Near-surface velocity characterization at Priddis and installation of fibre-optic cables at Brooks, Alberta

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ABSTRACT

CREWES operates a shear-wave seismic source for multicomponent near-surface seismic studies. The source component of the system is a model A200 weight drop device with a 100 kg hammer accelerated by compressed nitrogen operating at 1000 psi. In 2016, we recorded a multicomponent walk-away vertical seismic profile at the Priddis Geophysical Observatory in to characterize the near-surface P-wave and S-wave velocity structure to a depth of 141m. P-wave data were collected with the source operating in a vertical force orientation. A pivot system enables the source to generate both P-wave and S-waves. The source mast can be operated in a vertical mode for generating P-waves and it can rotate ± 45 degrees transverse to the longitudinal axis of the trailer, in order to generate down-going P-wave and S-waves simultaneously. Pure-mode down-going S-waves are generated by subtracting records taken with the mast rotated in the positive and negative tilt modes. Good-quality zero-offset P-wave and S-wave VSP data recorded into the CREWES well with a 3C receiver spacing of 3.06 m. A thin surface layer and two thicker layers are interpreted from the first arrival P-wave and S-wave travel times, with the second layer thickness of 46 m. P-wave velocities are 2450 m/s and 3260 m/s and S-wave velocities are 796 m/s and 1346 m/s respectively in the two deeper layers. This yields Vp/Vs values of 3.06 in the second layer, and 2.50 in the third layer.

At the Brooks Field Research Station, being developed by the Containment and Monitoring Institutes, both straight and helical optical fibres have been installed in a 350 m deep well and in a 1.1 km trench, to assess optical fibre recording for VSP and surface seismic surveys. Recording into the fibre will be undertaken in 2017.

INTRODUCTION

In 2013, CREWES drilled and completed two observation wells on University of Calgary land near Priddis Alberta and form part of the Rothney Geophysical Observatory. A detailed description of the wells is provided by Hall et al. (2013). Of interest to the current study is the first well that was drilled to a depth of 140 m and 45 3-component geophones were strapped to the outside of Schedule 80 PVC casing and cemented into place. The geophone cables were interleaved, resulting in a geophone spacing of 3.06 m between depths of 6.67 m to 141.11 m below the ground surface. The layout of the geophone cables and geophones is shown in Figure 1. The original plan was to keep the inside of the casing open, so that retrievable sensors could be run into the well to compare with the geophones outside of the casing. In addition, a straight single mode optical fibre was also strapped to the outside of the casing, although no acoustic recording has yet been undertaken into this fibre.

Some early vertical seismic profiles (VSPs) were recorded into the well geophones using and Envirovibe source as well as a new S-wave thumper source that had been developed by CREWES in the preceding year. A description of the source design and construction is detailed by Lawton et al. (2013) and some test VSP data were shown by Bertram et al., 2013.

