The Shaganappi geotechnical experiments: 2-D and 3-D multicomponent seismic surveys and geologic logs

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SUMMARY

A set of 3-C seismic surveys were conducted from February to June, 1998 on the west end of the University of Calgary campus. This fieldwork, called the Shaganappi[3] surveys, included two 3C-2D lines shot with a P and S vibrating source and a thumper. In addition, a high-resolution 3C-3D seismic survey, 200m x 300m, was conducted with a mini-vibrator. A shallow well was drilled on the north end of the 3C-3D survey to provide geologic information for correlation with the seismic results. We conclude that viable and useful images can be acquired using these configurations and standard processing methods when scaled down to this smaller geometry. Air-wave noise is a problem on all of the data sets. The P-wave data correlate reasonably well among sections from different sources and geometries. The sections also have an interpretable resemblance to geologic reports from the well.

INTRODUCTION

The Shaganappi surveys were conducted to test shallow, multicomponent seismic techniques targeted at near-surface (environmental and geotechnical) problems. The survey site was selected for its easy-access and proximity to University personnel and facilities. Ultimately, we wanted a site that would be convenient for association with the Geo-Triad ’98 geoscience meeting held at the University between June 15th and 19th, 1998. In addition, it was desirable to have the 3-D seismic coverage extend to the drilling location of the shallow test well also conducted in collaboration with Geo-Triad ’98. The area is furthermore quite sensitive, being inside the city limits and home to somewhat fragile prairie plant and animal life. Regulations (and common sense) require seismic and drilling operations to be a safe distance from nearby homes, buildings, and roadways. Local bylaws also restrict noise levels to modest amounts from 2300hrs to 0700hrs. Careful consideration of all these factors resulted in the selection of the survey site shown in Figure 1. A 2-D test survey was shot in February and May of 1998. Using results from this test line, a 3C-3D survey was designed for the same site.

In order to perform these surveys, the help of the local geoservice community was requested. The community responded very generously, providing 665 geophones, 2000 24-bit channels, vibrator sources, land surveying, field technicians and data processing.

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[3] The survey is named after the four-lane road (Shaganappi Trail) that bounds the west side of the survey area. The word "Shaganappi" has aboriginal origins, and has the meaning "green rawhide".

Figure 1. Map showing the survey area, seismic lines, and well location.

GEOLOGY AND WELLS

The University of Calgary Bowness research well (10-25-24-2 W5M) was drilled in the survey area to evaluate the near-surface geology and correlate well information with 3-D seismic data. It was also conducted as a demonstration exhibit for GeoTriad '98. The well was drilled to a TD of 67.6m and encountered Quaternary sediments. The hole was cased to 61m and the casing cemented – the well is available for further measurements. Following Costaschuk (1998), sediments penetrated by the well over the interval 19.5m to 28m were comprised of coal, loose sand grains, clay, and carbonate rock fragments. A sticky, light-brown mud layer occurs from 28 to 32m and coarse clastics (sandy gravels and gravelly sands) from 32 to 67.6m. This interval is completely unconsolidated with clastic and carbonate rock fragments likely sourced from outcrops to the west. There was a severe loss of circulation in the sandy gravels from 45 to 46.7m. While the grains themselves have little porosity, the gravels as a whole have high porosities exceeding 40%. Upper sediments may have been sourced from the east via the Laurentide ice sheet.

Previous information (Soodeen, 1988) from a nearby well, the SAIT Training Cross (13-21-24-1 W5M), suggests that the glacial drift extends to a sub-surface depth of 205m. This drift is a mixture of loose sand and gravel consisting of shale and sandstones. The top of the Tertiary Paskapoo formation is thought to occur at 205m and the SAIT well reaches a total depth of 760m. Sandstones, shales, and coals are encountered in the 205-760m interval.

2-D TEST SURVEYS

To select the best location for the 3C-3D, a test survey was performed along a 2-D line running 700m in a north-south direction. It traversed the area eventually selected for the 3C-3D work. Four different types of sources were tested when acquiring this 2-D line. The first source-type used was a Bison EWG-II accelerated-mass weight drop (Figure 2). This source is owned by the Department of Geology and Geophysics at the University. It is a relatively inexpensive, convenient, reliable, and repeatable source that can be fired every 15s. The 3-C geophones used are from the CREWES Project and were connected to a special-purpose 3-C cable (Figure 2). This 3-C cable has three-channel takeouts on one connector that allow rapid and accurate connection of the 3-C geophones.

Three months later the same line was shot using buggy-mounted IVI Minivib sources (Figure 3) provided by NRG Engineering Ltd. These 5200 kg units can be fitted with standard vertical pads (Figure 4a), or shear-wave pads (Figure 4b). Specializing in high-frequency sweeps of 10-550Hz, these units produce a theoretical force of 26.7 kN (6000lbs equivalent weight) using a 140kg reaction mass. Vertical-geophone data were acquired using all three source configurations (P-, SH- and SV-). Details of these surveys are shown in Table 1.

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Figure 2. Acquisition equipment for 2-D test line. Special-purpose 3-C cable (left) uses a single 6-pin geophone connector to ease deployment and eliminate field-connection errors. Bison EWG-II "Thumper" (right) uses an accelerated-mass drop as a source (Sue Miller's dog "Tundra" is shown for scale).

Date	Type	Source type	Source spacing	Receiver type	Receiver spacing
Feb. 18, 1998	2-D (700m)	Bison EWG Thumper	Every 10m on station	40 three component phones	Dual end-on spread 5m station separation
May 14, 1998	2-D (700m)	Mini Vibroseis P, SH, SV	Every 10m on station	151 three component phones	5m station separation
June 18, 1998	3-D	Mini Vibroseis P source	8m station separation. 20m line separation.	665 three component phones	8m station separation, 14m line separation.

