A multicomponent seismic survey at Calgary International Airport, Alberta

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ABSTRACT

A 2.4 km multicomponent seismic line was acquired near Calgary International airport to evaluate Vibroseis® source and receiver parameters for recording P-S data. A series of source tests was undertaken using one and two vibrators, several different sweep lengths and frequency bandwidths. Linear as well as and non-linear sweeps were also evaluated. Reviews of the source tests indicated that 2 vibrators were required to obtain visible reflections from basement rocks (1.8 s P-P time). Optimum source characteristics for P-S data were found to be a non-linear sweep (-3 dB/octave) from 6 Hz to 100 Hz over 12 seconds. Vibrator separation was also tested in a 'walk-away' experiment to evaluate this source parameter on data quality. Conventional 3-C geophones as well as new '3-C nails' were also tested. One test line processed to date indicates P-P reflections with bandwidth over the full spectrum of the source sweep and P-S reflections with bandwidth from 6 Hz to approximately 60 Hz.

INTRODUCTION

The University of Calgary Geophysics Field School was held over a ten-day period in late August 2000 near the Calgary International Airport. The objective was to undertake a P-S survey using a Vibroseis® source and to evaluate optimum source sweeps and receiver parameters for P-S data. Ground penetrating radar (GPR) data were also collected along the seismic line to determine if GPR data could be used to assess the near surface. These results are discussed in another paper (Stewart, et al., 2001). Secondary objectives of both the seismic and GPR programs were to evaluate the shallow subsurface for a new runway development proposed for the airport within the next ten years. Surveying and positioning were undertaken by CREWES staff.

The location of the study area and the seismic line recorded is shown in Figure 1; the line is located on Ministry of Transport land northeast of airport terminal building. The study area is also immediately south of the Crossfield Pool that produces gas from the Cretaceous Cardium Formation. Hence an objective was to undertake a joint interpretation of P-P and P-S data for mapping the Cardium zone.

The seismic line was laid out in a north-south configuration (Figure 1) with a station interval of 10 m. All experiments were undertaken using a static spread with all 240 geophones live for all source tests and production shooting. Litton LRS 3-component geophones with 10 Hz elements were used, with data recorded using I/O System II instruments provided by Veritas DGC Ltd. Some additional tests were undertaken using 15 Geospace 3-component 'nails' that were used in parallel with the Litton geophones as well as clustered in short arrays for comparative purposes.