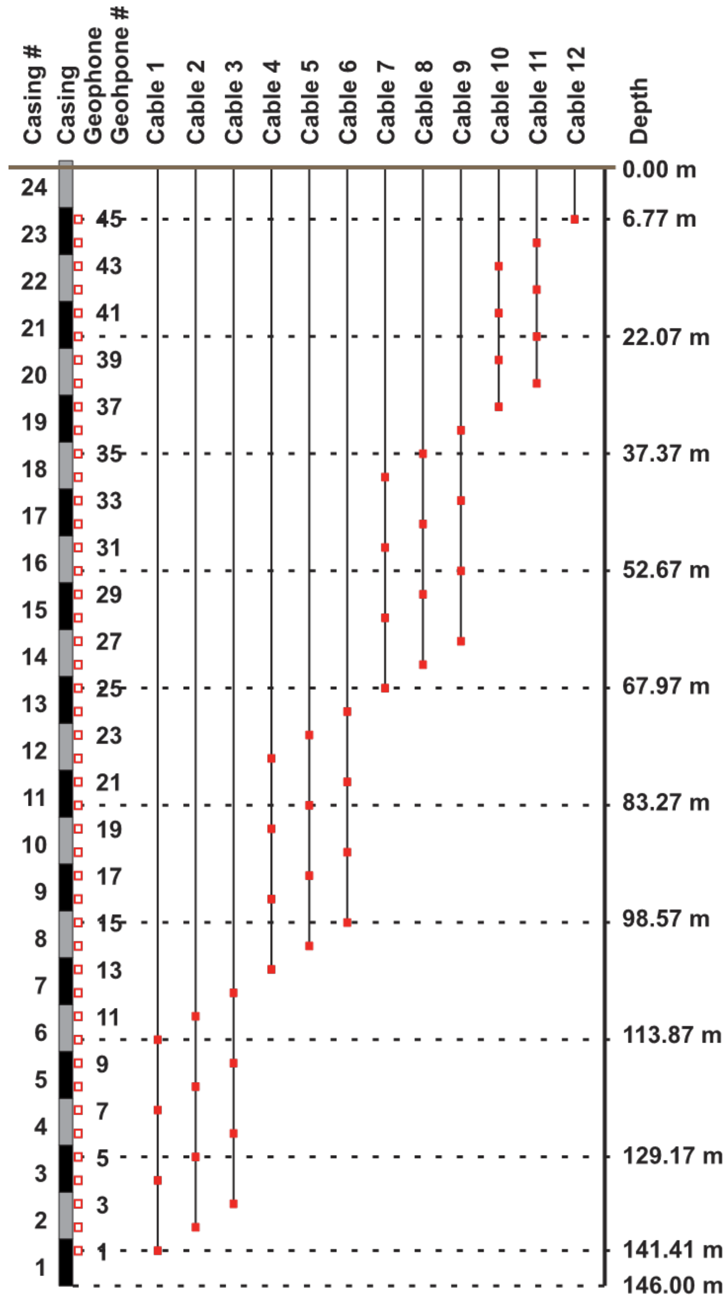

FIG 1. Layout of VSP cable and geophones (from Hall et al., 2013)

In the late summer of 2016, a small 3C3D survey was acquired at the Rothney Geophysical Observatory using a new Hawk nodal recording system and simultaneously recording the downhole geophones in the instrumented well. This program is described by Bertram et al. (2016). The goal was to record data in the downhole geophones and the surface 3D Hawk array using both the Envirovibe and S-wave thumper source. The survey using the Envirovibe was completed successfully, but the S-wave source suffered a catastrophic failure on the first shot and that survey had to be abandoned. The source was ultimately repaired and a single azimuth surface 2D line and a walkaway VSP profile were recorded in September,2016. This paper describes some of the initial findings from this survey.

ACQUISITION PROGRAM

The experiment was undertaken with the 45 down-hole geophones and a 40-station 3C2D surface geophones recorded simultaneously. For the surface spread, the geophones were spaced at 5 m, yielding a maximum offset of 200 m from the well (the near-offset from the well was 5 m). Figure 2 shows a picture of the S-wave thumper source in operation. When the mast is vertical, it operates essentially as a P-wave source. For generating S-waves, the mast is rotated ±45 degrees and the two records are subtracted.

FIG 2. Thumper seismic source in vertical force mode. Malcolm Bertram operating.

Figures 3 and 4 show a close up view of the source system operating in S-wave and P-wave modes, respectively. The strike plate is made of aluminum and has a serrated base to ensure good coupling with the ground. The mast rotates about a pivot to record the ±45 impacts.

Surface spread

Initially, P-wave and S-wave mode source configurations were recorded into the 3C geophone spread at source intervals of 10 m over the full length of the surface spread, out to a maximum offset of 200 m from the well. Figure 5 shows the P-wave data recorded from both ends of the active surface spread, and Figure 6 shows the S-wave data from the same end-shots. The S-wave source was operated in SH mode, with the excitation direction perpendicular to the receiver line direction.

FIG. 3. Source hammer operating in S-wave mode.