Table 1. Summary of 2-D and 3-D surveys at Shaganappi.

Figure 3. Two buggy-mounted IVI Minivib sources were loaned by NRG for work on the 2-D test line (shown) and the 3C-3D survey at Shaganappi. One buggy was fitted with a P-wave pad, while the other was fitted with a shear-wave pad.

Figure 4. IVI Minivib vibrator sources: a vertically vibrating pad (left) for P and P-S surveys and a horizontally vibrating pad (right) for pure-shear surveying.

3C-3D SURVEY DESIGN

The 3C-3D seismic survey was designed with several objectives: a) to have even P-P and P-S fold over a 200m x 300m area, b) to provide good imaging at a 50m depth, c) to use only 665 3-C geophones with no moves nor rolls, and d) to accomplish the full recording as quickly as possible. These objectives led to the following survey parameters:

Receiver interval	8m
Receiver line interval	14m
Source interval	8m
Source line interval	20m
Source & receiver stagger	2m
Patch	16 lines by 40 stations

Table 2. Survey design parameters for Shaganappi 3C-3D

Design of the 3C-3D geometry was performed with the aid of Omni, a software package from Fairchild/SIS. Figures 5 and 6 show the survey design of the Shaganappi 3C-3D. Analysis of the survey was performed to aid in the selection of survey parameters. Again, as the survey was to be recorded using 3-C geophones, it was important to consider not only P-P fold, but also P-S fold. Failure to plan for P-S fold can result in stripy, non-uniform fold coverage for converted waves – even when P-P fold maps show reasonable uniformity (Lawton, 1994).

FIELD RECORDS

Having used four different types of sources on the 2-D test line, we were able to compare the effectiveness of these sources. Field records (Figures 8-11) immediately show that source airwave and ground-roll dominate the raw data. Even after applying an f-k filtering to these shot records, the signal-to-noise ratio remains very low. An air-noise suppressing geophone, currently under development at CREWES, could significantly enhance these records.

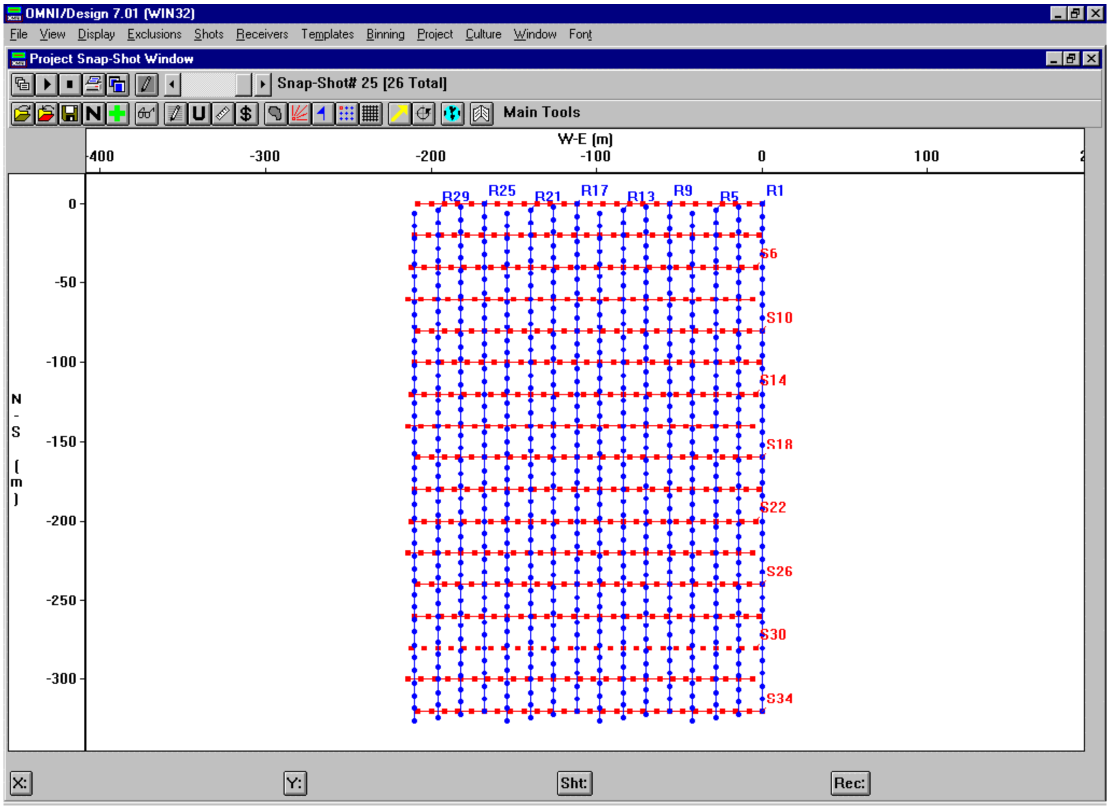

Figure 5. Shot / receiver layout for the Shaganappi 3C-3D survey.