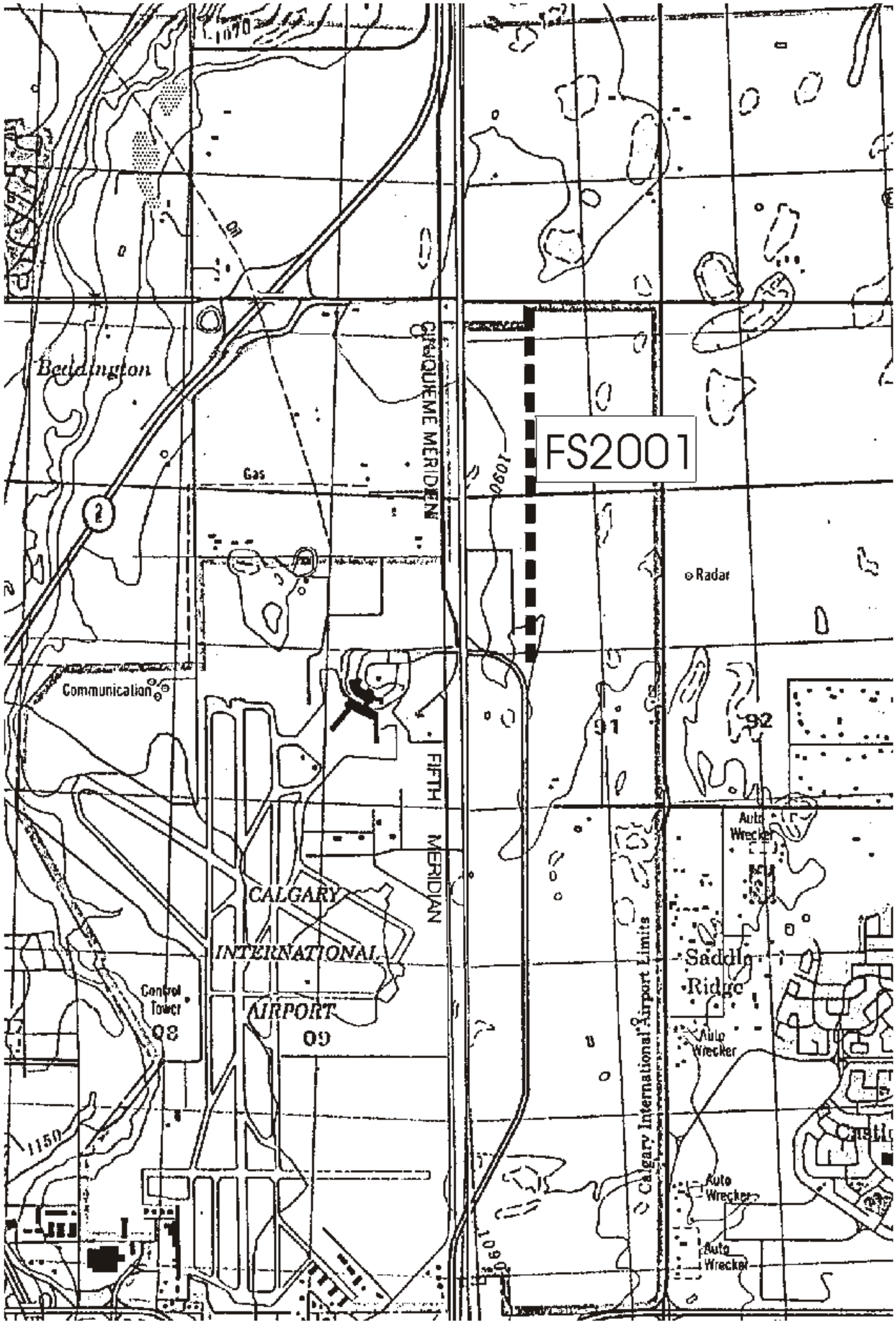


FIG. 1. Location of Field School seismic line FS2001

SOURCE TESTS

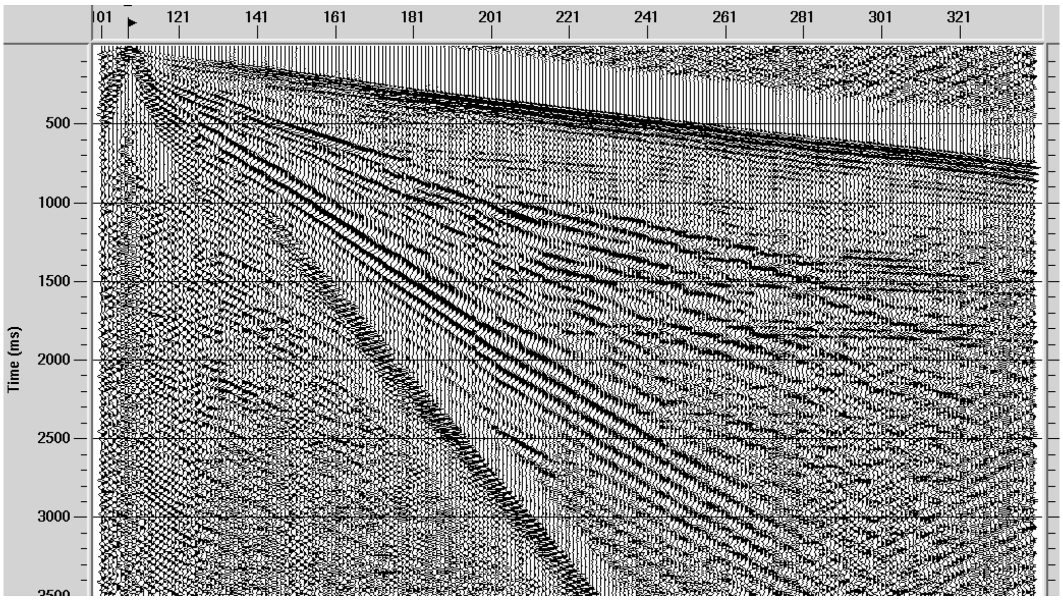
A range of source tests were undertaken to assess various sweep parameters. A single vibrator was used initially, but inspection of records in the field indicated that two units were required for optimum data quality. Subsequent field tests and production recording was undertaken using two vibrators. Source test parameters are listed in Table 1.

Parameter	Values
Sweep bandwidth (Hz)	10-150 10-100 8-100 6-100
Sweep length (s)	6, 12, 16, 20
Sweep type	Linear, +3dB/octave, -3dB/octave, -6dB/octave
Number sweeps/VP	6,12,20
Sweep taper	Cosine taper 0.1, 0.2

Table 1. Source test parameters

Filter tests of initial records showed that frequencies above 100 Hz are not present in the field data, so the upper limit of the source sweep was fixed at this value for all subsequent tests and production shooting. The start frequency initially selected was 10 Hz, but reduced to 8 Hz, then 6 Hz in an attempt to optimize the bandwidth of the P-S data that is known to be limited at the high end from previous studies in Alberta (Stewart et al., 2001). No recording filters were applied during data acquisition. Sweep lengths of 6 through 20 seconds were evaluated and there was not significant improvement in data quality for sweep lengths greater than 12 seconds, so this was adopted as optimum.

Linear versus non-linear sweeps were tested at a range of source locations along the line. A non-linear sweep of +3dB/octave was rejected since the sweep accentuates the high-frequency component at the expense of the low frequency part of the sweep and P-S reflections appeared weak. Linear sweeps and non-linear sweeps with a taper of –3dB/octave resulted in similar records, although the non-linear sweep was favoured since it was thought that this could yield a higher P-S signal-noise ratio. Examples of vertical, radial and transverse components of a test record are shown in Figures 2 through 4 respectively, with raw data in the upper panel (a) and the lower panel (b) displaying the same data after surface-wave suppression and bandpass filter (6 – 70 Hz). All displays have agc applied with a 600 ms operator. The source sweep was non-linear (-3dB/octave) from 6 Hz to 100 Hz and was 12 seconds in length. The record is a vertical stack of 12 sweeps. The vertical component (Figure 2) shows clear first arrivals and the record is dominated by dispersive shot-generated noise and a strong airwave. After noise attenuation, clear reflections are visible across the



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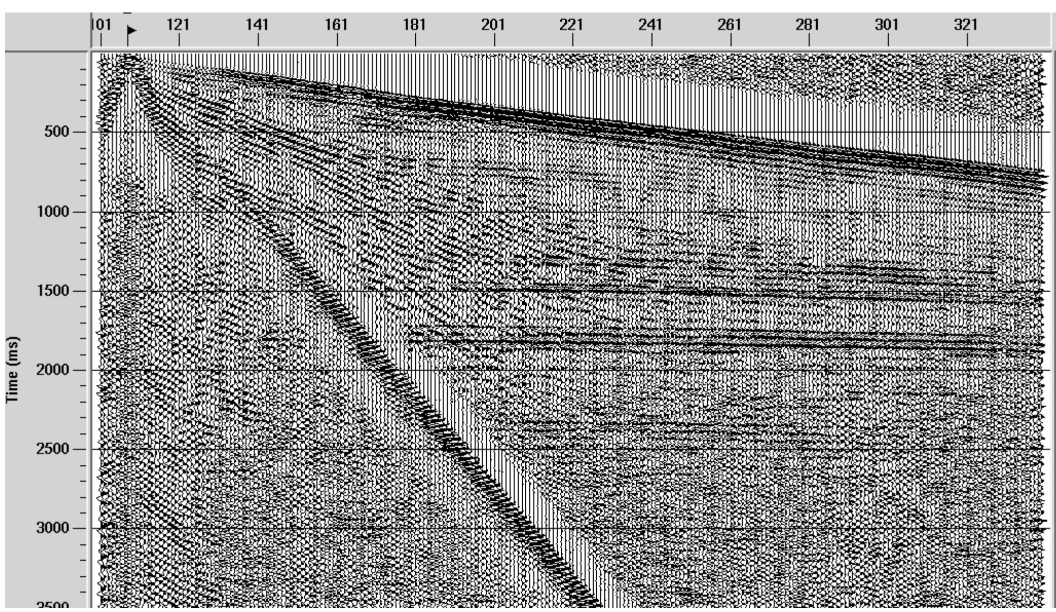

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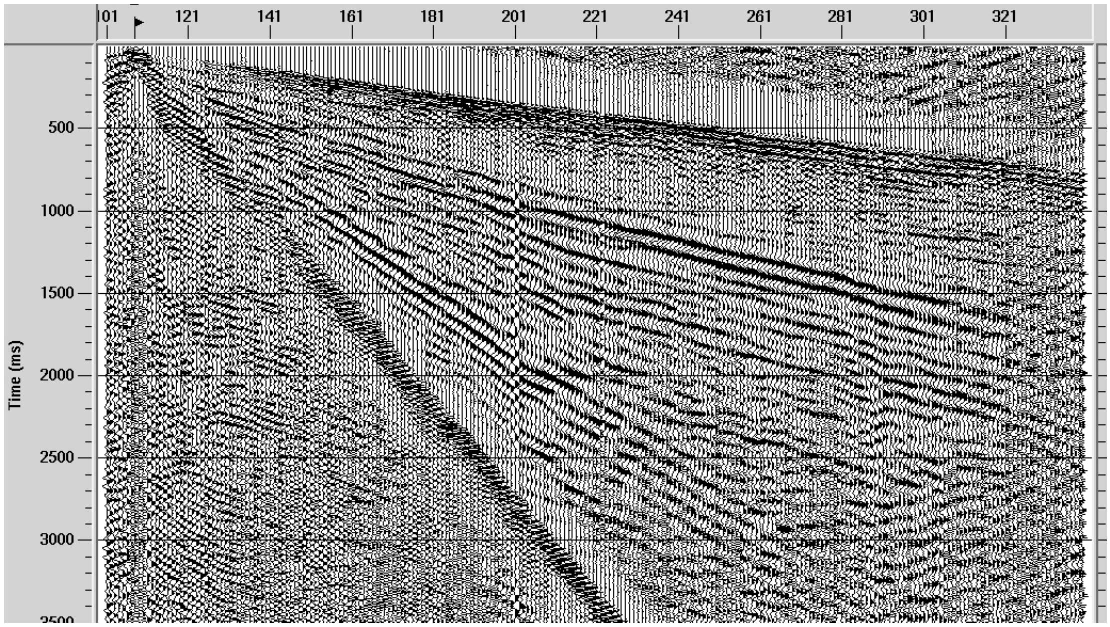
FIG. 2. Vertical component test record. Nonlinear sweep (-3db/octave) over 12 seconds. (a) raw record; (b) record with surface-wave suppression, bandpass filter (6 – 70 Hz) and agc with 600 ms operator.



