

Figures 16 and 17 show the GS-14-L9 vertical and radial component results for receiver gathers at 74 m depth for all dynamite and vibe shots recorded by that system. In this case, the geophone orientations are unknown, so the component rotation was performed using a peak vector amplitude algorithm in SeisSpace/ProMAX.

Figures 18 and 19 show USSI OptiPhone vertical and radial component receiver gathers for the receiver at 75 m depth for all dynamite and vibe shots recorded by that system. Once again, the sensor orientations are unknown, so the peak vector amplitude rotation was used again. The data were resampled to 1 ms to match the sample rate of the geophone data. This system is sensitive to the acceleration of ground motion, but the data have not been converted to velocity for this report. This is the first time we have used this system in the field, and due to our unfamiliarity with the system, not all of the shots were recorded. The USSI system is susceptible to vibration, and went offline and had to be reset every time the Vibe was close to Testhole2.

The bottom halves of Figures 12 through 19 show the first 200 Hz of the amplitude spectra for each trace. Note that most of the energy is in the 0-40 Hz band, which is disappointing. This story may improve after ground-roll removal and stacking. Narrow horizontal bands indicate the presence of electrical noise, likely due to the presence of the USSI recording system and associated generator and battery chargers within the active spread. The repetitive nature of the bands indicates the electrical noise has harmonics.

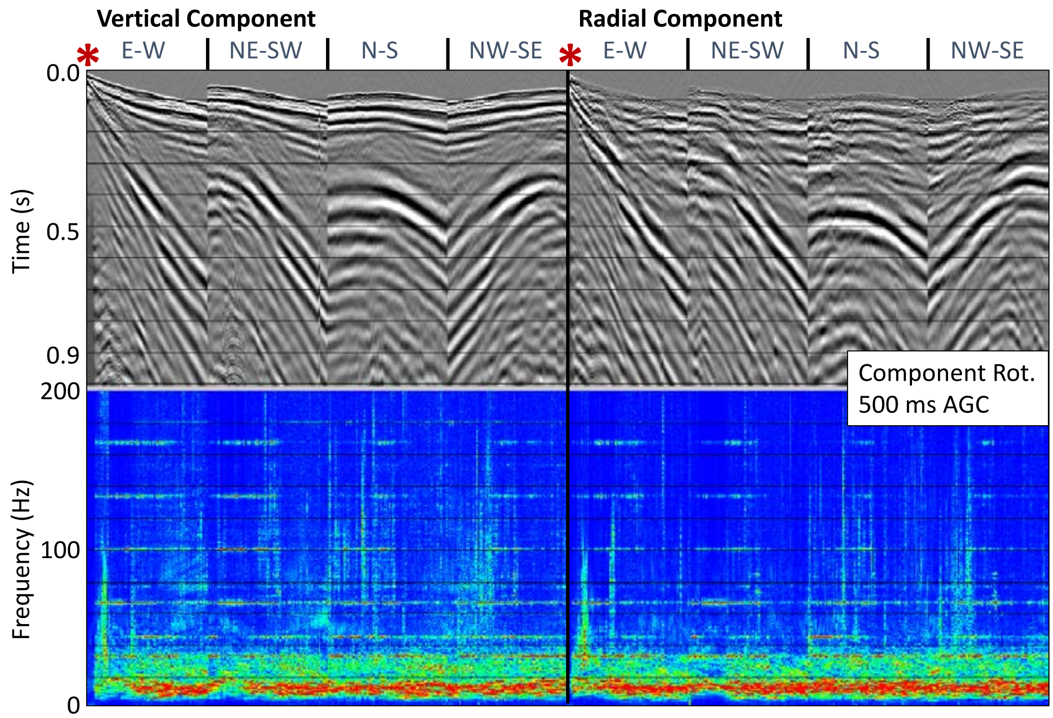


FIG. 12. SP 2101, 0.125 kg Dynamite @ 5m, SM-7.

