Preliminary processing and analysis of the Blackfoot walkaway VSP

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ABSTRACT

In November 1997, the CREWES Project with assistance from Boyd Petrosearch Consultants Ltd. and PanCanadian Petroleum Ltd. conducted a high-resolution 3C-2D seismic survey combined with a walkaway VSP in Blackfoot field. This VSP survey was acquired in well BF09-08-23-23W4 by Schlumberger of Canada, using a 5-level 3-component ASI downhole receiver string with 15 m receiver interval and dynamite sources. Ten deep levels from 1425m to 1560m are processed. All procedures in the processing flow are performed in the shot gather domain. A median filter is used to separate downgoing and upgoing wavefields. A deconvolution operator is extracted from the downgoing wave and applied to the upgoing wave. The VSPCDP map ties in quite well with the migrated CMP section from the 2-D surface seismic line which is acquired simultaneously. The VSP AVO gather does not show an obvious amplitude anomaly at the position of target channel.

INTRODUCTION

In November 1997, a high-resolution 3C-2D seismic survey combined with a walkaway VSP in Blackfoot field was acquired by the CREWES Project with assistance from Boyd Petrosearch Consultants Ltd. and PanCanadian Petroleum Ltd.. This VSP survey was conducted in the production well BF09-08-23-23W4 by Schlumberger of Canada, using a 5-level 3-component ASI downhole receiver string with 15 m receiver interval. There were twenty downhole receiver levels using normal surface seismic shots (1×4 kg @ 18m) at all shot offsets. The ten receiver levels (1425 m to 1560 m) are called the deep positions, the ten at 250 m to 385 m are called shallow positions. Five additional receiver levels from 400 m to 460 m were recorded using two-hole pattern shots (2×2 kg @ 9m) situated in middle of the spread (Stewart et al, 1997). Figure 1 shows the layout of the survey.

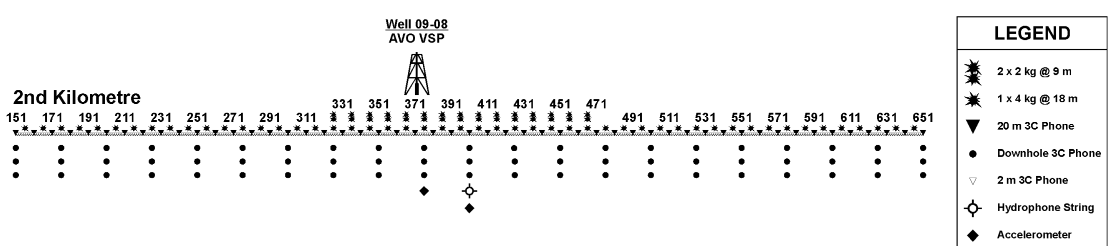


Fig. 1. Field layout for the Blackfoot walkaway VSP showing the shots and position of well 09-08.

The data of deep tool position from 1425 m to 1560 m are processed and described in this report. The ten levels, denoted by REC_SLOC 1~10, are divided into two groups: the receiver 1~5 corresponding to depths 1425 m to 1485 m have 36 live sources; receiver 6~10 have another 31 live sources, and only 29 left after editing. These 67 sources move from 1420m east of the well (SIN 1, positive offset) to 1550m west of the well (SIN 67, negative offset). Figure 2 shows the shot elevations and offset with a colour bar representing the SIN number. The elevation of KB of well 09-08 is 918.4 m above sea level. Data are sampled at a 1 ms interval.