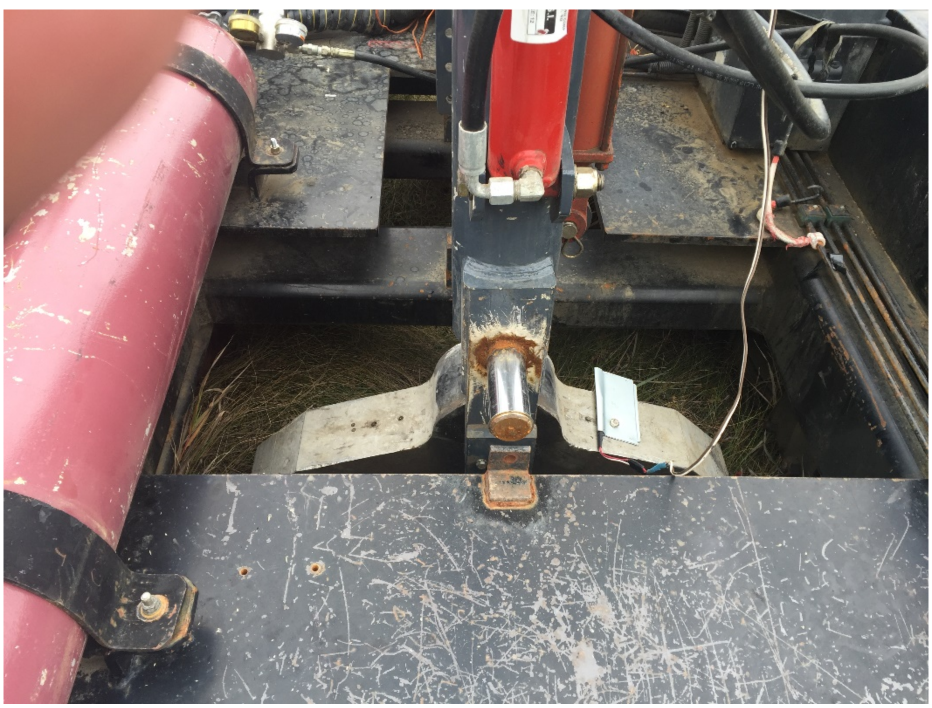

FIG. 4. Source hammer operating in S-wave mode

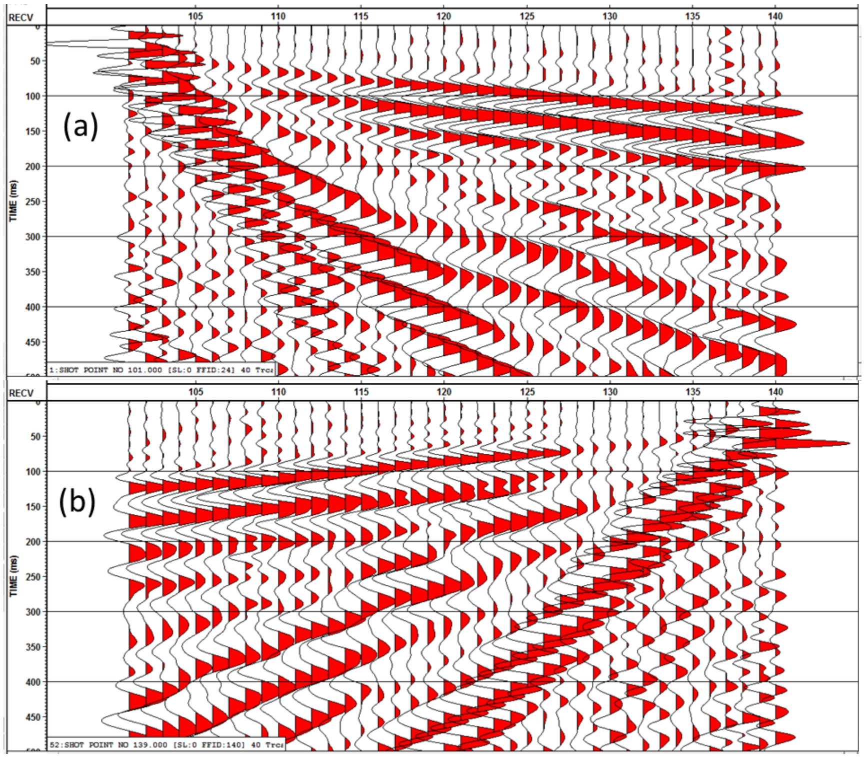

FIG. 5. P-wave end-shots from the surface 3C receiver line.