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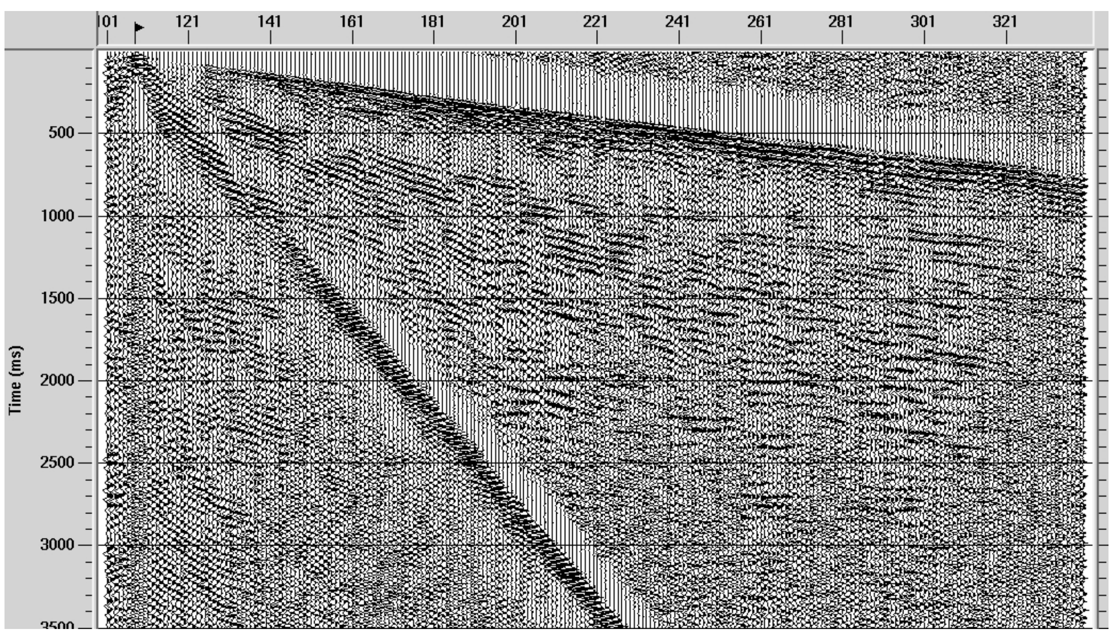

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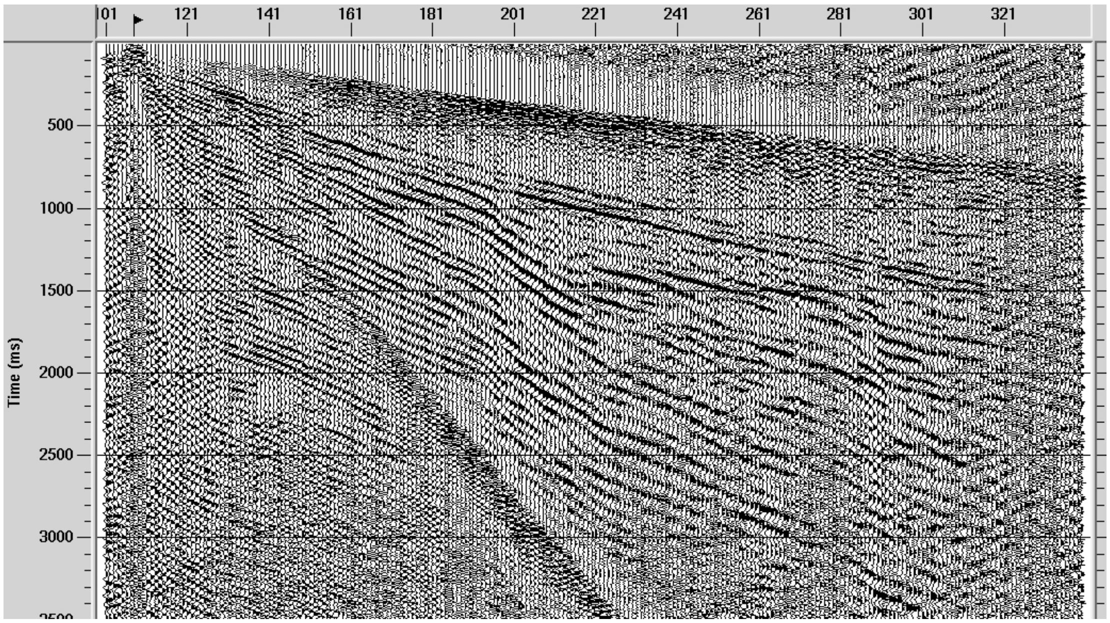
FIG 3: Radial component test record. Nonlinear sweep (-3db/octave) over 12 seconds. (a) raw record; (b) record with surface-wave suppression, bandpass filter (6 – 70 Hz) and agc with 600 ms operator.



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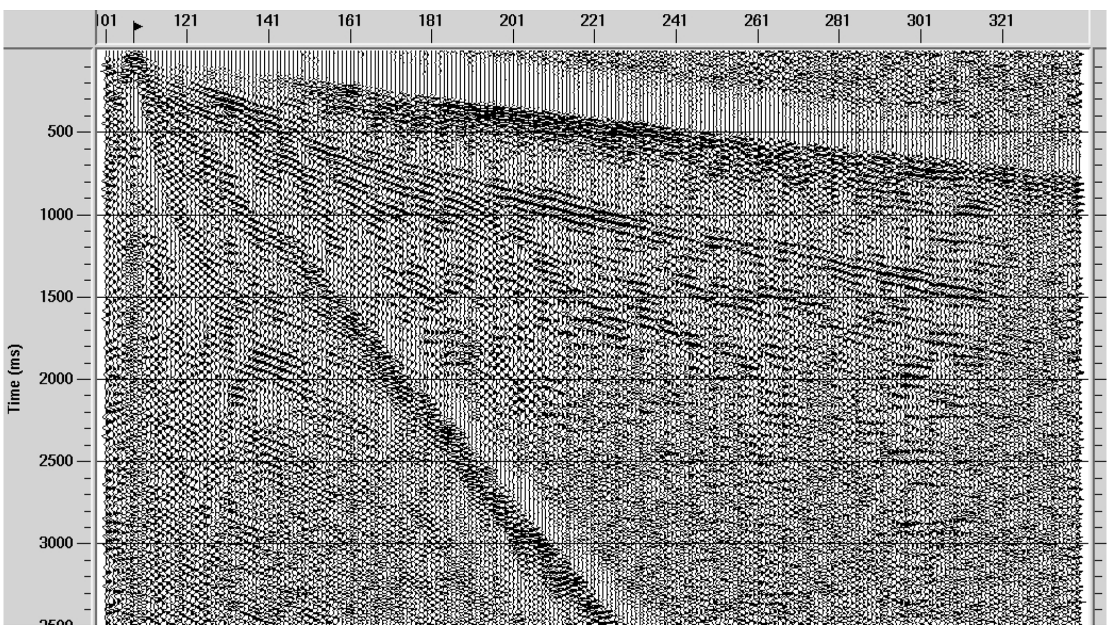