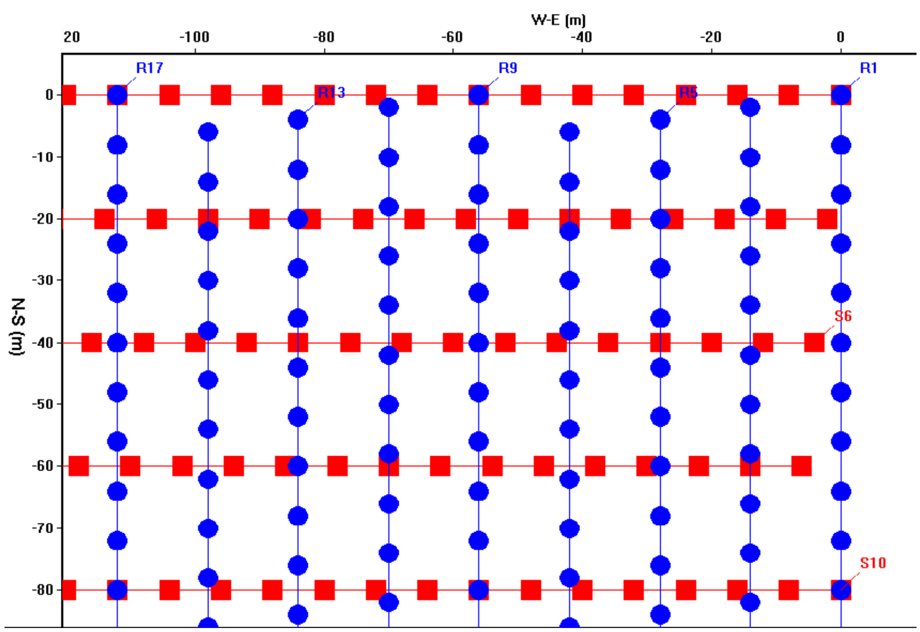

Figure 6. Close-up view of the survey origin. Note how the receivers (circles) and shots (squares) are staggered 2m from line to line.

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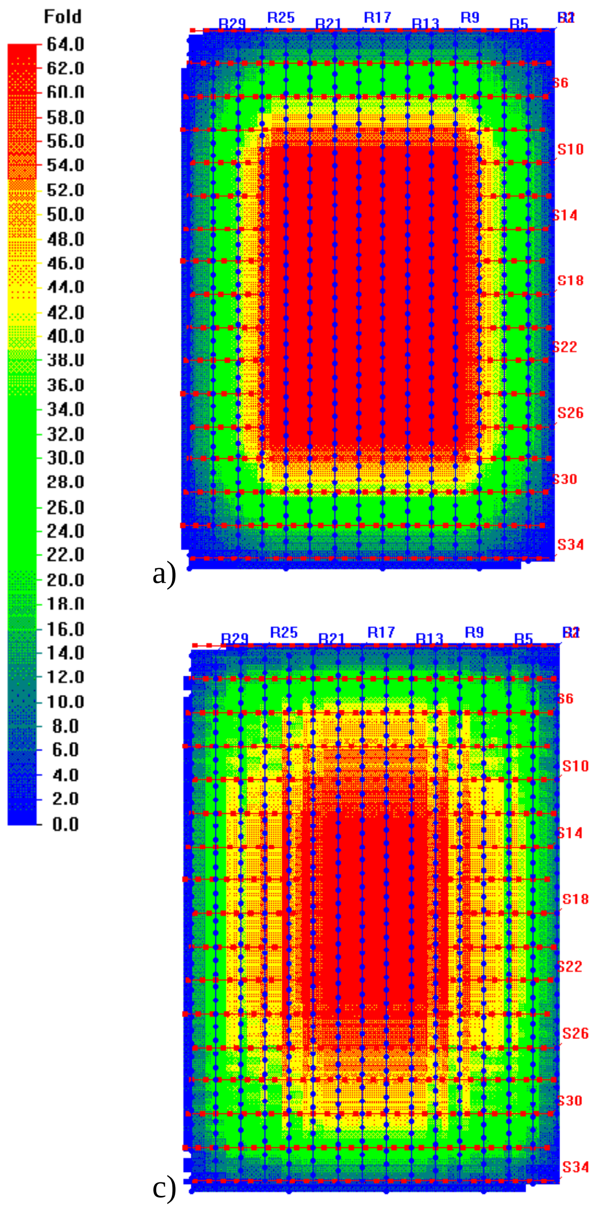

Figure 7. Fold maps for the Shaganappi 3C-3D seismic survey. a) shows conventional P-P fold distribution. Converted-wave fold is shown for b) Vp/Vs=2, c) Vp/Vs = 3, and d) Vp/Vs = 4.

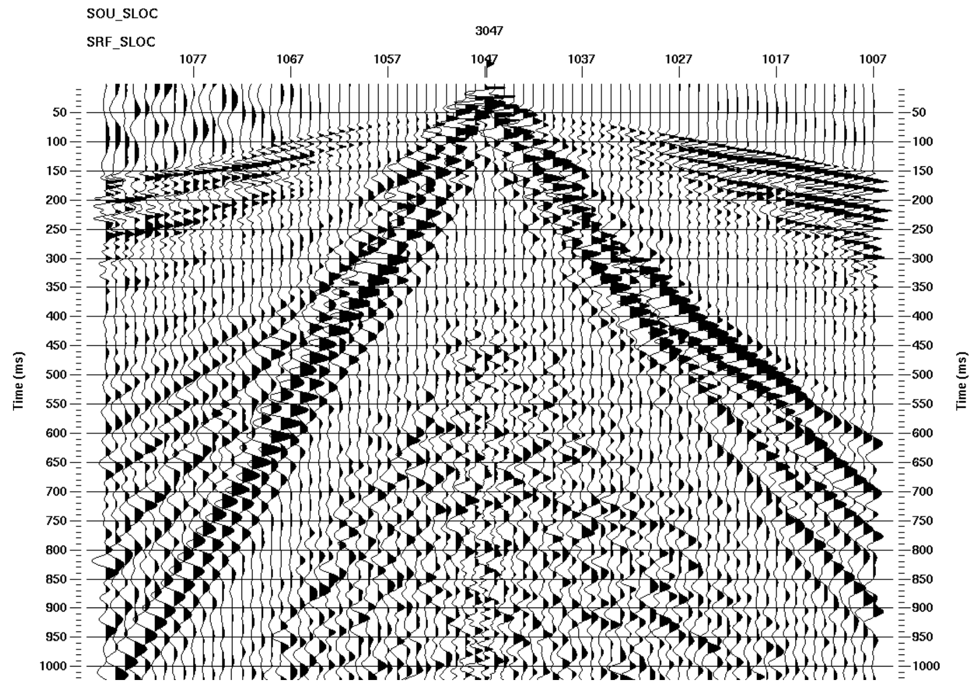

Figure 8. Vertical component shot gather composite from two "thumper" shots at location 1047 on the 2-D test line. Traces are separated by 5m, and the entire spread extends 400m. A 500ms AGC was applied for display.