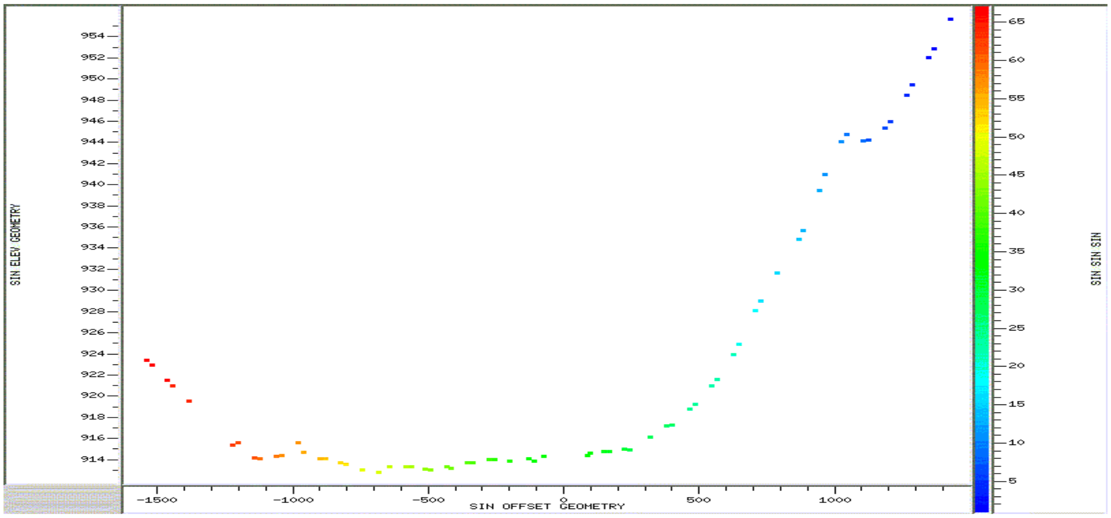


Fig. 2. Layout of shot elevation and offset. Colour bar shows the SIN number.

DATA

Amplitude

Figure 3 shows the vertical component data of these 10 receiver gathers, which are all displayed using only one scale factor. We note that the third (middle) geophone in the 5-level string (both REC_SLOC 3 & 8) has lower signal amplitude compared with other four levels. Relative high amplitude and higher frequency signals occur at 950ms to 1500ms in the near and middle source-offset area. These may be caused by inadequate couplings as they disappear on the far-offset traces.

Frequency

Figure 4 demonstrates the frequency spectrum of receiver gathers. The difference between the two half parts is that all traces in lower section are equalized by a 200 ms time window beginning from the first break, but raw data in the upper section. The dominant frequency is around 30 Hz on other 8 levels. The frequency band of REC_SLOC 3 & 8 is expanded and lifted. As well providing a overall view of the entire section, Figure 5 shows the frequency spectrum of two individual traces in shot number 3. On the left-hand side is trace No.1, and on the right-hand side is trace No. 3 (the third geophone). It would appear that the entire spectrum has moved to the high end, with the low frequency component being lost.

Both amplitude and frequency information indicate that poor coupling may occur between the third geophone and the wellbore.