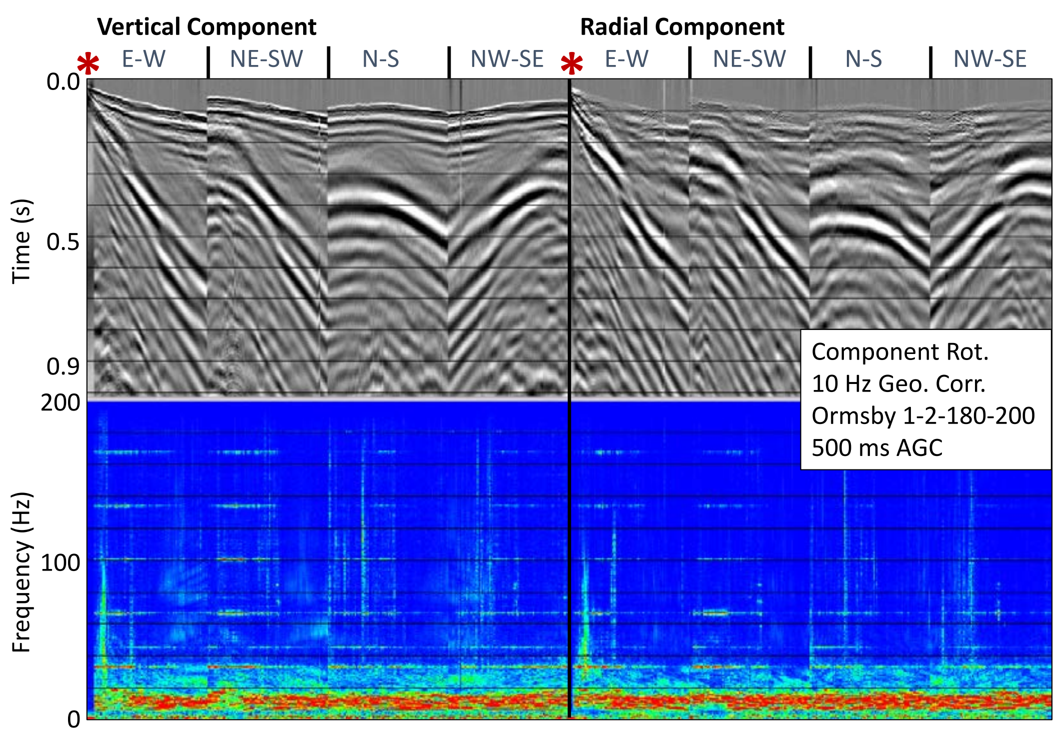


FIG. 13. SP 2101, 0.125 kg Dynamite @ 5m, SM-7.