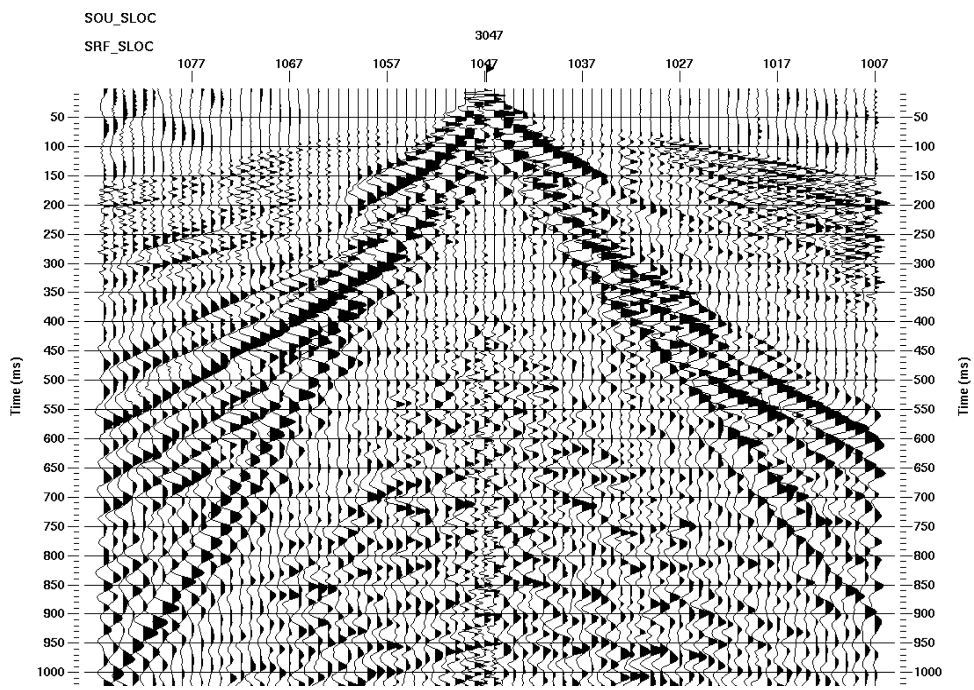

Figure 9. Radial component shot gather composite from two "thumper" shots at station 1047 on the 2-D test line.

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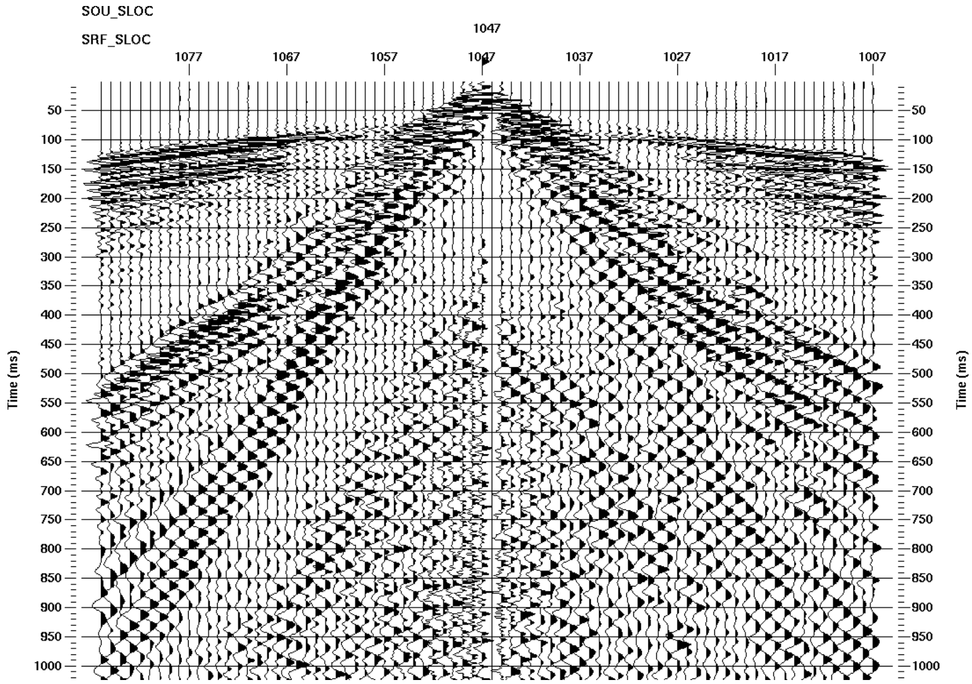

Figure 10. Vertical shot gather from P- wave "Minivib" source at station 1047 of the 2-D test line.

