Recent data from the Priddis Geophysical Observatory

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ABSTRACT

An analysis of selected data from two surveys conducted using the recently completed shear wave accelerated weight-drop seismic source shows that there is good shear wave energy generated by this device. Data are presented from both surface and down-hole geophones deployed at the new well location at the Priddis Geophysical Observatory in October 2013. The first survey used dynamite, an Envirovibe and the shear wave weight-drop as sources, while the second was a follow up survey to check completion of casing cementing and used just the Envirovibe and the shear wave weight-drop.

INTRODUCTION

Two new test wells were drilled at the Priddis test site in October 2013 (Hall et al., 2013). The first was completed to 146m and has 45 3C geophones installed on the outside of the PVC casing at a spacing of 3.06 m. There are also single- and multi-mode fibre optic strands installed in this well. The well was cemented to surface, but either a casing break or a failure of the float shoe allowed the cement to enter the inside of the casing and thereby drop to about 15m below surface in the outside annulus. A second well 55m away was completed and remains mostly open as a usable site for down-hole equipment, although cement is also present inside the casing of this well, at depths more than 120 m.

The first survey at the site was conducted in mid-October 2013 with a complex surface spread deployed as well as the down-hole geophones. The main acquisition was by the Envirovibe with four sweeps at every station along the two main surface geophone lines orientated north-south and east-west (Bertram, K., et al., 2013). The new shear wave weight-drop source had just been completed at this time, and this was the first field trial of the device (Lawton et al., 2013). This source uses a nitrogen gas pressured cylinder as a spring to accelerate the hammer. By striking the foot at a 45^0 angle, the source generates both P and S wave energy. Swinging the hammer to the opposite side provides a simple method of reversing the polarity of the generated S-wave energy. By subtracting data of one polarity from the other, the S-wave can be enhanced and the P-wave reduced. A limited number of shot points were acquired with this source during both surveys, and a discussion of these data is the main point of this paper. All weight-drop shot points had 10 composites acquired and subsequently stacked.

After discovering the cement loss outside the casing, the drillers returned to top off the well, and the second survey was conducted on October 31 to determine if there was any change in data quality and geophone coupling, particularly in the uppermost geophones, as a result. For this survey, a few shot points were acquired with the Envirovibe and a few with the shear wave source. Unfortunately the two surveys do not have any exactly matching shot or receiver locations on the surface, as time limitations prevented duplicating the more complex layout of the first survey. Figure 1 shows the Envirovibe and the shear wave thumper on site during the second survey.

FIG 1. The Envirovibe and the shear wave weight-drop in the field at the Priddis test site.

THE FIRST SURVEY

The first survey after completion of the new test wells was conducted on October 16, 17 and 18, 2013 (Bertram, K., et al., 2013). This survey was designed to test the down-hole equipment as well as to provide information about the near-surface velocity structure by shooting a series of small charges as an up-hole experiment. Some inclined shot holes were also drilled to test a hypothesis regarding generation of shear wave from dynamite charges (Guevara and Margrave, 2013). As well as the dynamite shots, the University's Envirovibe was used to acquire two shot lines and the new shear wave weight-drop was tested at a few locations to provide a first test of its capabilities. As part of this component of the survey, 100 thumps were acquired at a single location for a signal to noise versus number of stacks investigation.

There were two 3C geophone lines crossing the well location nearly at right angles, as well as two shorter 3C geophone lines set at a slight angle to the east-west direction to provide data for the dynamite shear wave generation experiment (Bertram, K., et al., 2013). There are also forty-five 3C GS14 down-hole geophones in the well at 3.06m intervals. These geophones are in a complex deployment and needed to be re-ordered into depth before any processing could be applied to the data. Following this survey and before the second survey these geophones were re-wired onto a patch panel and the order corrected to make the down-hole array more logical for future surveys.

An example of the data from the first of the dynamite shots is shown in Figure 2. This is the vertical component of the four surface lines 1 (N-S), 3 (E-W), 5 (NW-SE) and 7 (SW-NE) and one horizontal (X) component of the down-hole array. This shot is at location 6102 and is a vertical shot hole 25 m west of Well 1.

For all surface geophones, the cable entry was to the south, so the “inline” component is north-south and the “crossline” component is east-west. The down-hole geophones have random horizontal orientation, so rotation was required before any data analysis was undertaken.