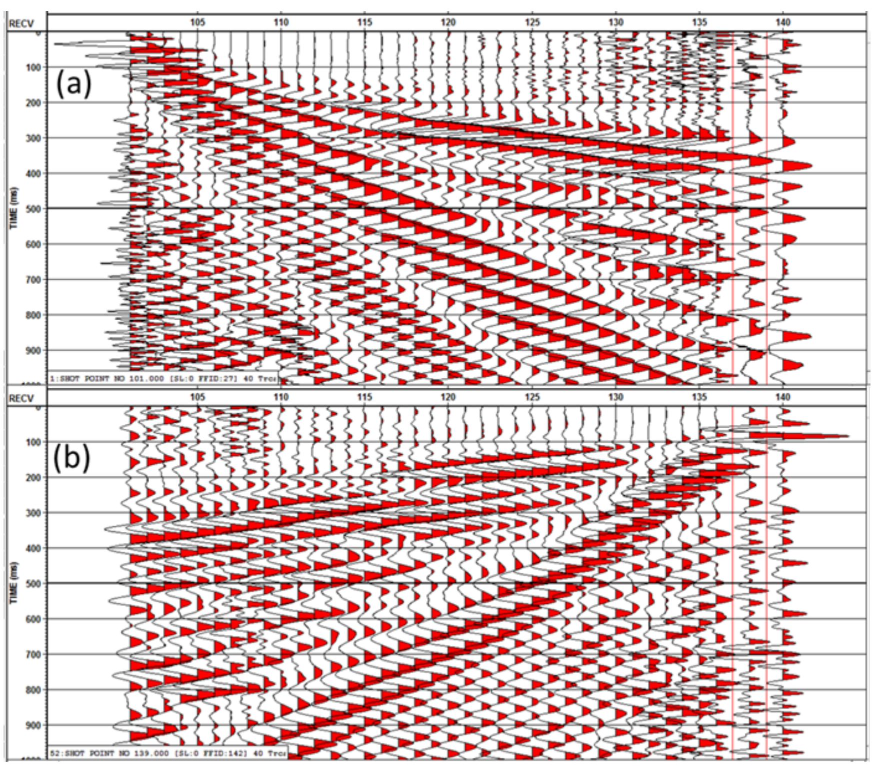

FIG. 6. SH-wave end-shots from the surface 3C receiver line.

First arrival velocity analysis of the data shown in Figures 5 and 6 was undertaken, yielding the results shown in Table 1.

Table 1. Refraction analysis, 3C surface refraction spread

Layer	Thickness (m)	Vp (m/s)	Vs (m/s)	Vp/Vs
1	12	330	200	1.65
2	45	2350	860	2.73
3		3400		

The velocities were determined by inverse slopes of the first-arrivals vs offset displays, and layer boundaries were determined from cross-over points identifiable on the first arrivals shown in Figures 5 and 6. For the P-wave data (Figure 5) the second cross-over point for the boundary between layers 2 and 3 is identified from a subtle change in slope at trace 132 in the forward shot (Fig 5a) and trace 108 in the reverse shot (Fig 5b). For the SH-wave data (Figure 6) the maximum offset was insufficient to capture first arrivals critically refracted from Layer 3.

Zero-offset VSP

The zero-offset vertical and horizontal-component data are displayed in Figure 7a and 7b respectively. Clear first-arrivals are evident and the travel times of the shallowest two geophones (6.77 and 9.80 m) show delayed times due to the shot offset (5 m). Both the P-wave and S-wave data show a change in slope at a depth of 46 m. Interval velocities for the three layers are provided in Table 2. These values were determined from the average slopes for each segment of the first arrival data shown in Figure 7.

Table 2. Refraction analysis, 3C surface refraction spread

Layer	Thickness (m)	Vp (m/s)	Vs (m/s)	Vp/Vs
1	10	330	200	1.65
2	44	2437	796	3.06
3		3365	1346	2.50

Velocities from the well data (Table 2) are quite comparable to those determined from the surface refraction data (Table 1), although layer 1 velocities are not well constrained in the VSP well data. Vp/Vs is low in the near-surface layer, interpreted to be above the water table. Values for layers 2 and 3 are both quite high, but consistent with values recorded in previous seismic surveys in Alberta (e.g. Lawton, 1990).