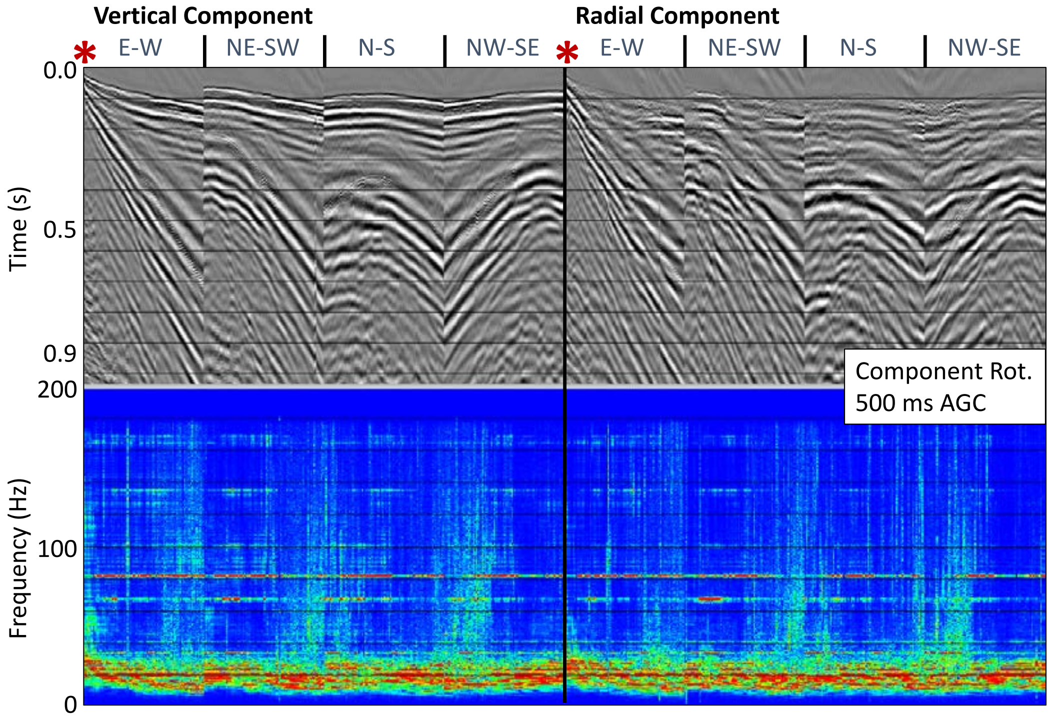


FIG. 14. VP 2101, Vibroseis linear 1.5-180 Hz sweep over 16 s, SM-7.

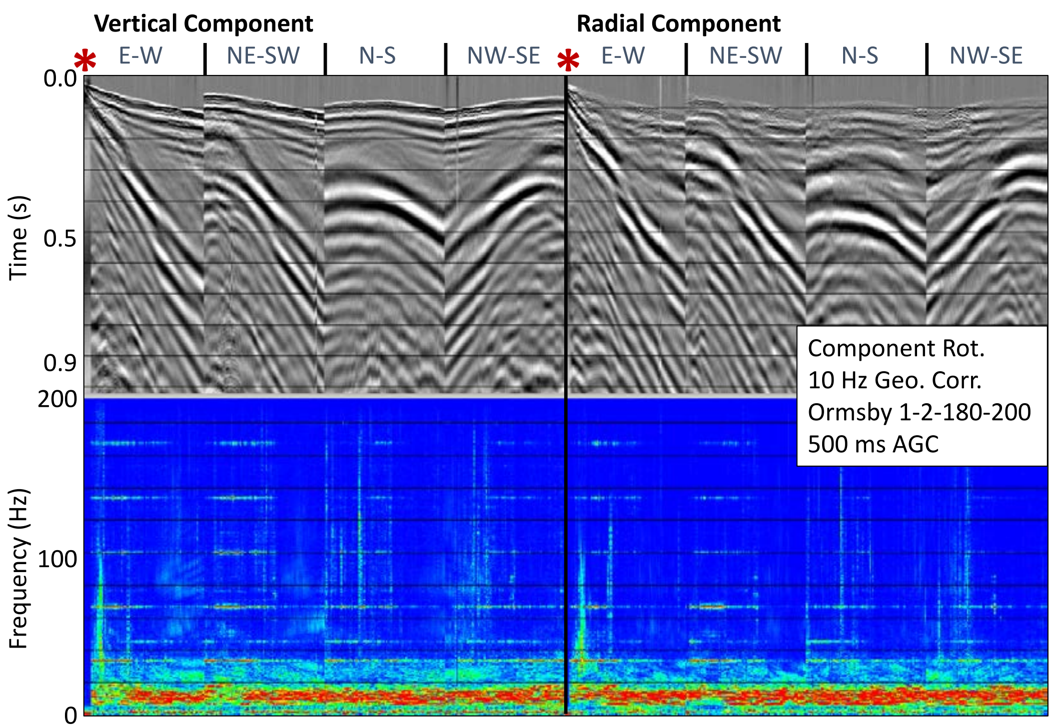


FIG. 15. VP 2101, Linear 1.5-180 Hz sweep, SM-7.