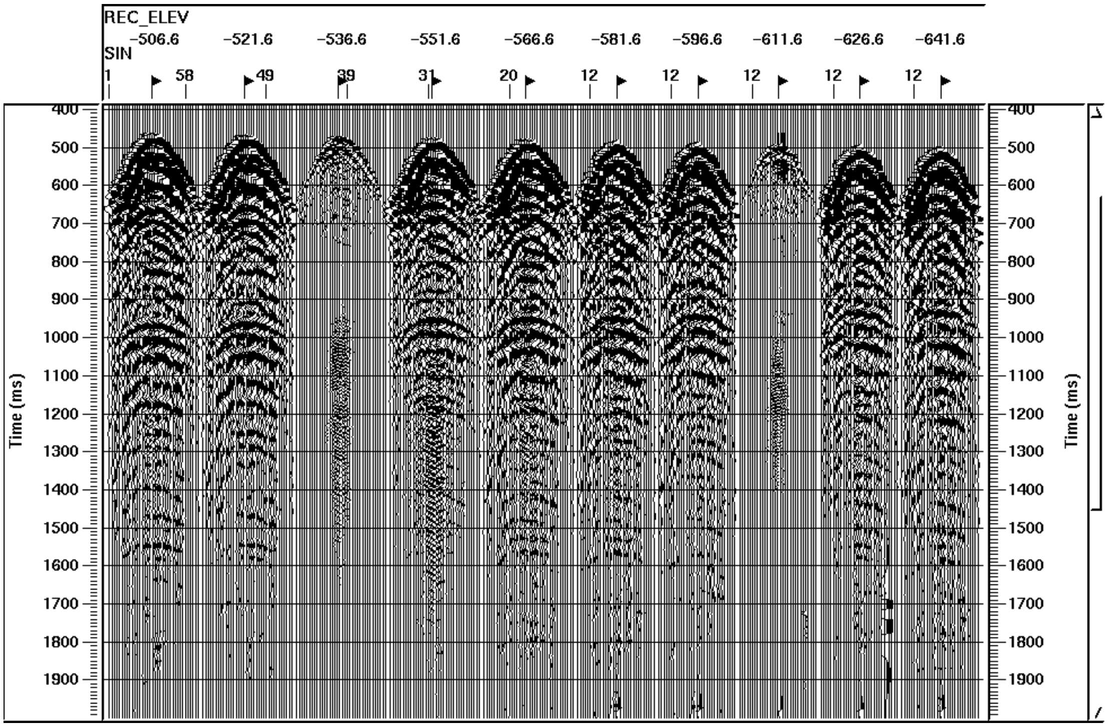


Fig. 3. Raw vertical component receiver gathers with entire section scaling.

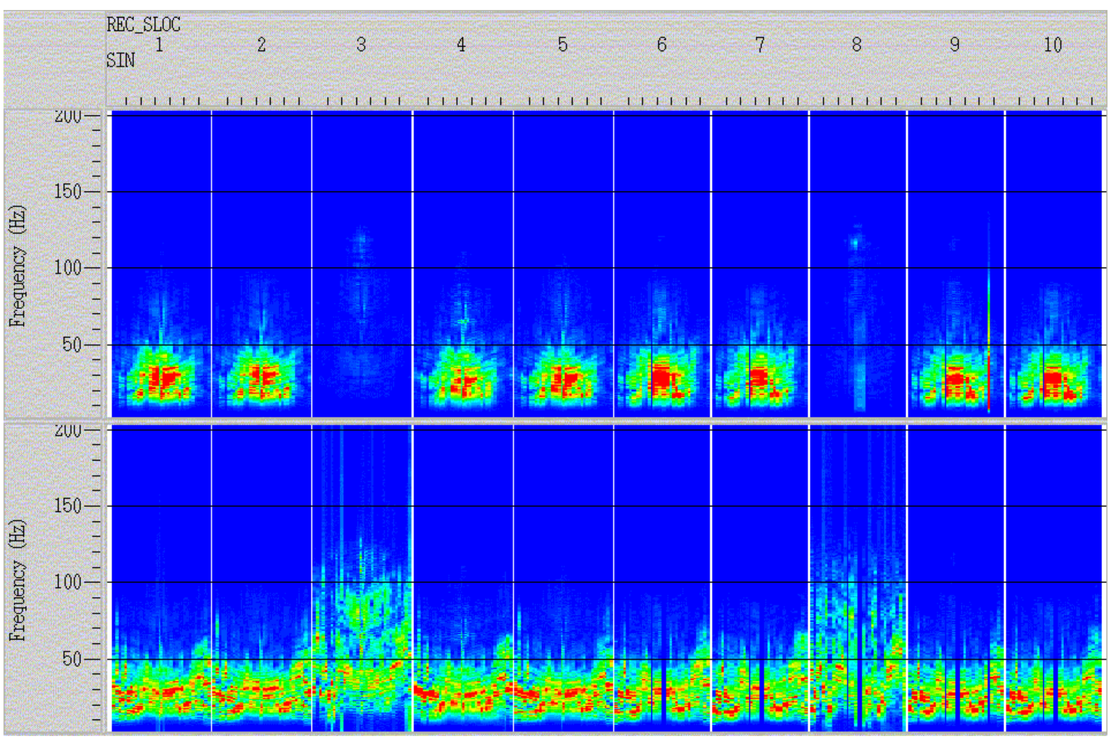


Fig. 4. Frequency spectra of 10 receiver gathers. The upper group is from the raw data presented in Figure 1, all traces normalized in the lower section.