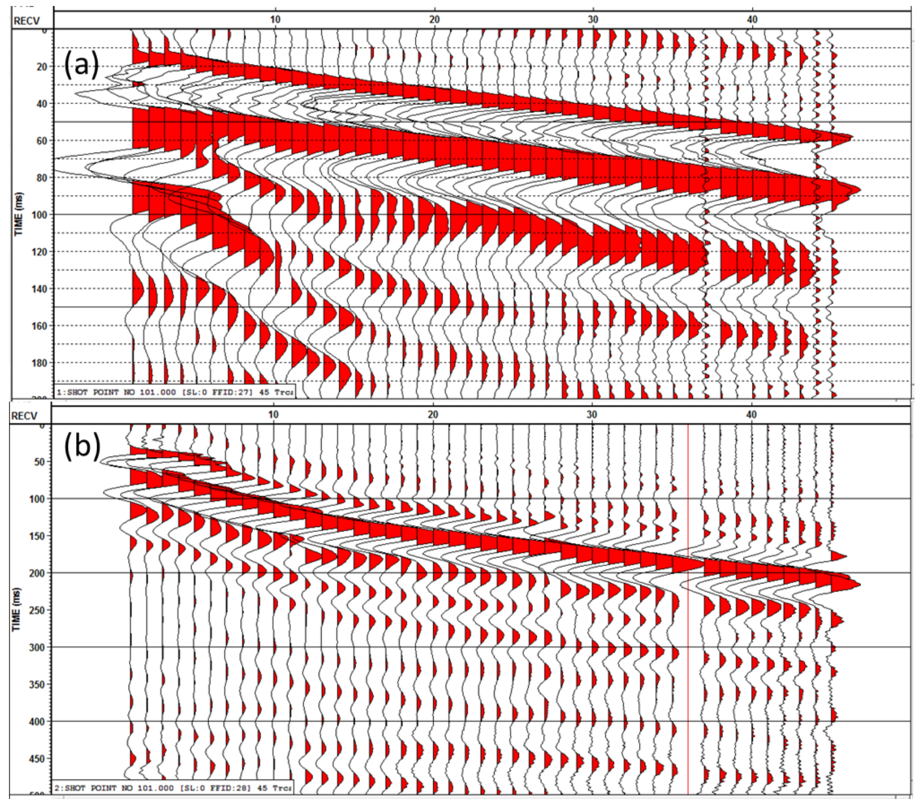

FIG 7. Zero offset VSP data from the Priddis Geophysical Observatory well. (a) Vertical component data {P-wave}. (b) Cross-line horizontal component data {SH-wave}.

Walk-away VSP data

P-wave and S-wave data were recorded into the VSP for all of the same shots that were recorded into the surface 3C geophone spread. Figures 8 through 11 show the P-wave and S-wave data for shot offsets of 50 m, 105 m, 155 m and 195 m respectively. The P-wave data have only be scaled, whereas for the S-wave records, the data from the positive (north) and negative (south) thumps were rotated, scaled and subtracted, to cancel the P-wave data that leaked onto the record, and to create the S-wave mode.

All the walkaway records have a similar pattern, with clear evidence of turning rays in both the P-wave and S-wave data. In the former case, turning rays are evidenced by delayed travel times in the upper section and a change in polarity across the point in the well at which the incident wave-field is normal to the borehole. Also, as expected, this point gets deeper in the well as the source offset increases. First arrivals located at geophones shallow than the normal incidence depth are upgoing waves, so the polarity of these arrivals is opposite to those arriving deeper in the borehole, which are propagating downwards. The S-wave arrivals also show a delay in travel time shallow in the well, but no change in polarity of the first arrivals. Further work will be undertaken on these data to extract information about vertical velocity gradients, which will generate turning rays at large offset to depth ratios.