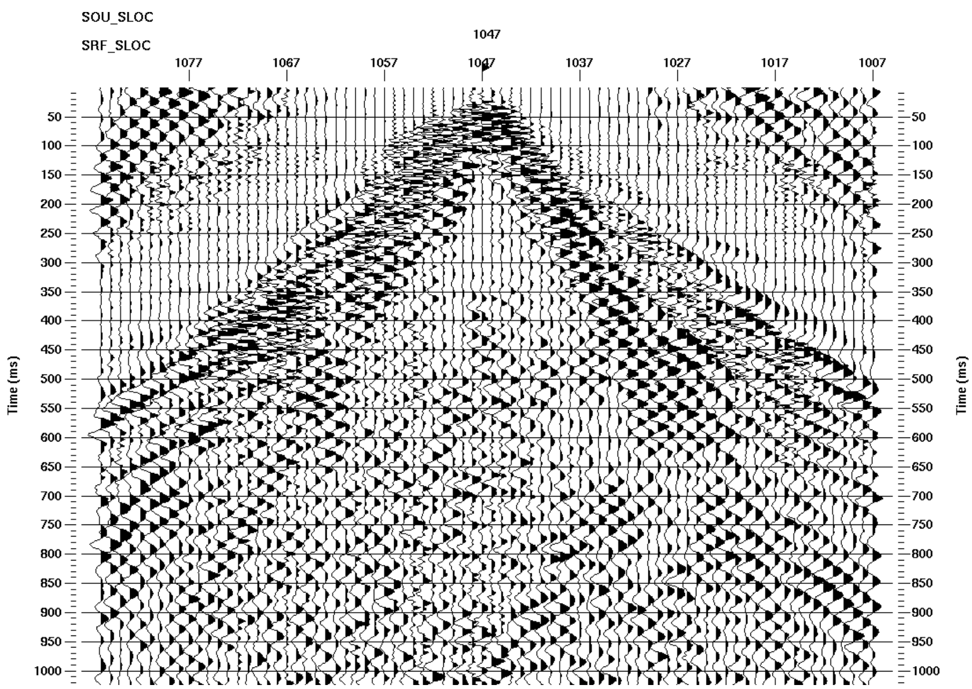

Figure 11. Transverse shot gather from SH- wave "Minivib source at station 1047 of the 2-D test line.

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PROCESSING / RESULTS

The seismic data from the 2-D test line were processed by Han-xing Lu of CREWES. Using data from vertical and radial geophone components, P-P and P-SV sections were obtained (Figures 12-15). The 3-D P-wave data were processed by Mike Werner of Apoterra and by Mark Harrison of Matrix Geoscience Ltd. of Calgary. Mark also processed the P-S 3-D data. Processing flows for each data set appear in Listing 1.

Elevation statics
Predictive deconvolution
TV whitening (vibrator data)
AGC
NMO
CDP Stack
F-X deconvolution
Bandpass filter
Trace mixing (vibrator data)

Listing 1. P-P processing flow for 2-D surveys (Han-xing Lu, CREWES)

Median trace-trace filtering
Predictive deconvolution
Refraction statics
AGC
NMO
Asymptotic conversion point stack
F-X Deconvolution
Bandpass filter
Trace Mixing

Listing 2. P-SV processing flow for 2-D (Han-xing Lu, CREWES)

Spiking deconvolution
Bandpass
AGC
Elevation statics
NMO (preliminary)
Surface consistent residual statics
NMO (final)
Stretch mute
Trim statics
Stack
FXY filter
Omega-X FD Migration

Listing 3. P-P processing flow for 3-D (Mike Werner, Apotera)

Rotate Horizontal Components into Radial/Transverse directions
Extract Radial Data
Amplitude Recovery: Spherical divergence correction
Surface-Consistent Deconvolution
TV Spectral Whitening
Apply Final Vertical Component Source and Receiver Statics
Residual Receiver Statics from Common Receiver Stacks
Surface-Consistent Statics
Asymptotic Binning, Vp/Vs = 2.75
Converted Wave Moveout Correction
Front-End Mute
Time-Variant Scaling
Asymptotic Conversion Point Trim Statics
Converted Wave Stack
TV Spectral Whitening
3D Phase shift Migration
Bandpass filter
Trace Equalization

Listing 4. P-SV processing flow for 3-D (Mark Harrison, Matrix)