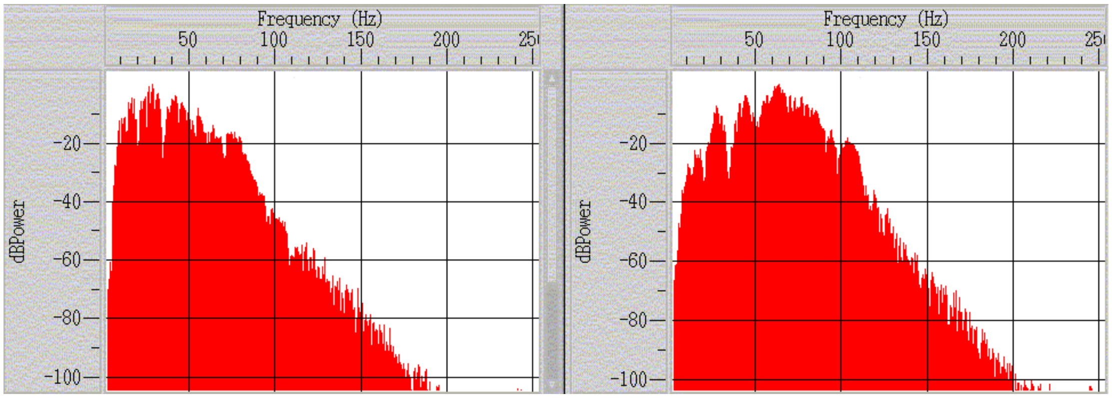


Fig. 5. Comparison of the spectra of two individual traces in same shot gather – SIN 3. On the left is the second geophone (Channel 2), and the right is the third level (Channel 3).

DATA PROCESSING

The processing flow for the vertical component is shown in Figure 6.

Geometry
Edit, bandpass filter, trace equalization
Shot static from surface seismic
First break picking
Median filter to separate wavefields
Upgoing wave deconvolution using downgoing wave
Exponential gain, T-V whitening
VSPCDP transform
f-x deconvolution

Fig. 6. Vertical channel processing flow

First, a bandpass filter (5-10-45-60 Hz) is applied to traces of REC_SLOC 3 & 8. Figure 7 shows the effect of bandpass filtering. After applying source statics from surface seismic, the first break is picked.

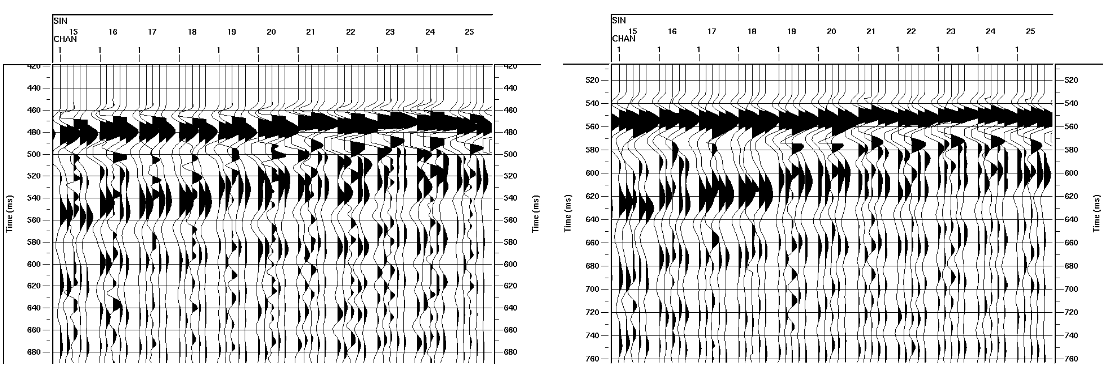


Fig. 7. Comparison of the raw data (left) and bandpass filtered data (right) of the third geophone. Screen individual scaling.