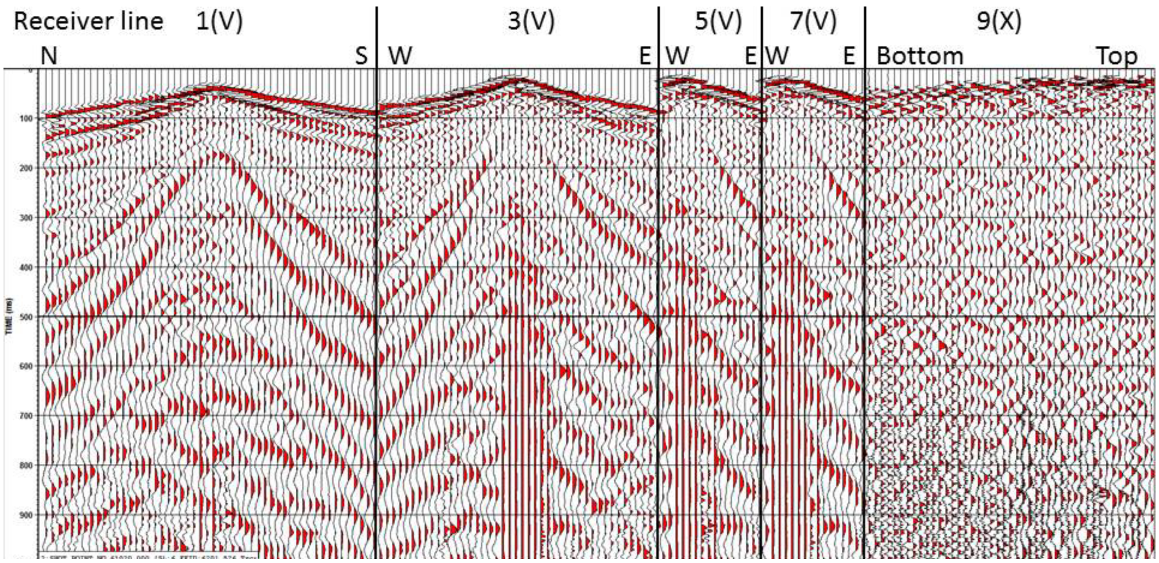

FIG. 2. Example of dynamite gather for shot 6102 (file 620) with 200 ms AGC applied. Lines 1, 3, 5 and 7 are the vertical components of the surface receivers; line 9 shows the X component of the down-hole array before re-ordering and rotation.

THE SECOND SURVEY

This survey was conducted after the casing was re-cemented to surface to check the coupling of the near-surface down-hole geophones. In this case two short lines were laid out crossing at the well, with only 16 geophones on each line to provide some quality control and comparison to the earlier survey. These lines were roughly coincident with lines 1 and 3 of the first survey.

The thumper was not used at many shot locations due to time constraints, and unfortunately there were no repeated shot locations between the two surveys. However, the shotpoint 80m west from the well was sufficient to allow reliable rotation of the down-hole horizontal axes as shown in this paper.

This second survey was also used to test an m-sequence vibrator sweep as a viable source option (Wong et al., 2012, 2013).

THE DOWN-HOLE GEOPHONES

The data from the down-hole geophones is of good quality. Figure 3 shows two shot gathers from thumps near the well from the second survey before component rotation. The examples are for vertical (upper) and northward (lower) thumps. For the shear thumps, the hammer strikes the foot at a 45^0 angle, generating both P and S wave energy.

The increase in shear energy on the horizontal elements in the bottom panel is visible as greater coherency on the X and Y axes.