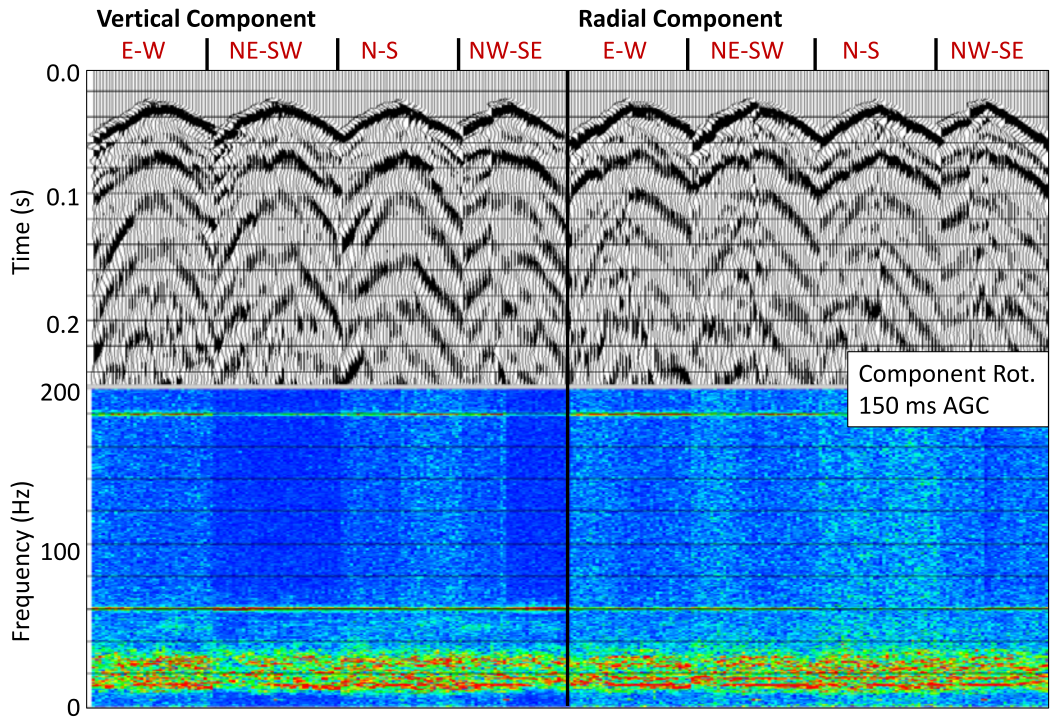


FIG. 16. Testhole1, 0.125 kg Dynamite @ 5m, GS-14-L9.

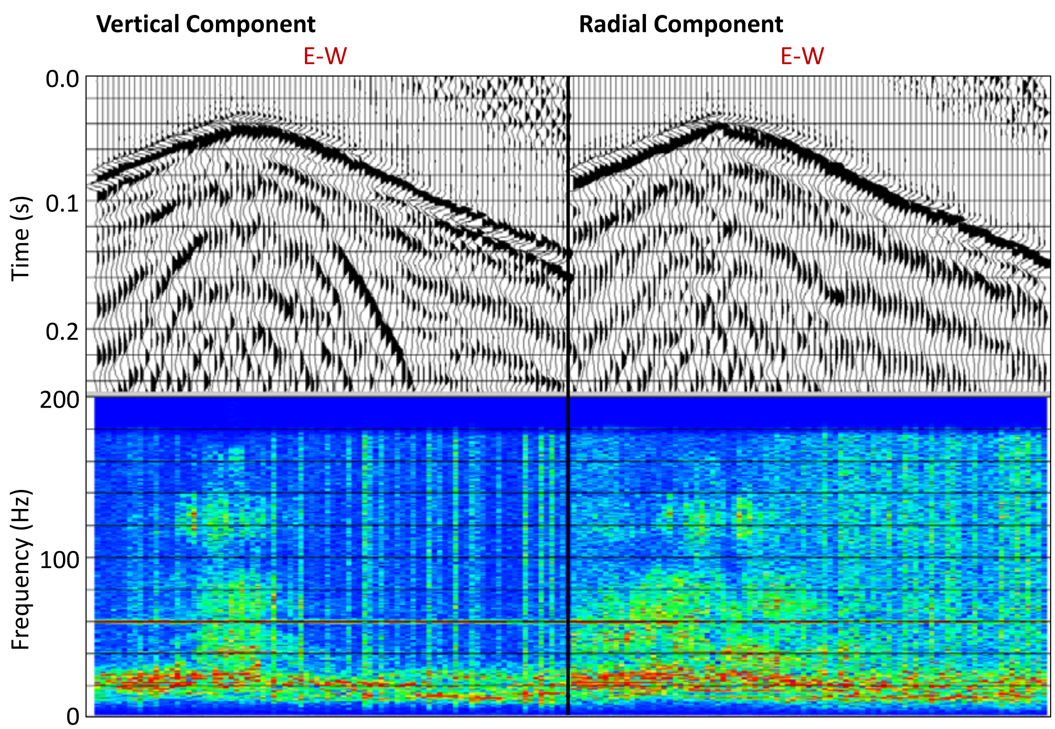


FIG. 17. Testhole1, Linear 1.5-180 Hz sweep, GS-14-L9.