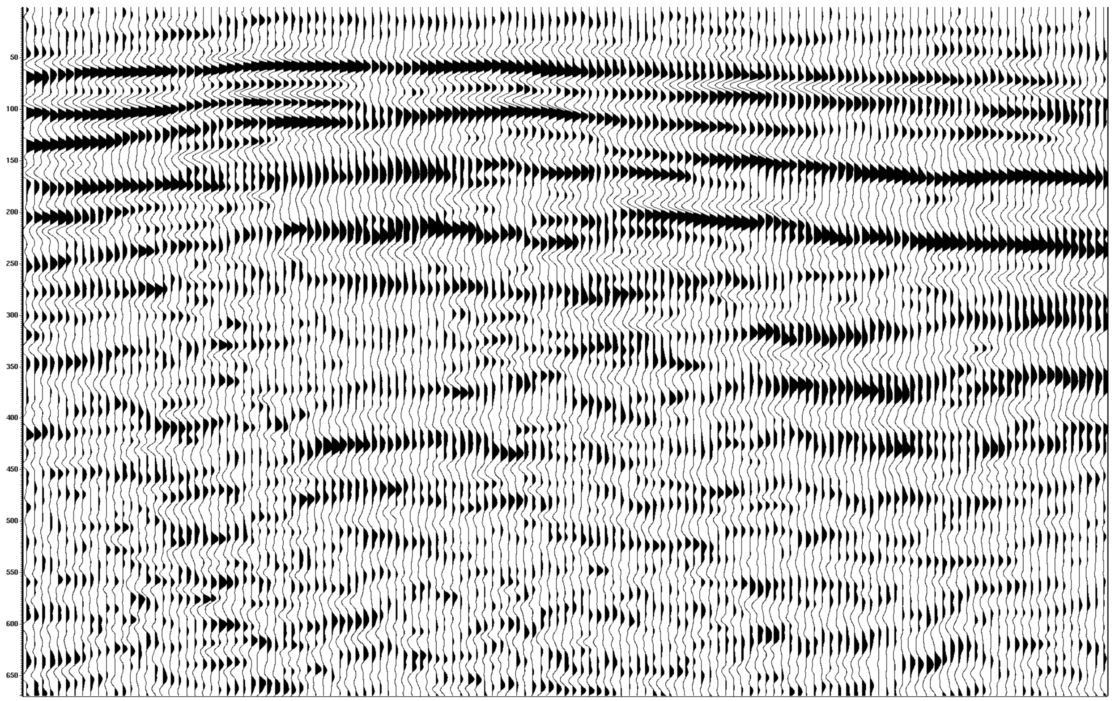

Figure 12. P-P stacked section from the 2-D survey acquired with a thumper source. This section shows stations 1051 (North / left) down to station 1000 (South / right).

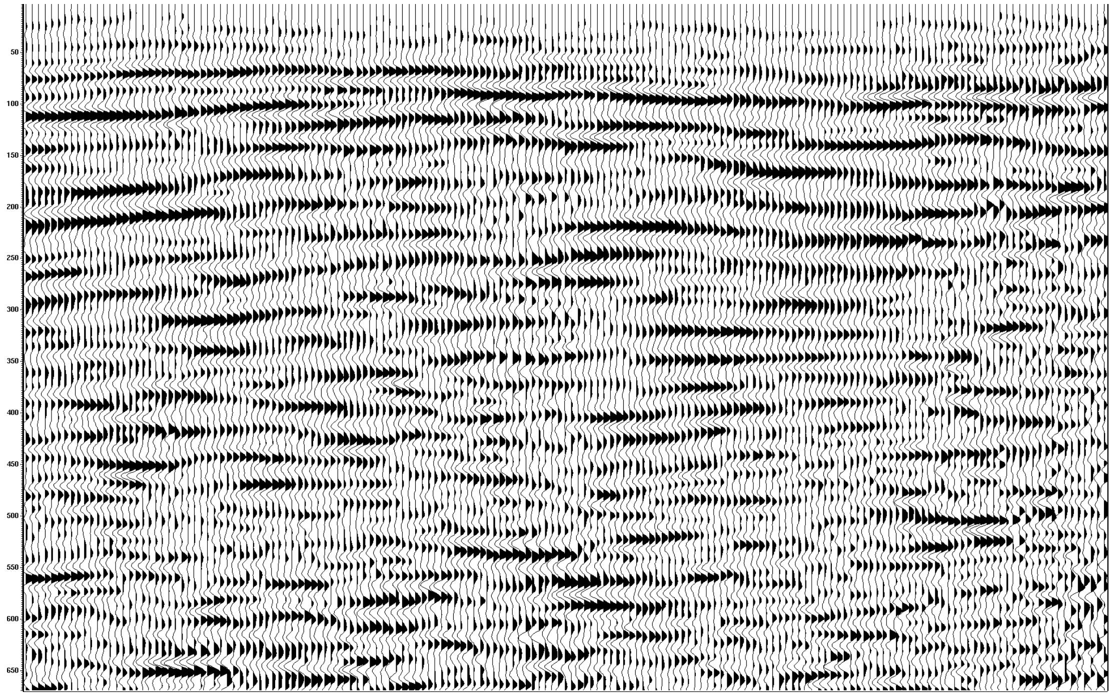

Figure 13. P-P stacked section from the 2-D survey acquired with the Minivib P-wave source. This section has the same end-points as the 2-D section in figure 12.

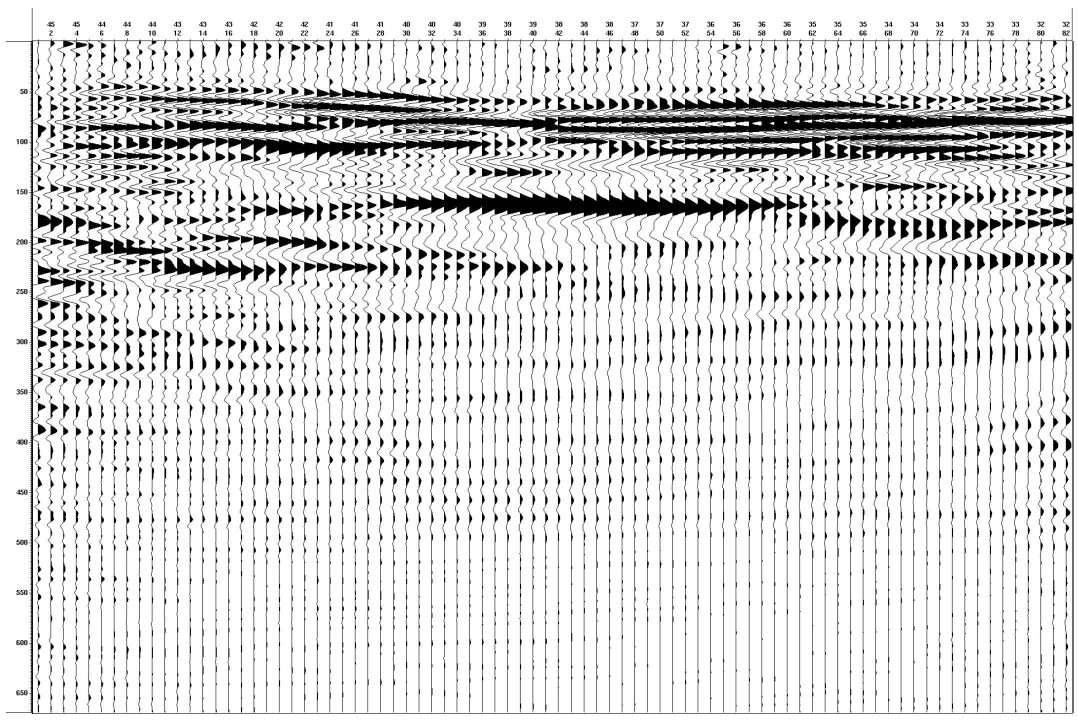

Figure 14. P-P migrated section from the 3-D survey acquired with the Minivib P-wave source. This section has the same end-points as the 2-D section in figure 12.