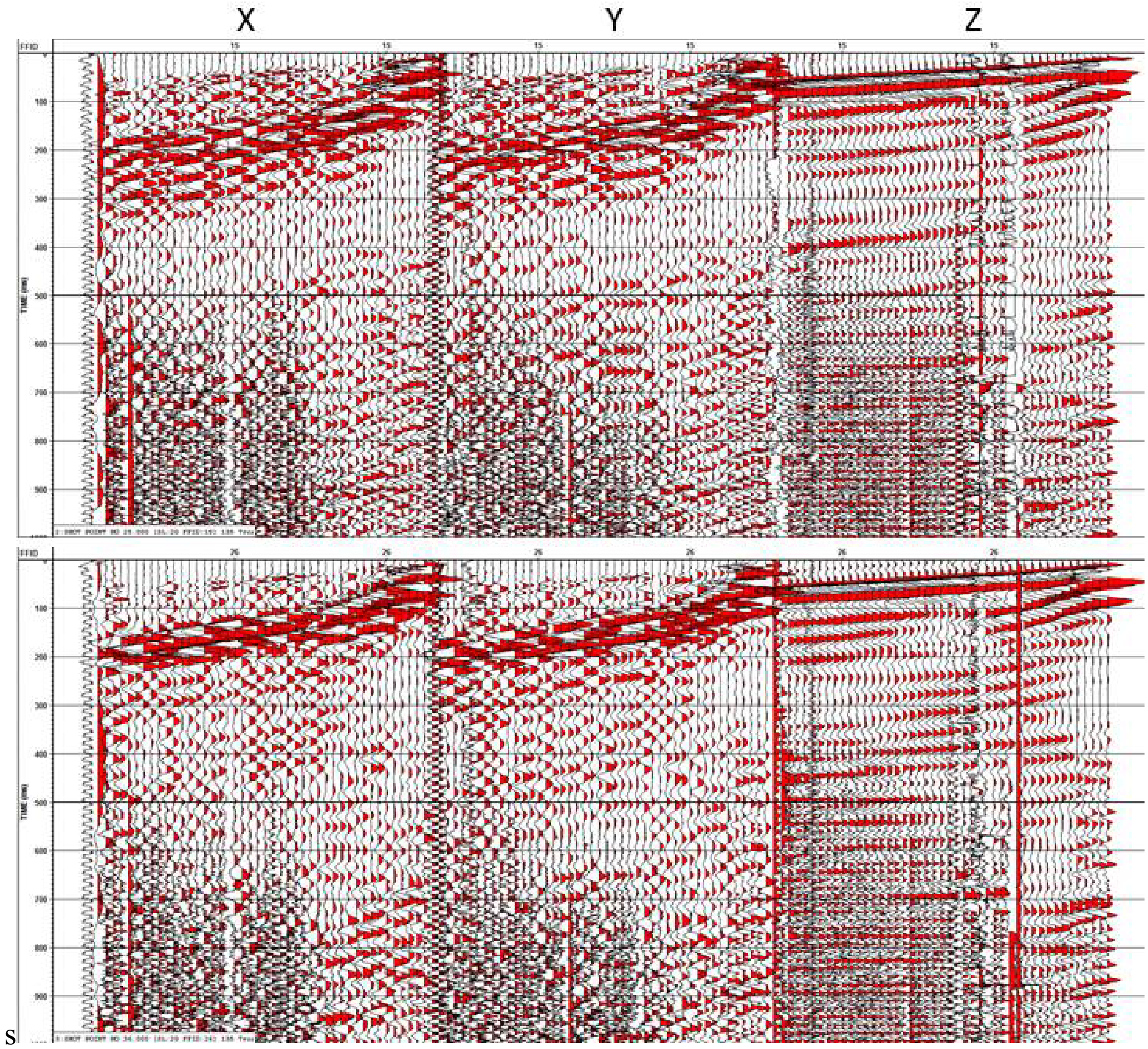

FIG. 3. Sample gathers from the thumper located near the well during the second survey. Upper is a vertical thump (file 15), lower is a thump at 45 degrees towards the north (file 26).

To rotate the horizontal elements in this survey, the vertical weight-drop shot at 80m west of Well 1 was used. Figure 4 shows the result of this rotation. The rotation was done using the Gedco Vista VSP hodogram routine, with the window set to 30 to 80 ms, using the first P-wave arrivals to rotate the data. After rotation, the horizontal axes clearly show the S-wave energy generated by the source. The rotation has aligned the X axis as the radial component and the Y axis as the transverse component relative to the shot-well azimuth. The reduction in direct P-wave energy on the transverse component shows that the rotation is robust. The top panel is from the vertical thump, and the other two are from the thumps at 45^{o} towards the north and the south respectively. Since these shots are oriented north-south with the shot location to the west of the well, the polarization of the energy is the SH mode on the transverse component of the gather. There does appear to be some down-going P to S conversion taking place at a shallow depth which can be seen on the radial component. This is apparently an SV-wave which has the same polarity for all source shot directions since it is derived from the down-going P-wave energy.