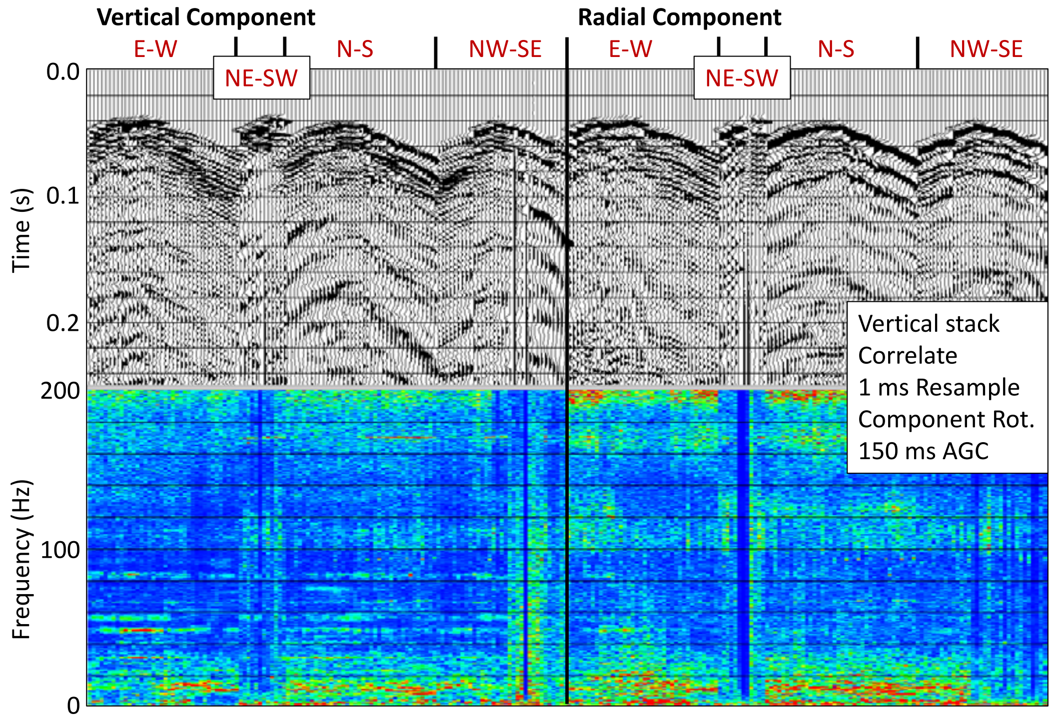


FIG. 18. Testhole2, 0.125 kg Dynamite@5m, OptiPhone.