(b)

FIG. 4: Transverse component test record. Nonlinear sweep (-3db/octave) over 12 seconds. (a) raw record; (b) record with surface-wave suppression, bandpass filter (6 – 70 Hz) and agc with 600 ms operator.

record although signal is weak at times later than the airwave arrival. A strong S headwave arrival and source-generated noise dominates the radial component (Figure 3). The noise attenuated record shows a clear P-S event on far offsets (at 1 s), and discontinous P-S events at later times. On the transverse component, there is evidence of a high-amplitude SH headwave (Figure 4a), with the record dominated by Love waves and airblast. After noise attenuation, hints of a P-S reflection are evident at around 1 s, suggesting some shear-wave splitting.

Figures 5 through 8 show comparisons between linear and non-linear sweeps for the same frequency band and sweep length. Figure 5 displays a comparison between the vertical component for linear (Fig 5a) versus non-linear (-3dB/octave, Fig 5b) sweeps for raw records, while Figure 6 shows the same data after surface-wave suppression and bandpass filter. In the raw data (Fig 5), both records are dominated by source-generated noise. After noise suppression, the reflections appear to have higher amplitudes and greater coherency for the non-linear sweep than for the linear sweep. Figures 7 and 8 display similar comparisons for the radial component of the same records, although after noise suppression, there is little visible difference between the linear sweeps (Figure 8a) and non-linear sweep (Figure 8b).

PRODUCTION DATA

Following the source tests, the 2.4 km line was recorded three times. For the first and second production datasets, the source occupied every station and the entire line was live for all shots. This yielded P-P fold that increases linearly to 120-fold at the centre of the line. In both cases, a non-linear sweep (-3dB/octave) from 6 Hz to 100 Hz over 12 seconds was employed, with 6 sweeps summed per vibrator point. Data were recorded in correlated format. The only difference between the 2 datasets was that the sources were centred on the station for the first line, and located at the station mid-point in the second pass. For an additional comparison, the line was recorded a third time (every 4^{th} station only) using a linear sweep instead of a non-linear sweep. .

Results

At the time of preparation of this report, only the first data set had been processed. The vertical component data were processed following a standard processing flow. The migrated section (Figure 9a) is of excellent quality with clear reflections to basement and good bandwidth, particularly in the shallow part of the section. The P-S data were processed using depth-varying common-conversion-point mapping and finite-difference post-stack time migration. Interval Vp/Vs values extracted from the Vp/Vs stacking are shown in Table 2.

The data in Table 2 indicate that Vp/Vs departs only slightly from 2 over most of the section, including the very near-surface interval. This is unusual as high Vp/Vs values are often found in the weathering layer below the water table (Lawton, 1990). Deeper in the section, intervals with higher Vp/Vs correspond with shale-prone strata of the Alberta Group. The migrated P-S section is shown in Figure 9b and shows the best signal/noise in the centre of the line where the fold is highest. Overall, the quality of the P-S data is good. Figure 10 shows P-P and P-S sections correlated

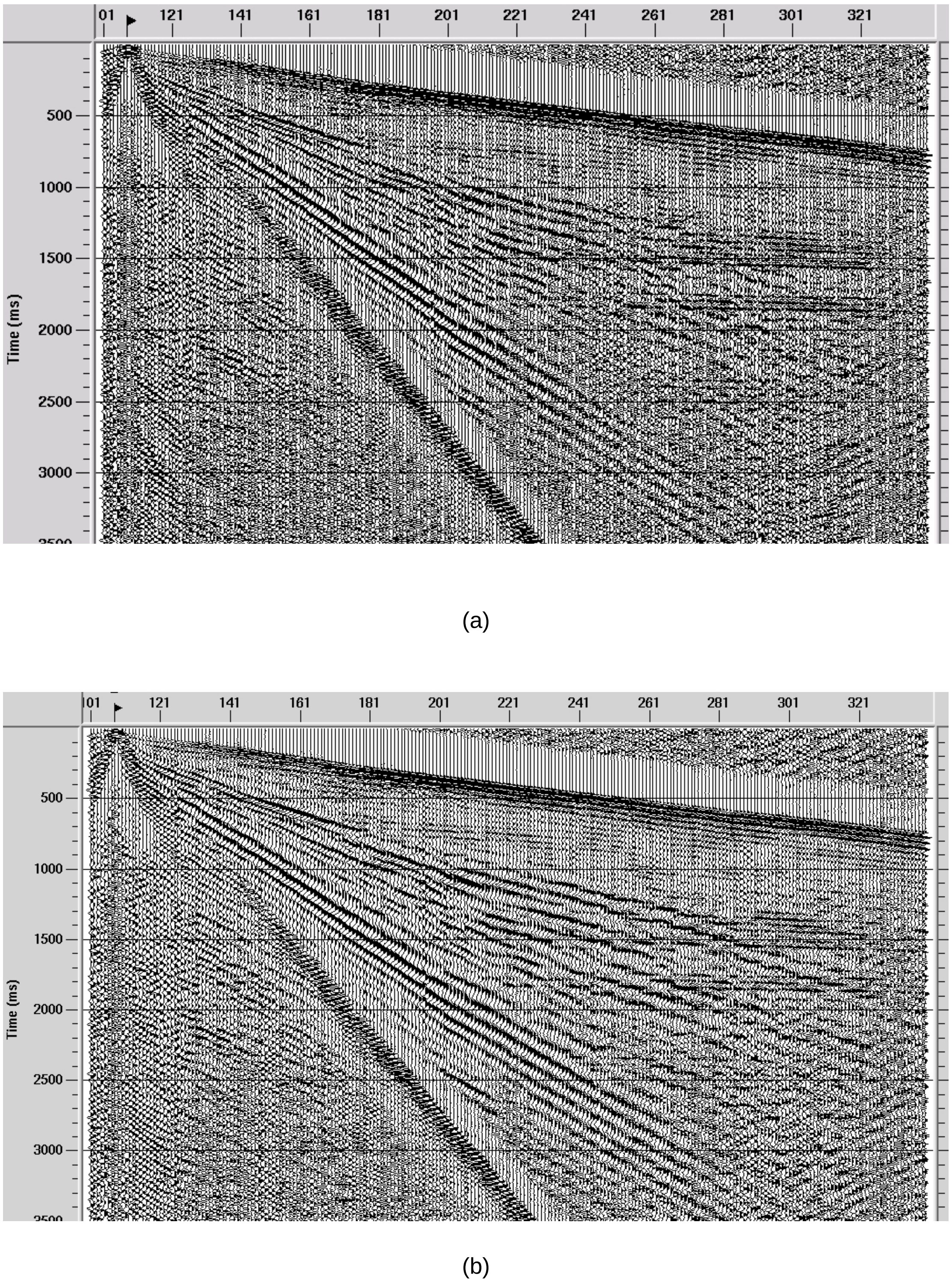
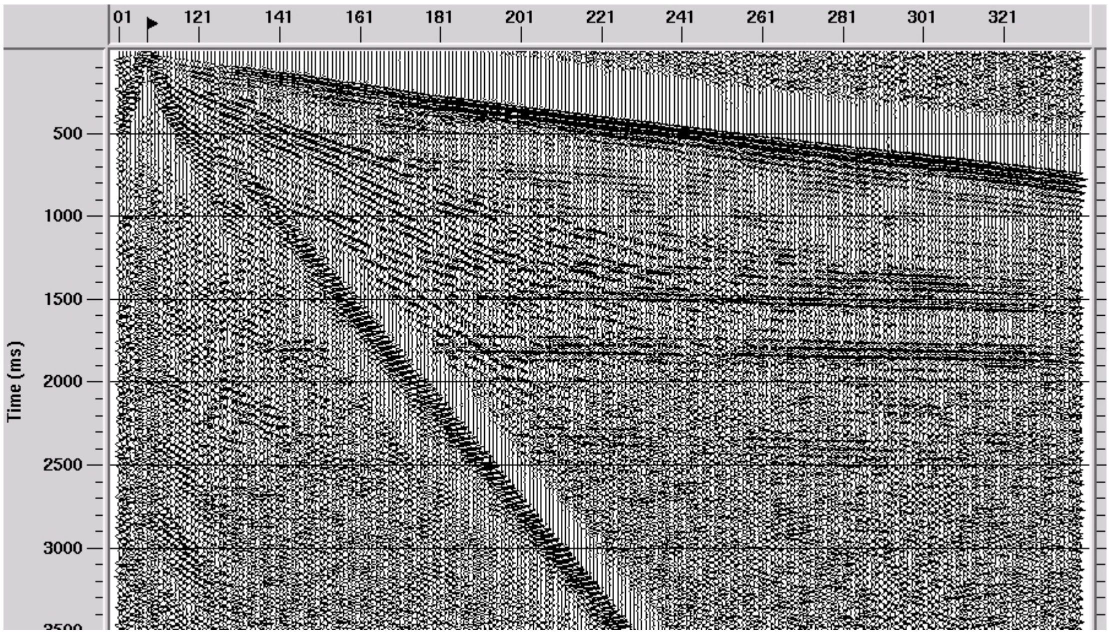