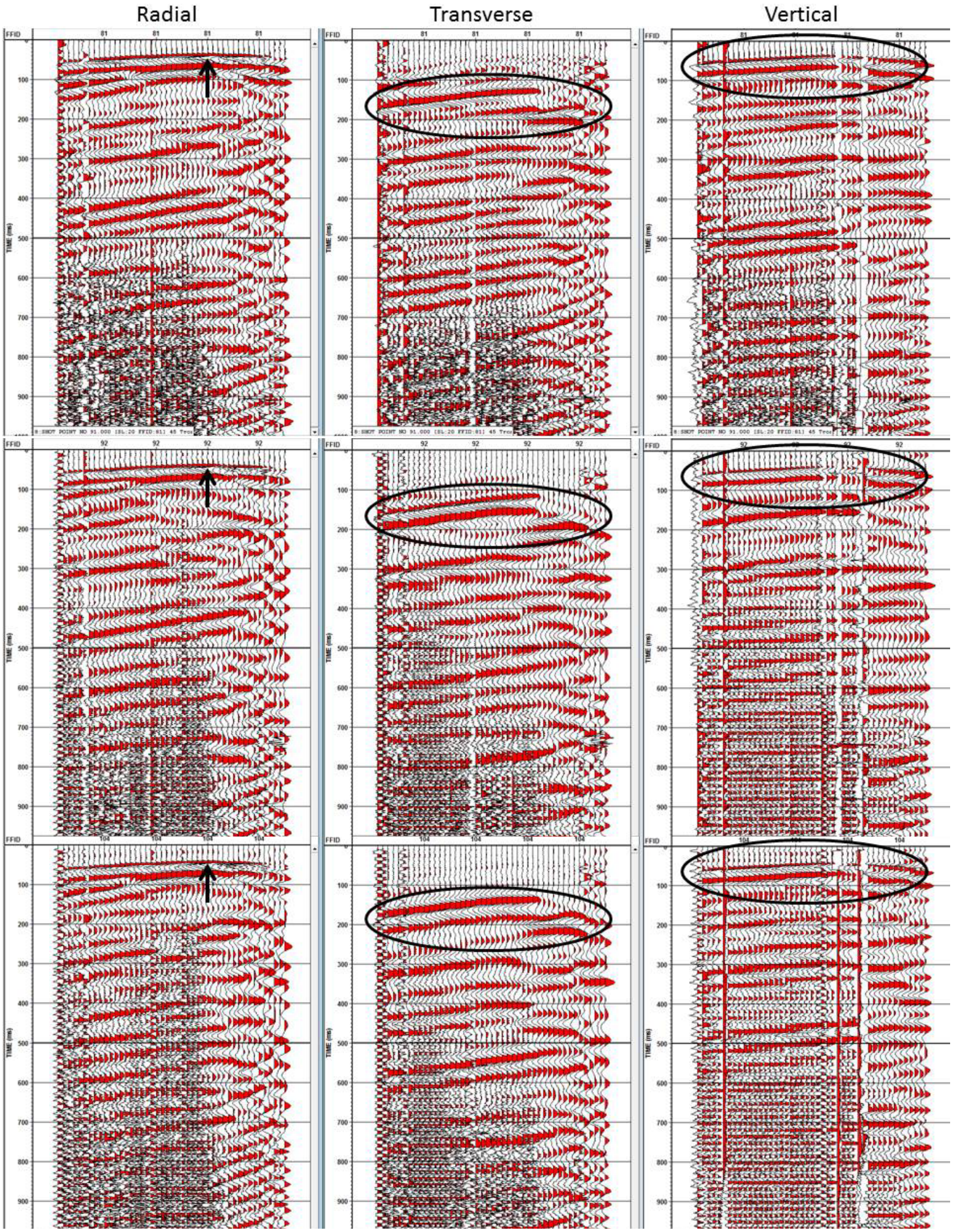

FIG 4. The down-hole gathers for the Vertical thump (file 81, upper), 45^0 northward thump (file 92, centre) and 45^0 southward thump (file 104, lower) for the shot point 80m west of Well 1. The P-wave arrival is outlined on the vertical component, and the S-wave on the transverse component. The arrow on the radial component indicates a P to S conversion..

From these gathers, the energy is clearly shown to be separated between the P and S wave components with the SH-wave dominant on the transverse component. Comparing the transverse components of the 45^0 thumps from Figure 4 yields the plot shown in Figure 5.

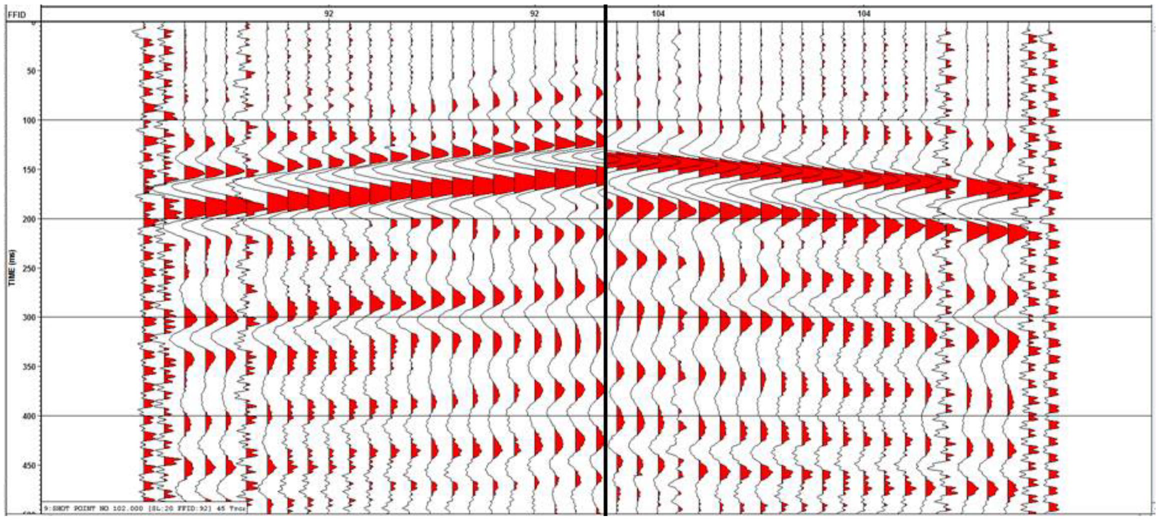

FIG. 5. The two thump directions compared for the transverse component of the down-hole geophones – northwards thump (file 91) on left, southwards thump (file 104) on right (trace order reversed).

This figure shows a clear SH-wave polarity reversal as expected. If the two gathers are scaled then added and subtracted, the data shown in Figure 6 results.