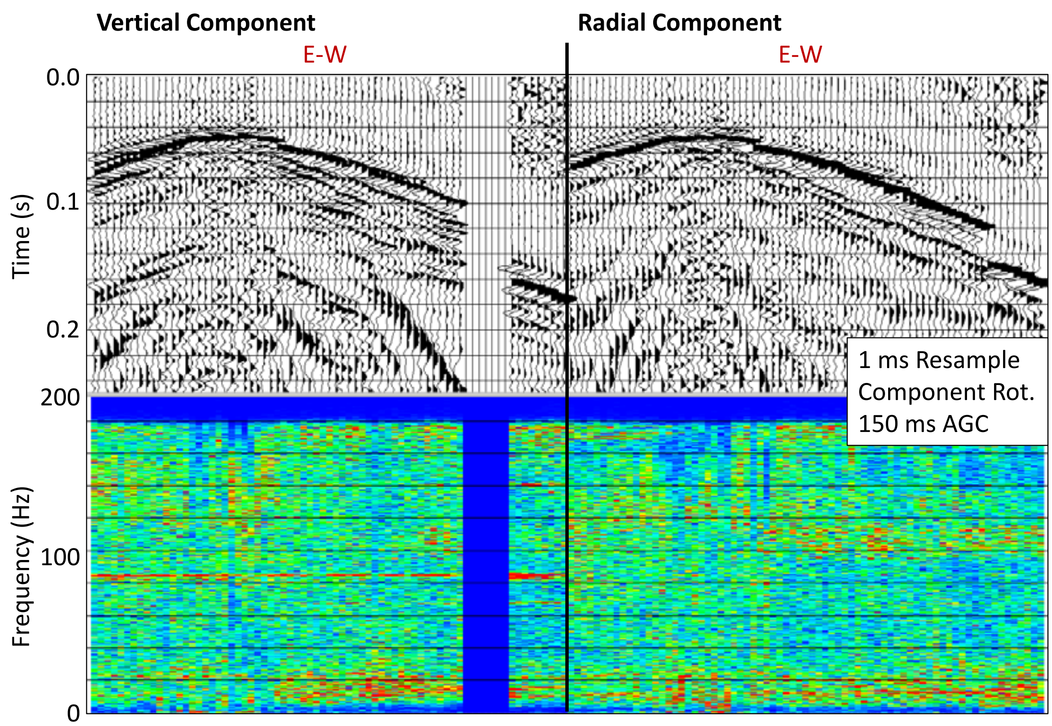


FIG. 19. Testhole2, Linear 1.5-180 Hz sweep, OptiPhone.

ELECTRICAL NOISE

The average spectra derived from individual trace spectra shown above for uncorrected data (Figure 12, Figure 14, and Figures 16 through 19) are shown in Figure 20 (dynamite) and Figure 21 (vibe) in order to have a closer look at the electrical noise present in the data. These figures highlight 60, 120 and 180 Hz with blue arrows. This electrical noise is 60 Hz and harmonics from the local power lines along the west side of the survey area, and has been previously observed in data from other surveys at this location.

The SM-7 data show a series of spikes spaced approximately 33.5 (~0.5 * 60) Hz apart at 33.5, 67, 100.5, 134, 167.5 Hz that are larger than the spike at 60 Hz. This is probably due to the small generator used to power the USSI system which was located close to the geophone lines. This generator was a small single cylinder unit with poor speed regulation, and was fairly noisy. Some baffling was attempted during the survey to try to reduce the acoustic signature of it. A smaller spike also exists at 45 (~0.66 * 60) Hz which is likely due to acoustic noise from the diesel generator on our recording truck, which has been observed on previous surveys (Figures 20a and 21a).

The GS-14 data show large spikes at 60 and 180 Hz that are higher amplitude than the data (Figures 20b and 21b). These spikes are not as prominent or not observed on the SM-7 and OptiPhone data. A possible explanation for this is the fact that the adapter boards used to connect the downhole geophone cables to our Aries system are completely unshielded. Also these geophones are high impedance (3000 Ω) which causes greater pickup of electrical noise.

The reduction in the amplitude of the 33.5 Hz data and harmonics on these downhole geophones relative to the surface data indicates that this is indeed an acoustic (airborne) noise from the generator that the surface geophones are picking up.

The OptiPhone data show a general rise in noise level with increasing frequency that is not seen on the other systems (Figures 20c and 21c). This rise can also be observed in the 0.25 ms data before resampling, and is due to this data still being in acceleration rather than being integrated to velocity.