FIG. 5. Comparison of linear (a) versus non-linear (b) sweep for vertical component records. Raw records with 600 ms agc operator applied.



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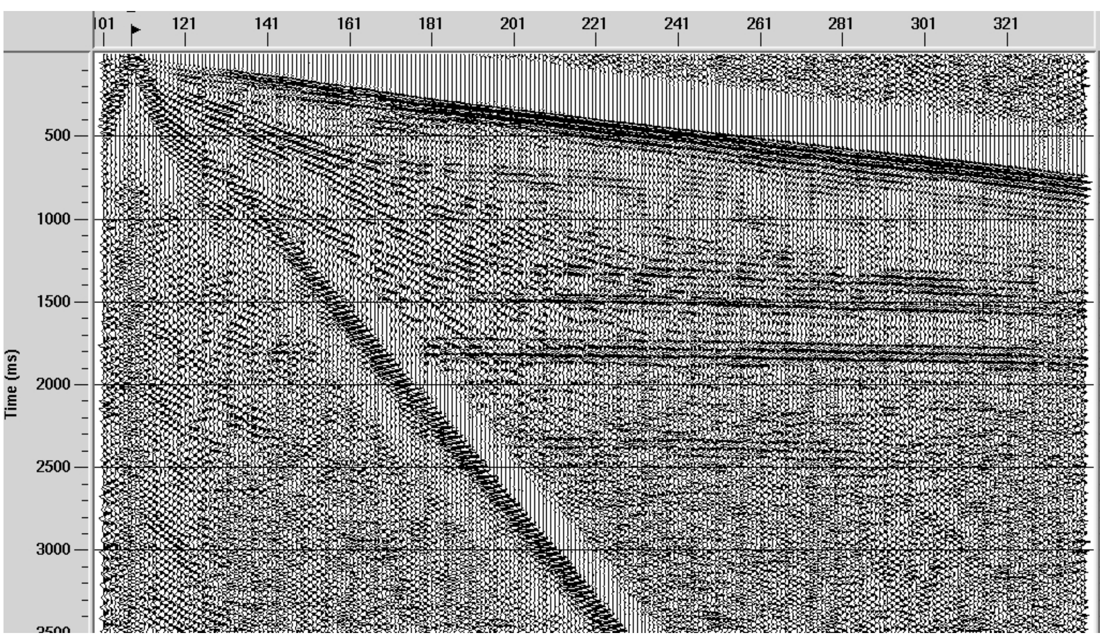
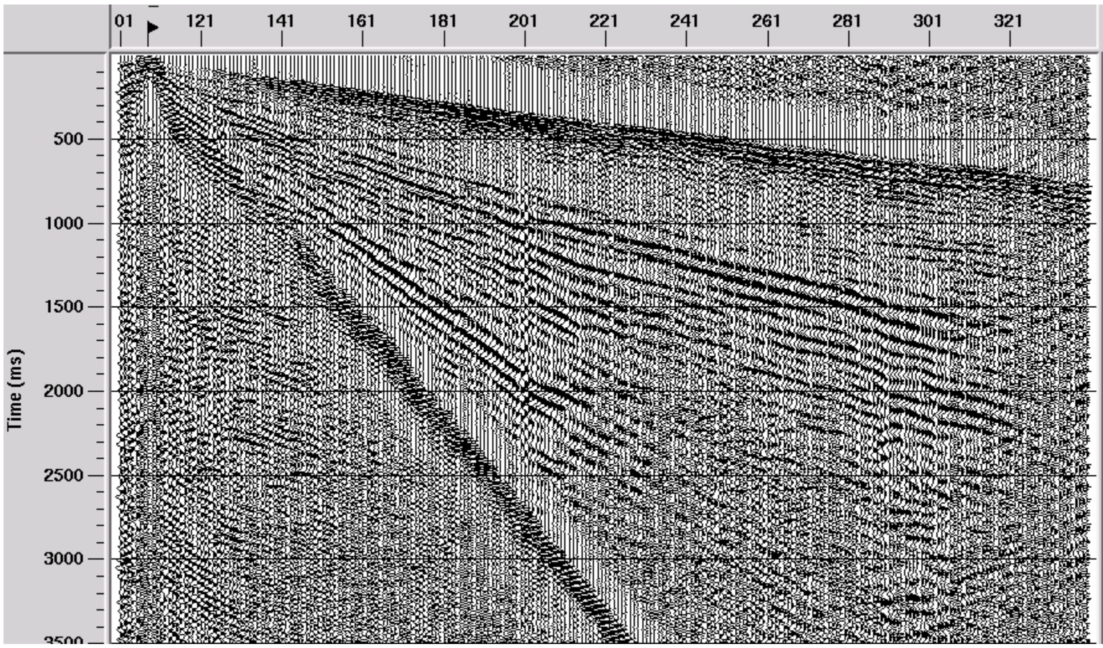


(b)

FIG. 6. Comparison of linear (a) versus nonlinear (b) sweep for vertical component records. Surface-wave suppression applied, with bandpass filter (6 – 70 Hz) and agc with 600 ms operator.