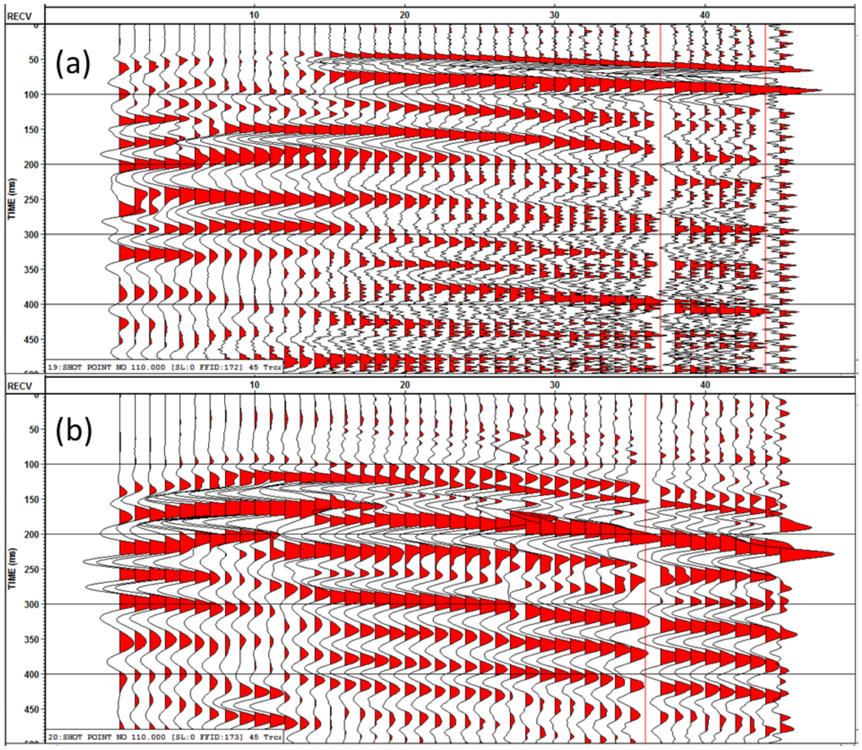

FIG 8. 50 m ffset VSP data from the Priddis Geophysical Observatory well. (a) Vertical component data {P-wave}. (b) Cross-line horizontal component data {SH-wave}.

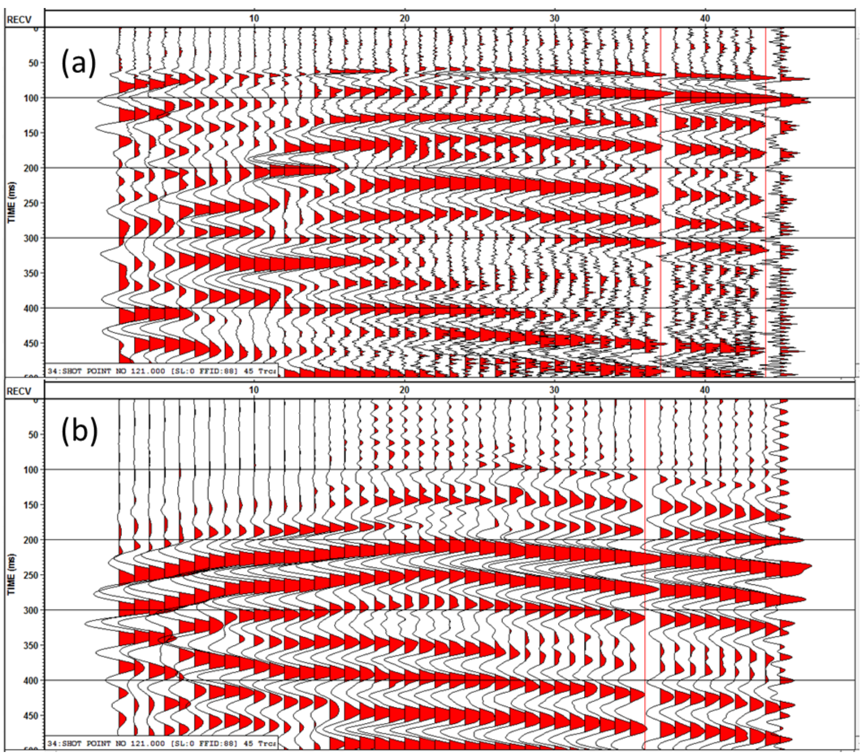

FIG 9. 105 m offset VSP data from the Priddis Geophysical Observatory well. (a) Vertical component data {P-wave}. (b) Cross-line horizontal component data {SH-wave}.