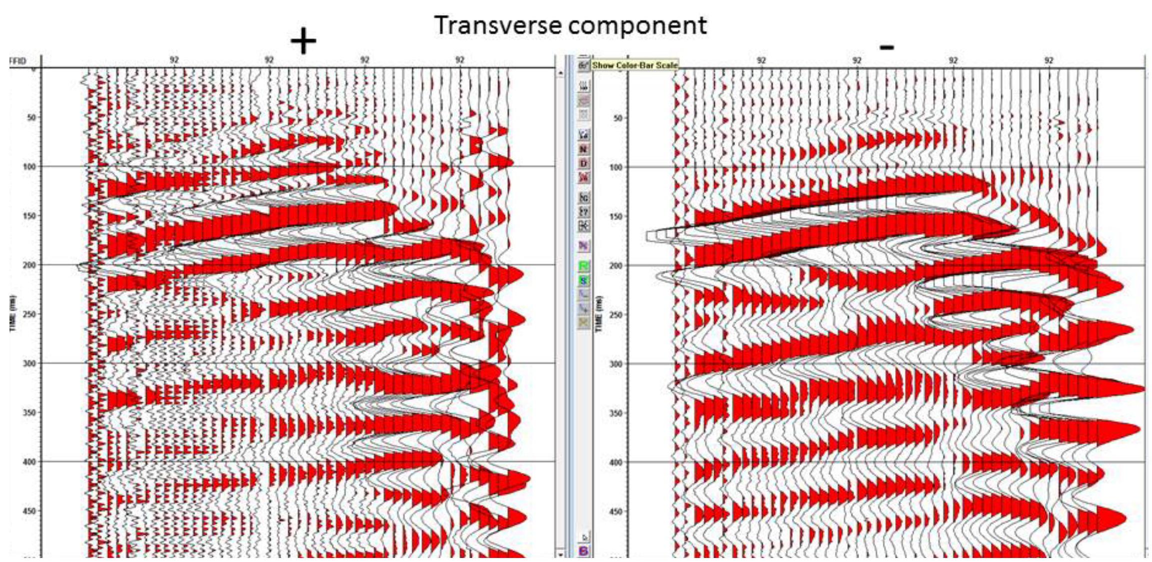

FIG. 6. The result of adding and subtracting the transverse component of the two thump directions from the previous example. The left panel shows the added data, the right shows the subtraction. First 500 ms of data are shown.

The processing assumes that the time break is consistent between the two directions of source polarization. However, as the hammer foot is re-positioned between the two sets, there is a possible small bulk static error. In Figure 7 the two data sets have been aligned in time with a 3 msec static added to the southward thump before the math functions are applied. This time shift was derived from the two gathers by correlating the peak of the southward thump to the trough of the northward thump. There is a noticeable difference in the added data (Fig. 7 left), but less in the difference (Fig. 7 right).

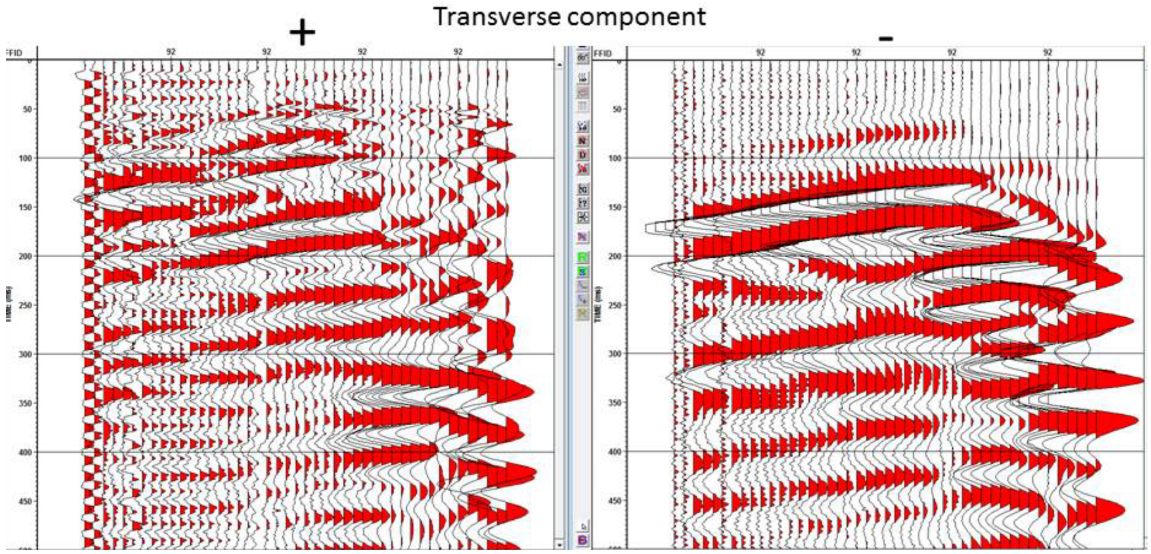

FIG. 7. The same data as Figure 6 with a bulk shift of 3 msec added to the southward thump to align the gathers. First 500 ms of data are shown.

The full set of gathers with the two thumps at 80m west of Well 1 are subtracted and added, with the results shown in Figure 8. The separation of the modes is very good as can be seen from the almost total loss of P-wave energy on the subtracted vertical and radial components, while the SH-mode is enhanced. The opposite holds true for the added gathers. These gathers were scaled with a simple trace balance prior to being added and subtracted.

After applying the component rotation to the down-hole geophones, it is possible to examine the near offset shots in more detail. Figure 9 shows a gather from a northward thump near the well. The separation of energy between axes is very good, and the near surface velocity information is easy to determine. The measured values from these arrivals are: P-wave (right panel) 3060m/s; S-wave (centre panel) 623m/s to a depth of 40m then 1530m/s to TD. The depth at which the S-wave velocity change is observed is about the same depth as the P-S conversion previously indicated (Figure 4).