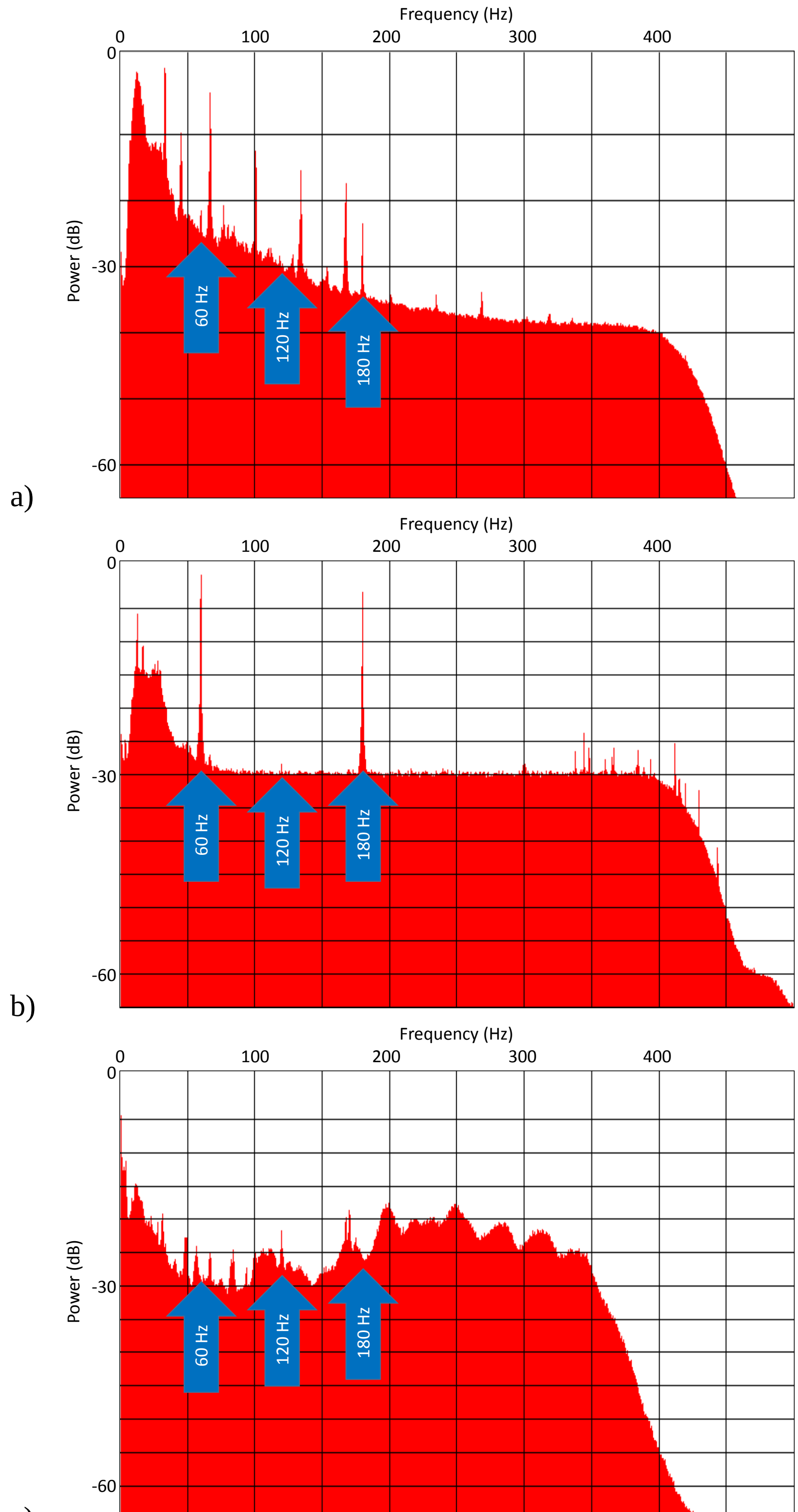


FIG. 20. SP 2101, 0.125 kg Dynamite @ 5m, SM-7 (a). Testhole1, 0.125 kg Dynamite @ 5m, GS-14-L9 (b). Testhole2, 0.125 kg Dynamite@5m, OptiPhone (c)