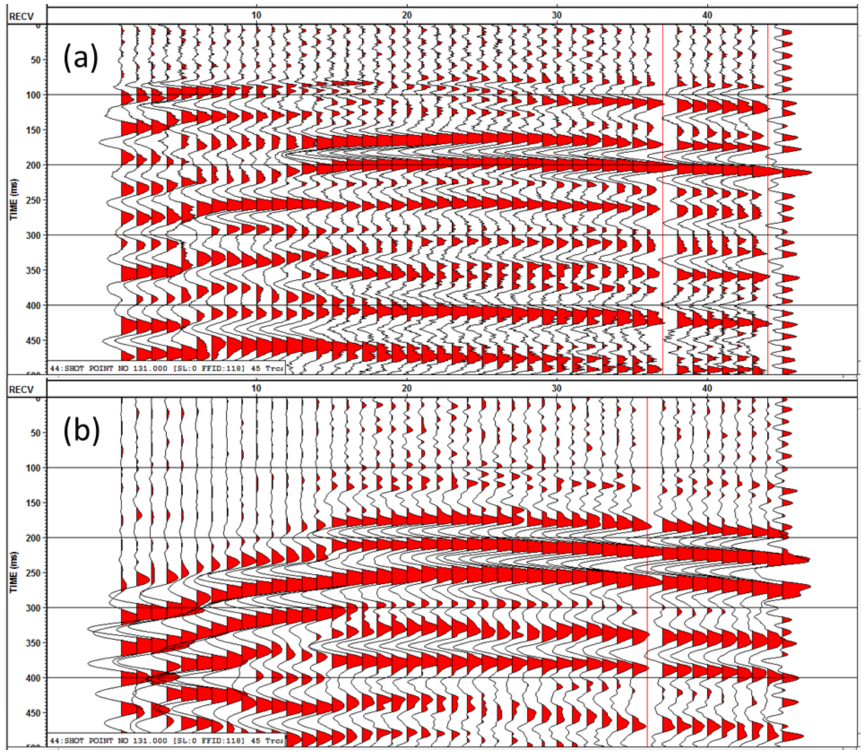

FIG 10. 155 m offset VSP data from the Priddis Geophysical Observatory well. (a) Vertical component data {P-wave}. (b) Cross-line horizontal component data {SH-wave}.

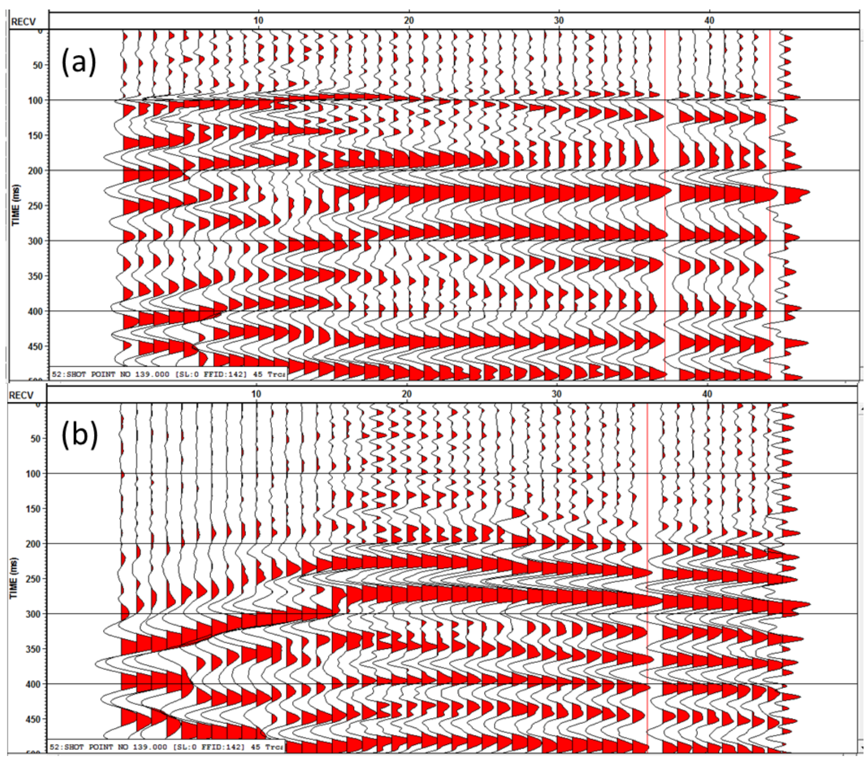

FIG 11. 195 m offset VSP data from the Priddis Geophysical Observatory well. (a) Vertical component data {P-wave}. (b) Cross-line horizontal component data {SH-wave}.

OPTICAL FIBRE INSTALLATION AT THE CAMI FIELD FRS

At the Containment and Monitoring Institute (CaMI) Field Research Station in southern Alberta, a loop of Digital Acoustic Sensing (DAS) optical fibre was installed in two observation wells at the facility, as well as in a 1.1 km long trench. The purpose is to evaluation straight and helical wound optical fibre cable with geophone data in a well, and also to compare the performance of the helical wound cable with straight single mode fibre for surface acquisition with the fibre and packed down in a trench.