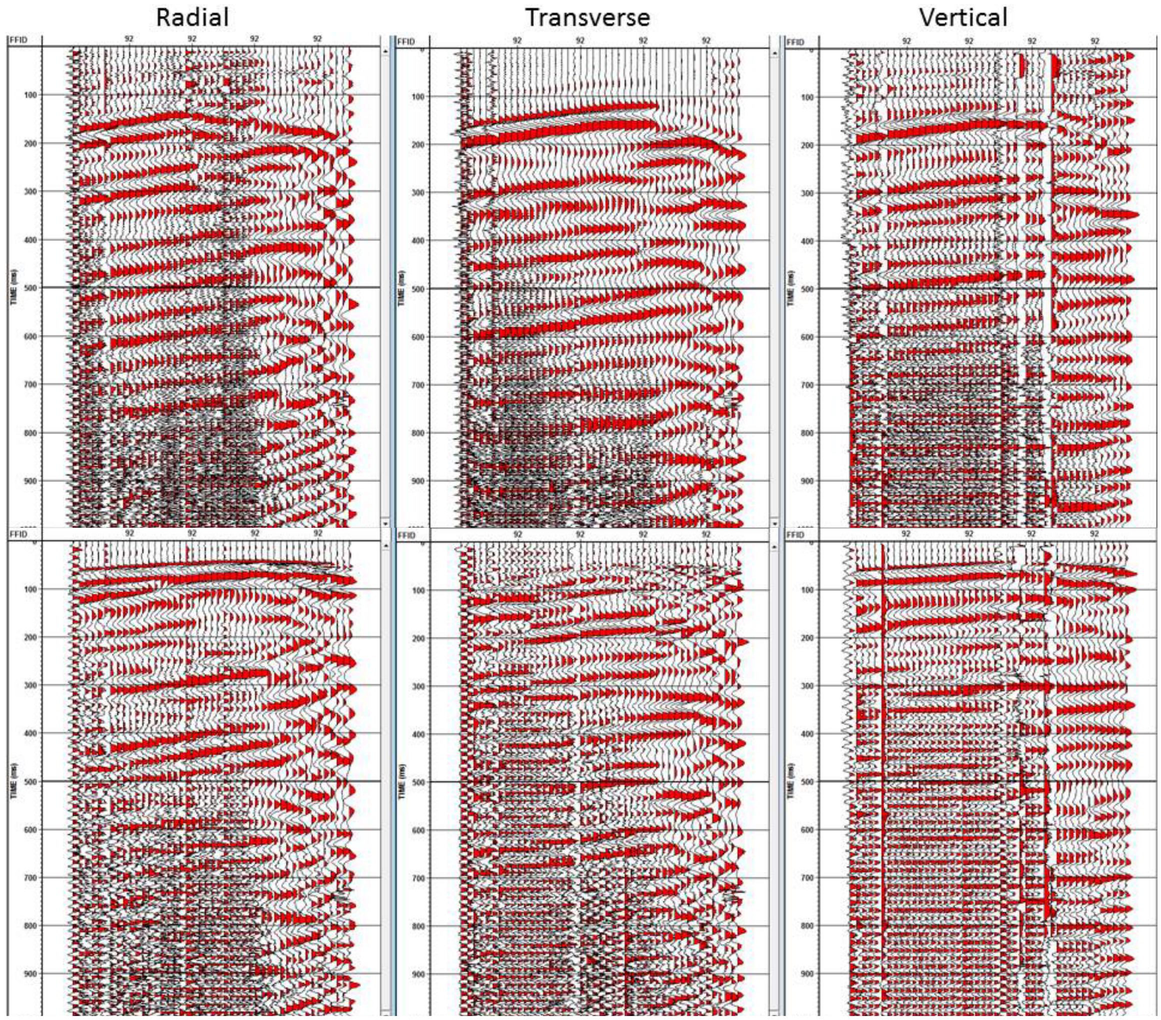

FIG. 8. The full set of subtracted (upper) and added (lower) gathers for the north and south thumps at the shotpoint 80m west of Well 1.

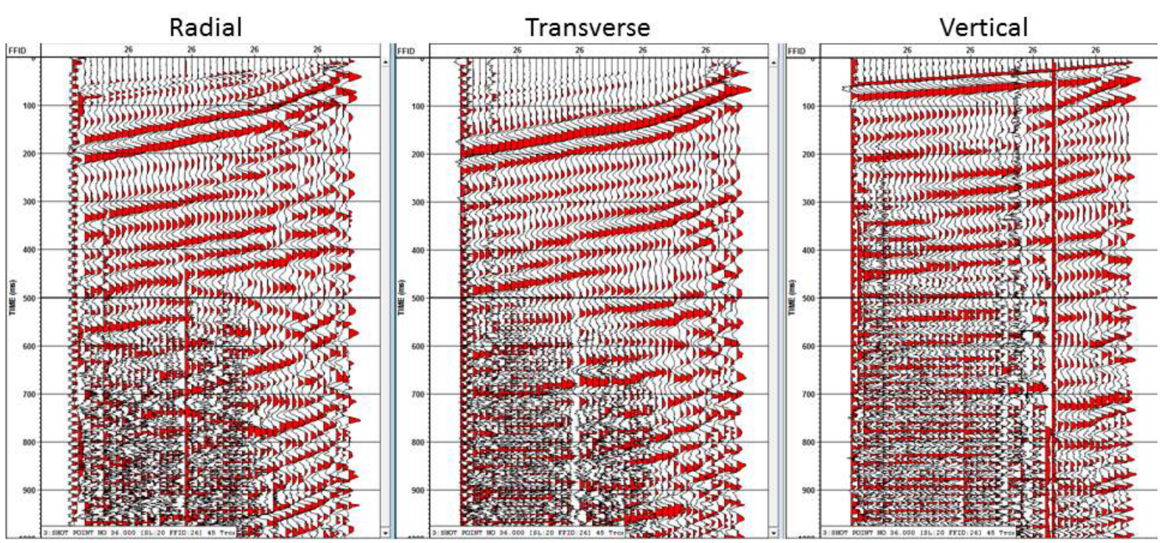

FIG. 9. The gather from a northward thump at a location 2.5m west and 3.7m south of Well 1 (file 26).