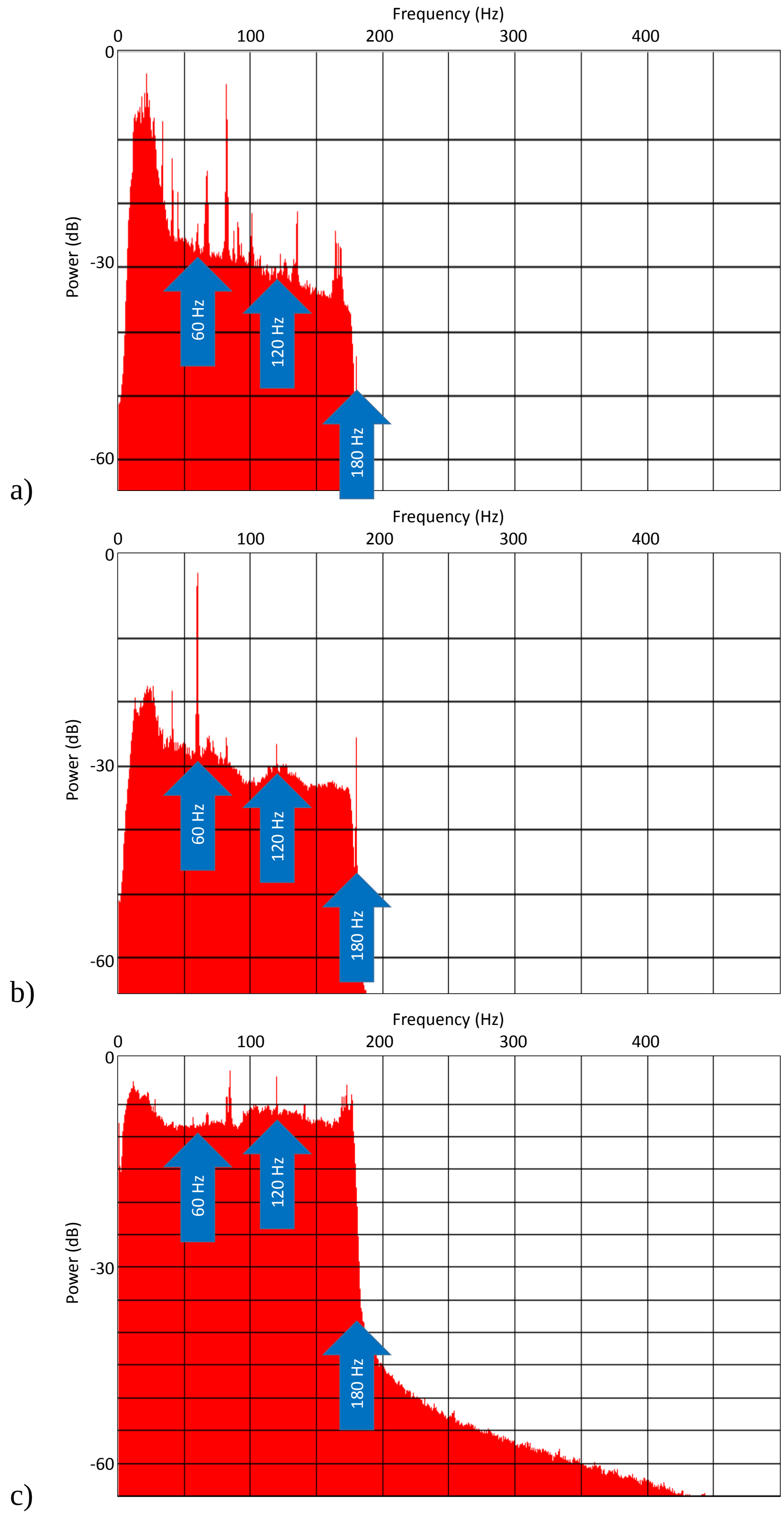


FIG. 21. Testhole2, Linear 1.5-180 Hz sweep, SM-7 (a) GS-14-L9 (b) OptiPhone (c).

FUTURE WORK

The horizontal data need to be more carefully rotated to radial and transverse components. Some of the dynamite shots will be used in order to determine the actual orientation of the permanent geophones in Testhole1 for future surveys. Electrical noise issues need to be dealt with, possibly by modelling and subtraction, especially on the SM-7 data. Ground-roll needs to be carefully removed in order to preserve shallow reflections. All data volumes, including the ones we don't have copies of at time of writing, need to be stacked, migrated, inverted and interpreted.

DISCUSSION

The well-logging and seismic programs were successfully carried out, meeting all of the initial objectives. However, there are some issues with electrical noise in the data that will need to be addressed.

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