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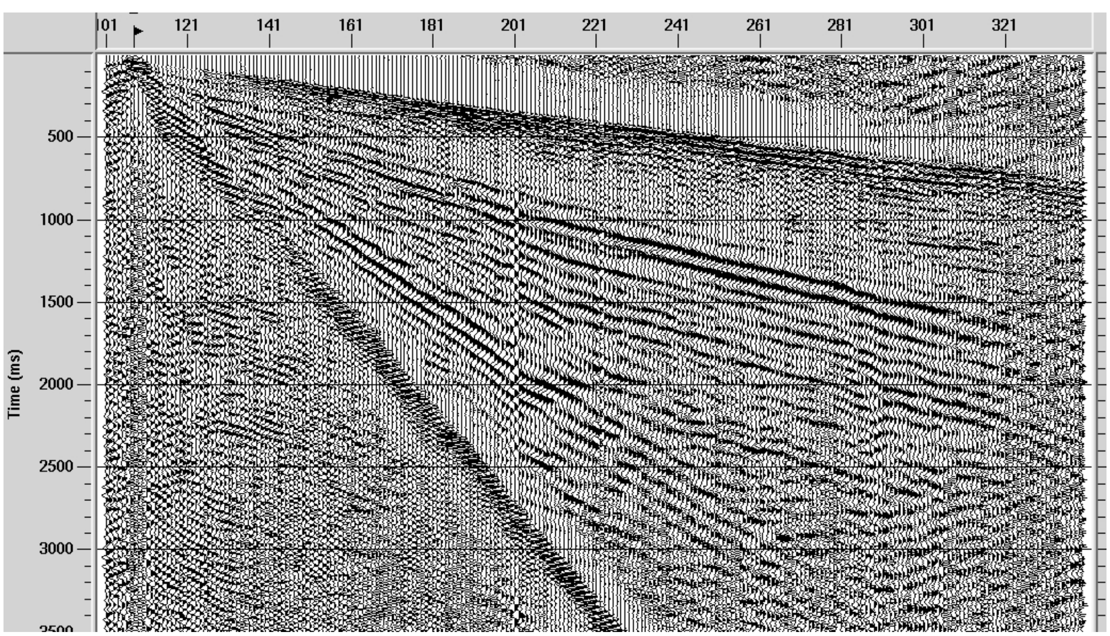

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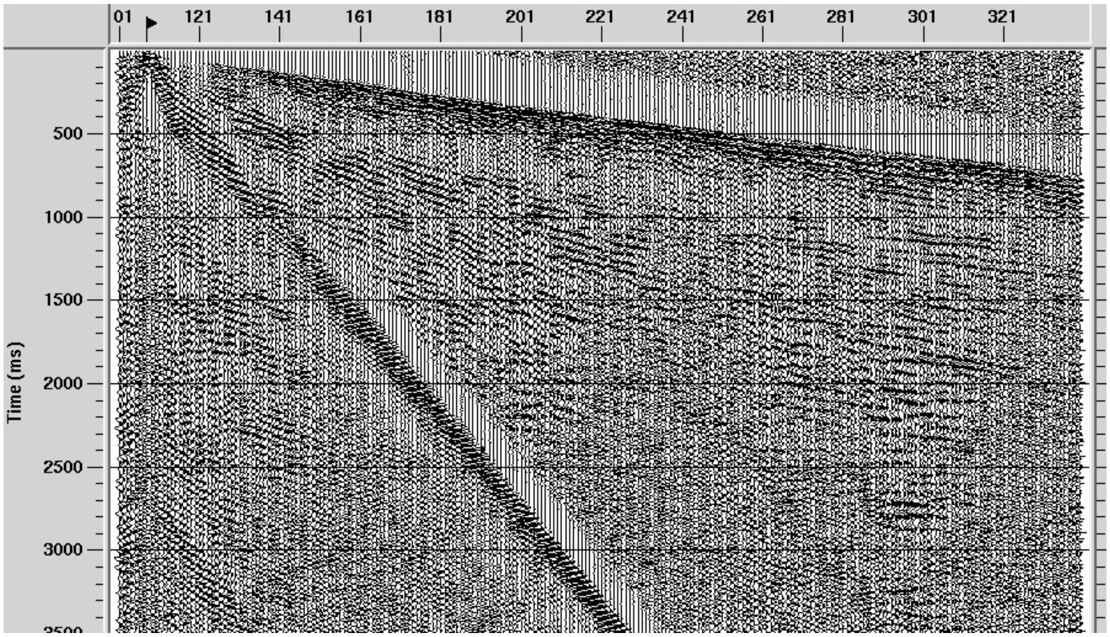
FIG. 7. Comparison of linear (a) versus nonlinear (b) sweep for radial component records. Raw records other than application of agc with 600 ms operator.



(a)

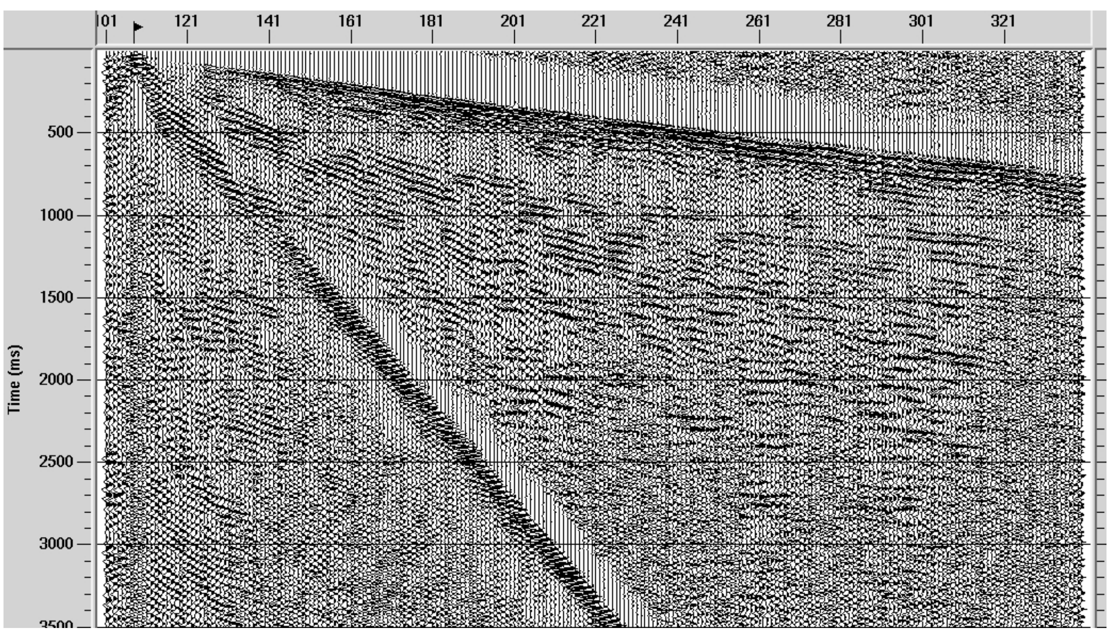


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FIG. 8. Comparison of linear (a) versus nonlinear (b) sweep for radial component records. Surface-wave suppression applied, with bandpass filter (6 – 70 Hz) and agc with 600 ms operator.

correlated through P-P and P-S seismograms from a well in the area. The seismograms were generated using the SYNTH program developed in CREWES. Figure 11 shows P-P and P-S sections juxtaposed about the midpoint of the line. The P-S data are displayed in P-P time, including compensation for vertical Vp/Vs. Major events between the two sections tie well and this correlation will be used for additional processing and interpretation.