Returning to data from the first survey, the same procedure (adding and subtracting) was used for the surface geophones in order to separate the S-wave information. In this case, the shotpoint at the north end of receiver line 1 is used (shot location 14101). Figure 10 shows the data from the north-south geophone line (line 1, 11, 21) for the 45^0 thumps oriented east and west.

In this case the geophones are already aligned with the radial and transverse components known from the planting procedure, with all the geophone case cable entries set to the south, so no further rotation is required.

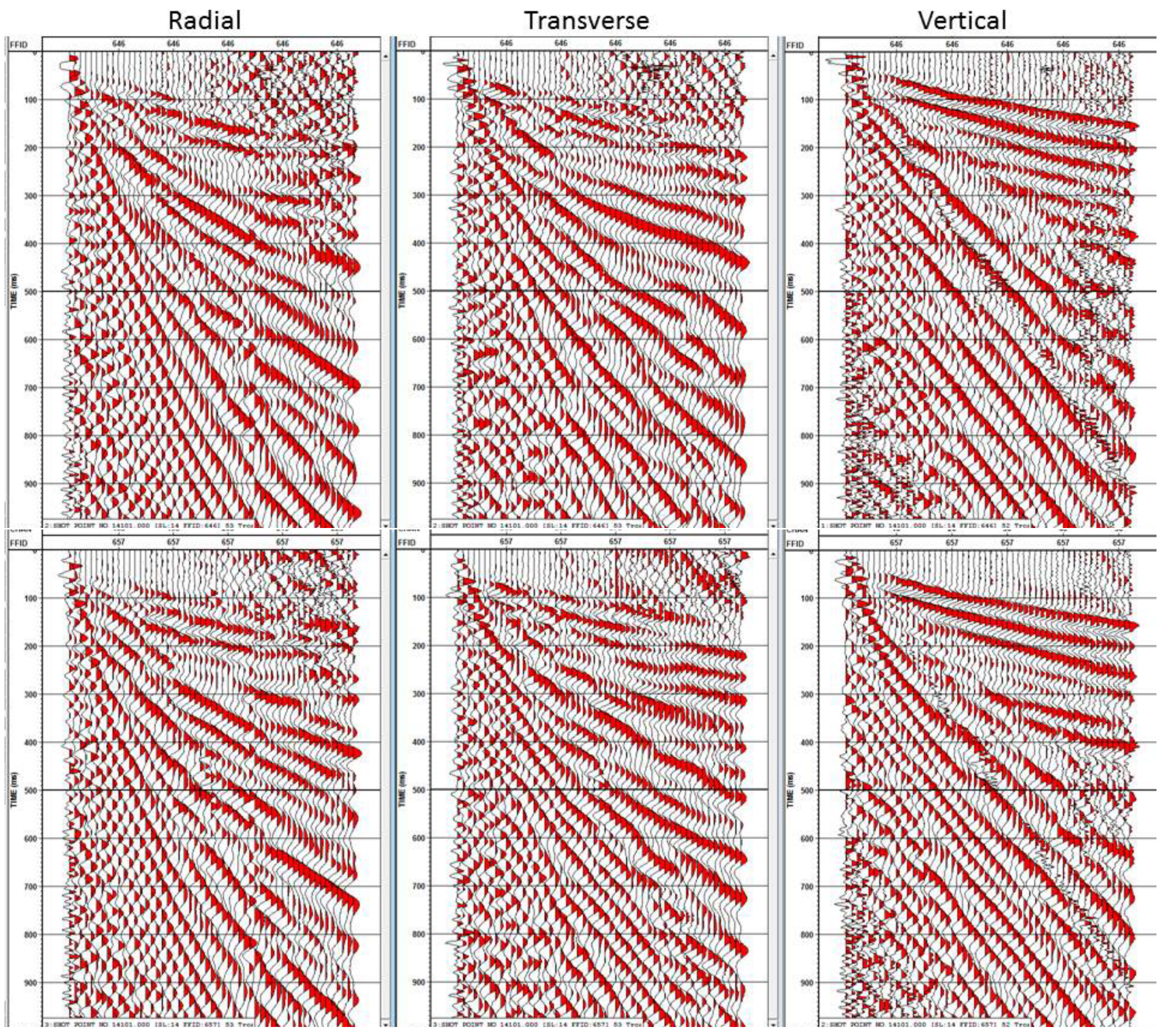

FIG. 10. Surface seismic data from S-wave thumps at shot location 14101. Upper row eastward thump (file 646); lower row westward thump (file 657).

After trace scaling, then adding and subtracting these two files, the results are shown in Figure 11. In this case a 2 ms static correction was made between the gathers to account for the re-location of the thumper foot between the two source points. This was determined from the vertical component data from the gathers. The expected enhancement of the different modes is clear on the vertical component of the added gathers and on the transverse component of the subtracted gathers. This again indicates that the S-wave thumper is indeed providing the desired SH energy.