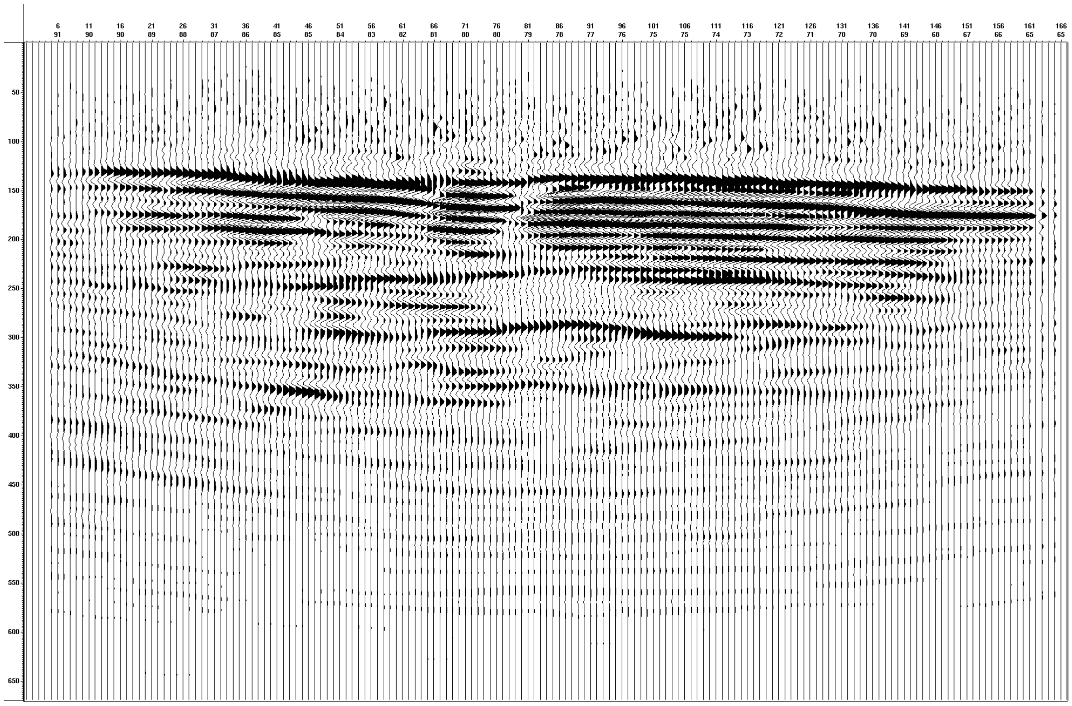

Figure 15. P-P migrated section from the 3-D survey acquired with the Minivib P-wave source. Data were stacked into higher resolution (lower fold) 2m x 2m CDP grid. This section has the same end-points as the 2-D section in figure 12.

INTERPRETATION

We are early stages of our interpretive effort with respect to these data, having received the processed sections in November, 1998. However, we first attempt a correlation between the various surveys. Shown in Figure 16 is a correlation for P-wave sections among the different sources and geometries (the 2-D line using the thumper source, mini-vibe 2-D line, and mini-vibe lines extracted from the 3-D volume). There is a rough correlation among the lines with the first major reflector fairly consistently at about 70ms. Using a standard weathering velocity for Alberta of 800m/s, this would correspond to a depth of about 28m. From the well results, we recall that the sticky mud layer was reported to be at 28m-32m depth. Thus, this first major reflecting event may well be associated with the mud layer. Another consistent event is picked at 90ms. If we use an interval velocity of 1500m/s, below the weathering velocity then this reflector would correspond to a depth of about 45m. Again, this could be the top of the porous gravel layer where we repeatedly lost circulation on drilling. Another good event is at 120ms. Using the same 1500m/s velocity would put this event at a depth of about 67m, or the total depth of the well.