Figure 12 shows the layout of CaMI.FRS. Relevant to this study are the locations of the monitoring wells (green dots) and the southwest – northeast trending trench that runs closely past the wells.

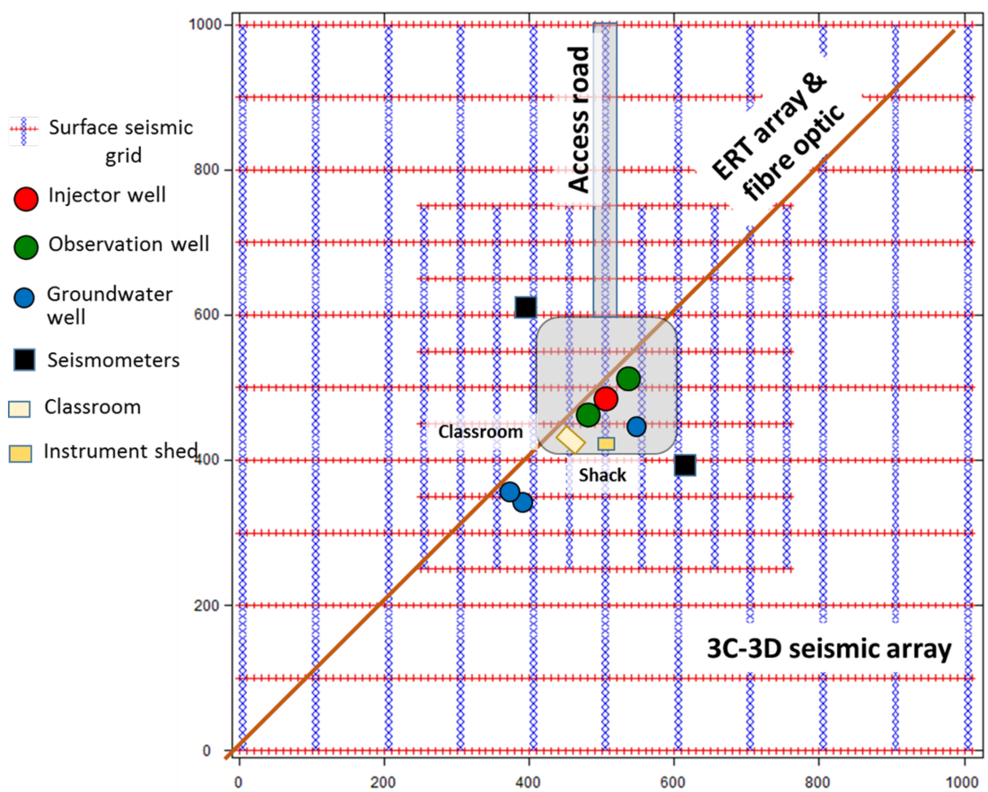

FIG 12. Layout of the CaMI Field Research Station near Brooks, Alberta.

The hypothesis being tested in this layout is whether the helical wound fibre has less directivity than the straight fibre since the fibre is sensitive to strain parallel to the fibre. Some initial results (Freifeld et al., 2016) demonstrate higher P-wave reflection signal with the helical fibres. Figure 13 shows both fibres deployed in the trench prior to burial, and a close-up view of the cable with the fibres viewed.

CREWES will be involved in acquisition of some of the seismic data acquisition into both fibres in 2017 and will have some access to the results obtained with the data recorded.

FIG 13. Straight (brown) and helical wound (blue) optical fibre cable in trench at the FRS.

CONCLUSIONS

Surface refraction 3C2D data and borehole seismic data showed consistent result with respect to the shallow P-wave and S-wave velocity structure at CaMI.FRS. Vp/Vs is less than 2 above the water table, but has a value of up to 3.06 in saturated sediments. Further seismic field tests are planned with the thumper source, particularly for processing and imaging the VSP data from the Priddis Geophysical Observatory.

At the CaMI.FRS near Brooks, Alberta, helical wound and straight optical fibre cables were strapped onto casing in wells at the site, in addition to installation in a 1.1 km long surface trench. CREWES will undertake some seismic data acquisition into the fibre within the next few months.

ACKNOWLEDGEMENTS

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