Time (ms)	Vp/Vs
86	3.26
330	2.0
510	1.89
1045	1.96
1385	1.86
2215	1.89
2620	1.89

Table 2. Interval Vp/Vs

Continuing Program

The other two production datasets as well as remaining source and receiver tests from the Airport line will be processed over the next few months and a full analysis of the program will be completed early in 2002. This will include correlation of P-S statics with ground-penetrating radar data.

CONCLUSIONS

Analysis of multicomponent seismic data from Calgary Airport, Alberta allows the following general observations to be made at this time:

- Vibroseis® sources are effective for multicomponent seismic surveys, although at near-mid offsets, the horizontal components are dominated by high-amplitude source-generated noise. Two vibrator units are required for reflections from basement (depth ~ 3.2 km).

- Non-linear sweeps are superior to linear sweeps for optimum P-S data

- High quality P-P and P-S data were acquired at the Calgary Airport site.

ACKNOWLEDGEMENTS

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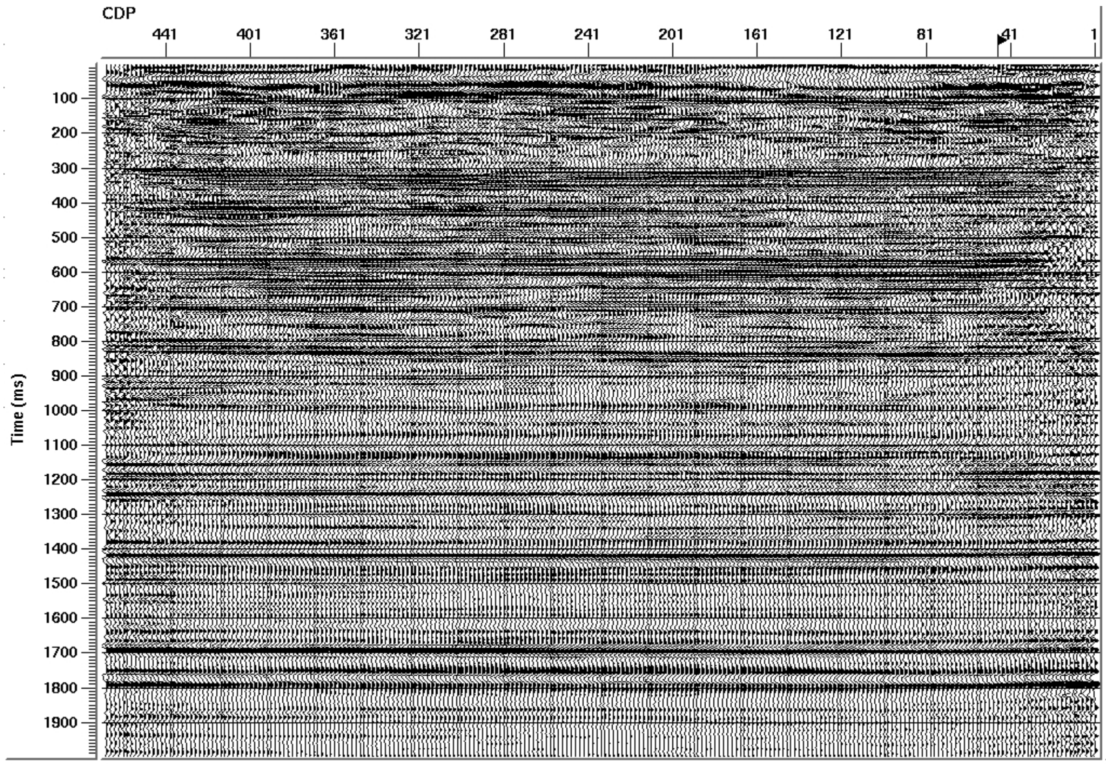

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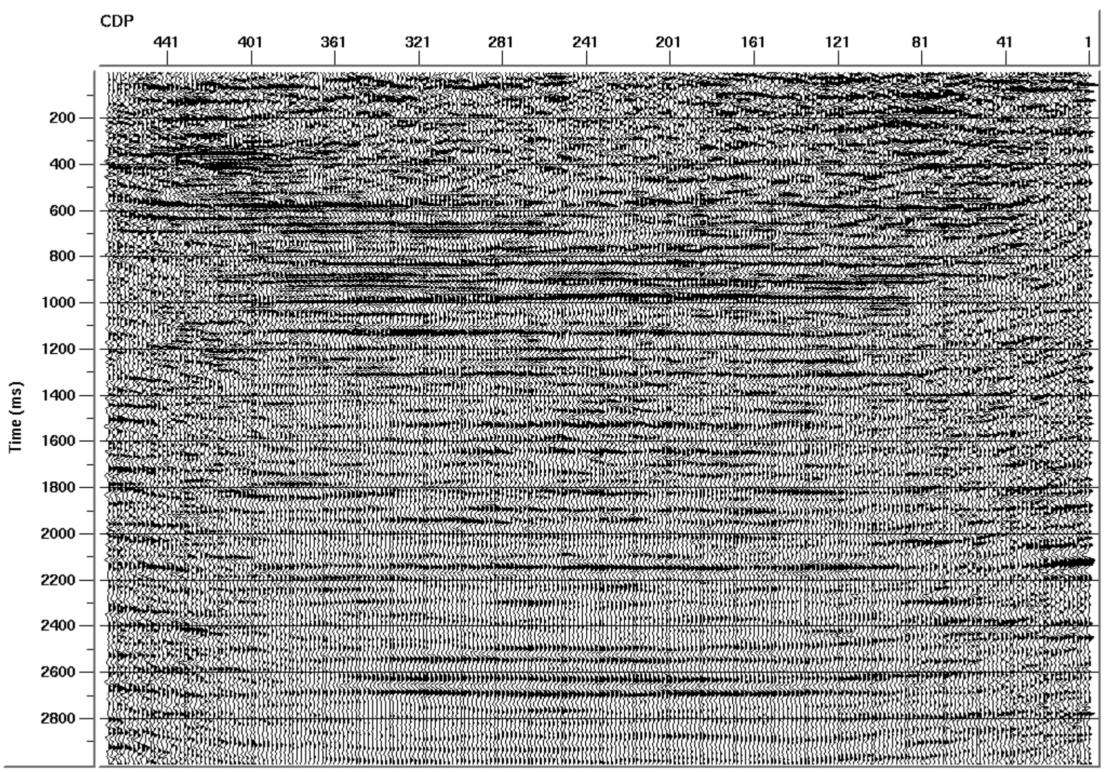

(b)

FIG. 9. Processed P-P (a) and P-S (b) sections using 6 – 100 Hz linear sweep.