The velocity from in the first breaks of the vertical component is about 2900m/s across the central part of the gather. This is similar to the down-hole velocity of 3060m/s derived earlier from the data from the down-hole geophones. The S-wave velocity is more difficult to determine because of topography and near surface static variations, but a generalized slope analysis shows the S-wave velocity to be about 1200m/s. This is in the range shown earlier from the down-hole geophones.

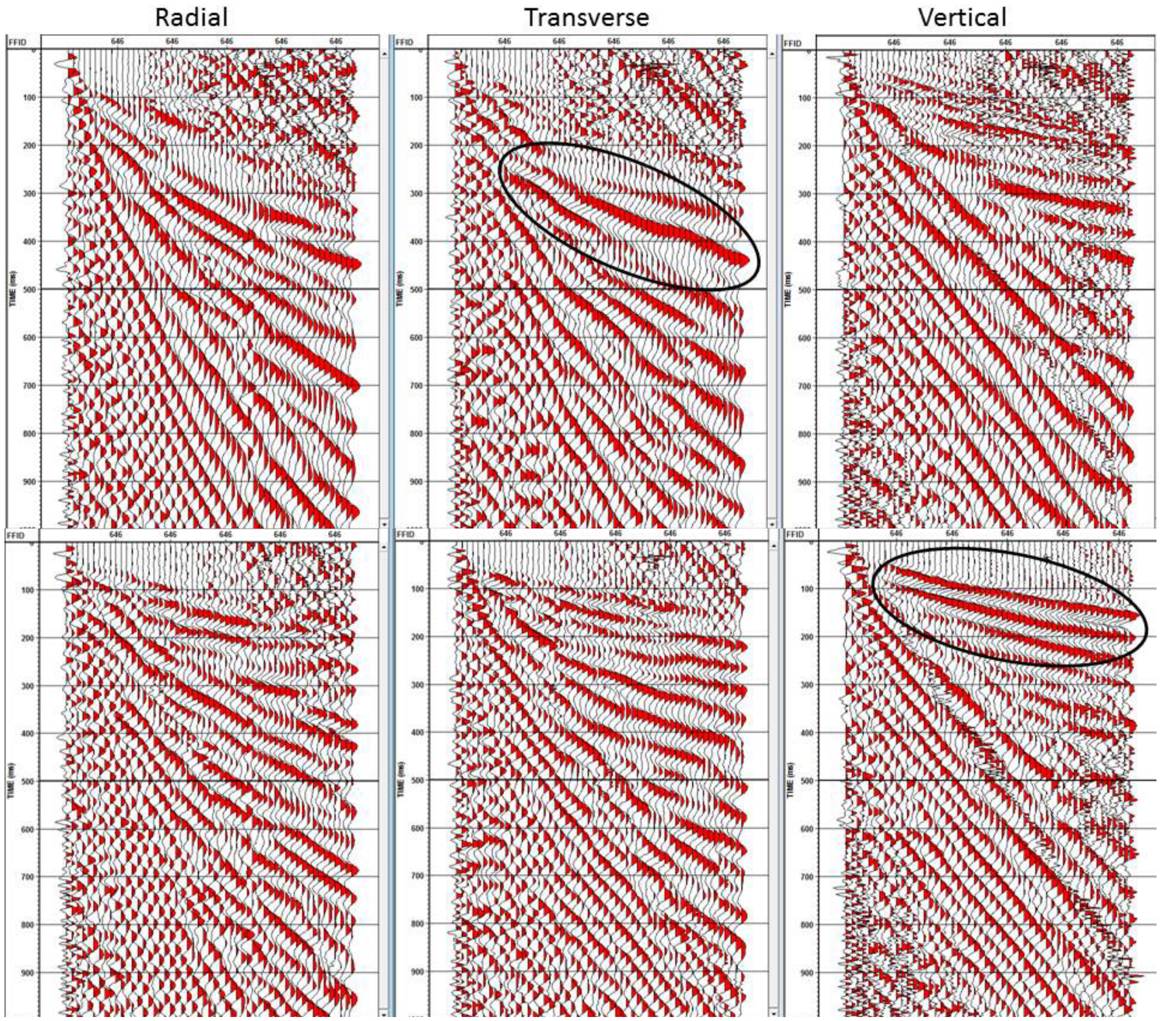

FIG 11. The result from subtracting (upper) and adding (lower) the two previous surface seismic gathers. The enhanced SH-wave is outlined on the transverse component of the subtracted gathers, and the P-wave is enhanced on the vertical component of the added gathers.

CONCLUSIONS

The new shear wave thumper source is providing a good source of shear wave energy for near surface investigations. The subtraction and addition of two 45^0 shots with opposite polarity is proving to be effective in separating the P and S wave energy.

To date only a small amount of data has been acquired, and more projects are planned at the Priddis Geophysical Observatory to further evaluate the source in terms of available offset range and frequency content, as well as attempting shear wave reflection acquisition. All the tests run to date have used a pressure of 750 psi in the nitrogen spring cylinder and show most of the energy is in the range of about 10Hz to 50Hz, with some higher frequency information in the shallow P wave data (up to 150Hz).

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