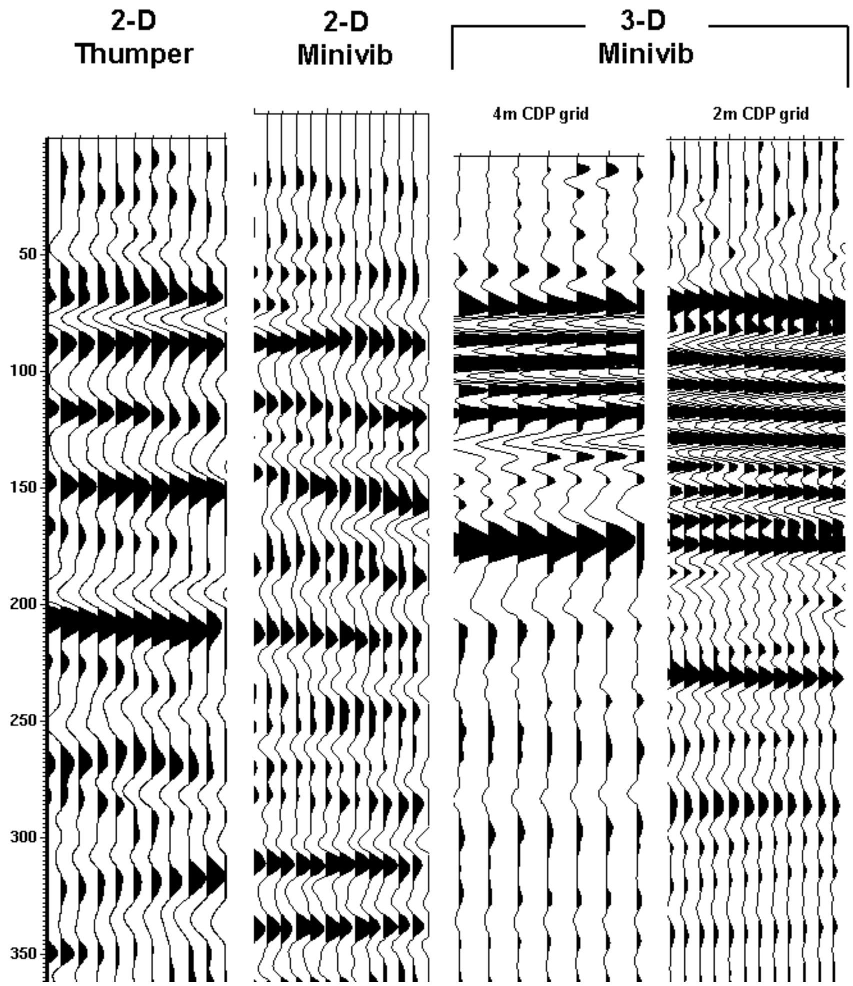

Figure 16. Comparison of P-P sections obtained from the Shaganappi surveys. Each strip shows a 25m section centred on station1007 of the 2-D line.

The radial component of the 3-C data were also processed by Han-xing Lu for P-S waves. The thumper source appears to provide a very continuous set of reflectors. Similarly, the 3C-3D data were processed by Mark Harrison for P-S events. We would once again interpret the first horizon, at about 150ms, as the top of the mud layer at about 30m. We note that this would indicate an S-wave velocity of about 400m/s

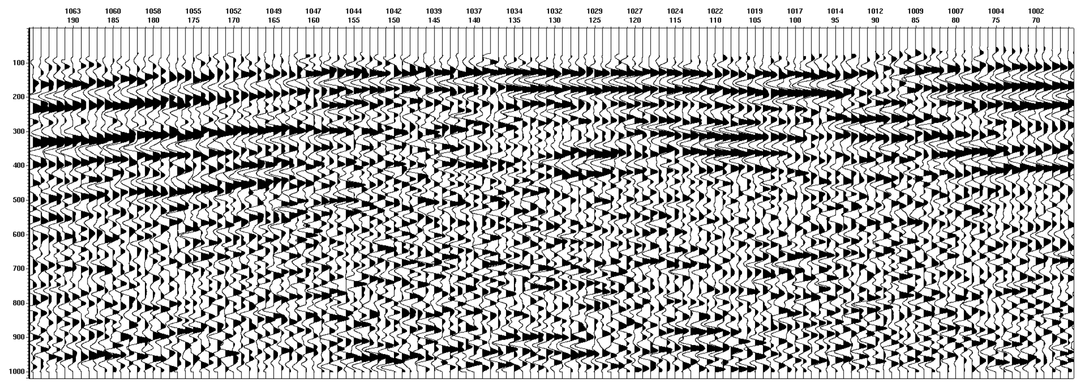

Figure 17. P-SV stacked section from the 2-D survey acquired with the thumper source. This section has the same end-points as the 2-D section in figure 12.

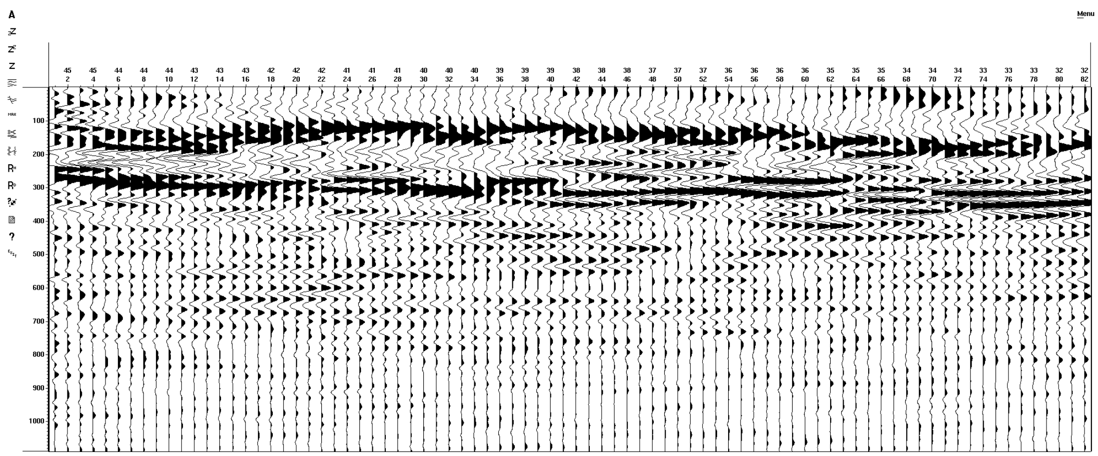

Figure 18. P-SV migrated section from the 3-D survey acquired with the P-wave vibrator source. This section has the same end-points as the 2-D section in figure 12.

CONCLUSIONS

This paper reports the preliminary findings of a set of multicomponent seismic surveys targeted at imaging shallow reflectors. We conclude that viable and useful images can be acquired using conventional shooting and processing techniques scaled down to this smaller geometry. Air-wave noise is a problem on all of the data sets. The P-wave data correlate reasonably well among different sources and geometries. They also have an interpretable resemblance to geologic reports from a well drilled on the north side of the survey.

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