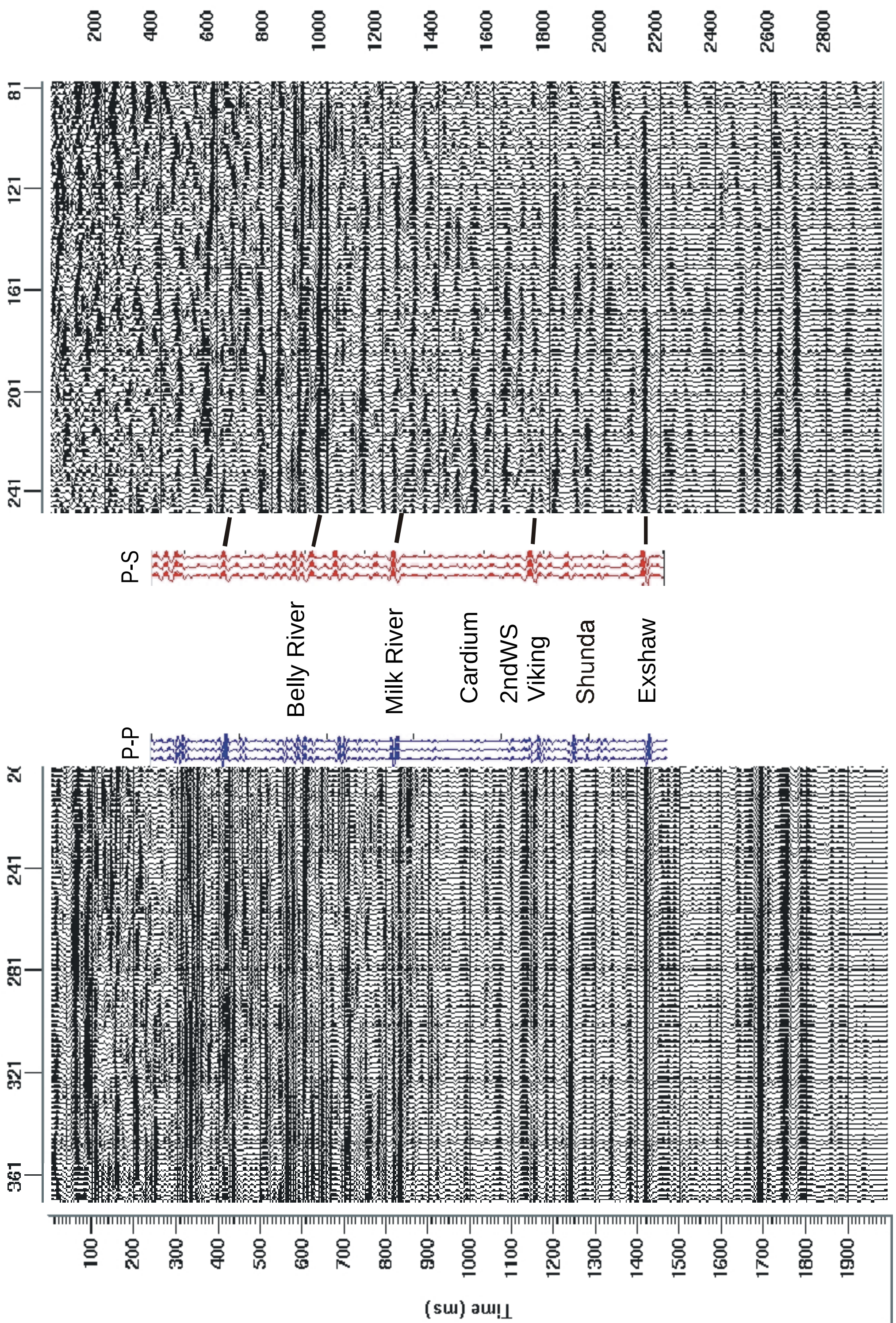

FIG 10. P-P (left) and P-S(right) sections, synthetic seismograms and horizon interpretation

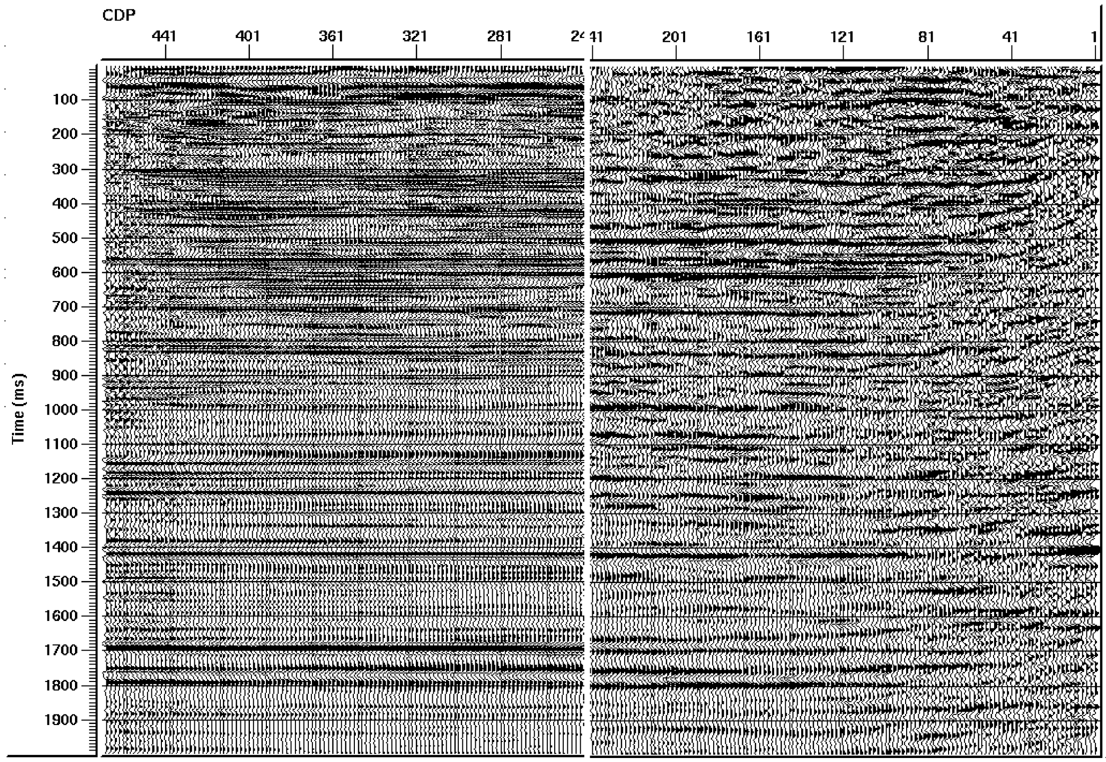

FIG. 11. Comparison of P-P section (left) with P-S section (right) displayed in P-P time.

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