Due to amplitude anomalies in the third geophone, trace equalization was used. A 200 ms time window around first arrival picked from the farthest offset trace (SIN 67, channel 1) is applied to the entire section, which also balances the energy of the first downgoing arrivals along the entire offset range.

Aligning the entire section of all shot gathers by first break at 530ms, a 9-trace by 7-sample 2D median filter is applied in order to separate the downgoing and upgoing wavefiled. Then, a trace-by-trace 200 ms inverse filter as the deconvolution operator is extracted from the downgoing waves and applied to the upgoing waves. The comparison of the upgoing wavefield before and after deconvolution is presented in Figure 8.

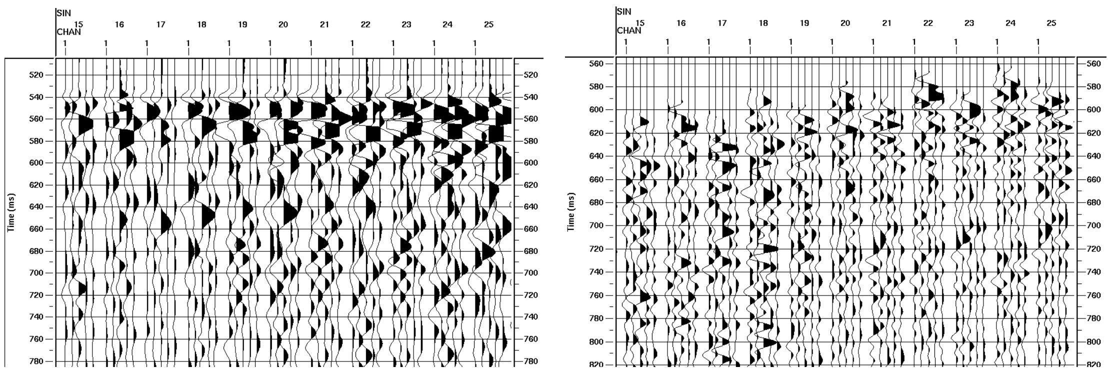


Fig. 8. Upgoing wavefield separated by median filter (left) and deconvolved upgoing wave (right).

Following deconvolution, the true amplitude of the upgoing wavefield is recovered using exponential gain $t^{1.7}$, and time-variant whitening is applied. Then, all traces are transformed into CDP domain using VSPCDP mapping with horizontal bin size of 30m and 30% stretch mute. Two interval velocity files in depth are used here: V1 is computed from the first break of the adjacent well 04-16 VSP survey which has fixed source-to-wellhead offset of 350 m; V2 comes from Blackfoot area information given by Gulati (1998). In addition, V1 beyond 04-16 VSP deepest depth is padded to 6000m by values equal to that of V2. The two velocity functions are corrected to the final datum of 1000 m above sea level. The final P-wave CDP map is shown in Figure 9. There is no large difference between these two sections except the traveltimes. They both have some non-flat events. The reason will be discussed later. The resolution looks lower between 1000 ms to 1150 ms because the stacking fold is higher when the image point move close to receiver, meanwhile, the incidence angle varies mostly.

Instead of flattening events in CDP section, we return to data sorted by Common Reflection Point bin number (RBIN_NUM), which have already been transformed to the t-x domain but not stacked. One RBIN_NUM corresponds to one shot number. The event at 1550 ms is roughly picked and flattened at 1445ms. This step is like a manual NMO tune. Then, CDP stack. The tuned CDP section is shown in Figure 10, compared with the migrated 2D surface seismic result. The 2D section is plotted every 3 CDPs with 10 m CDP bin size. We note that VSP image is improved and matched with 2D seismic very well.

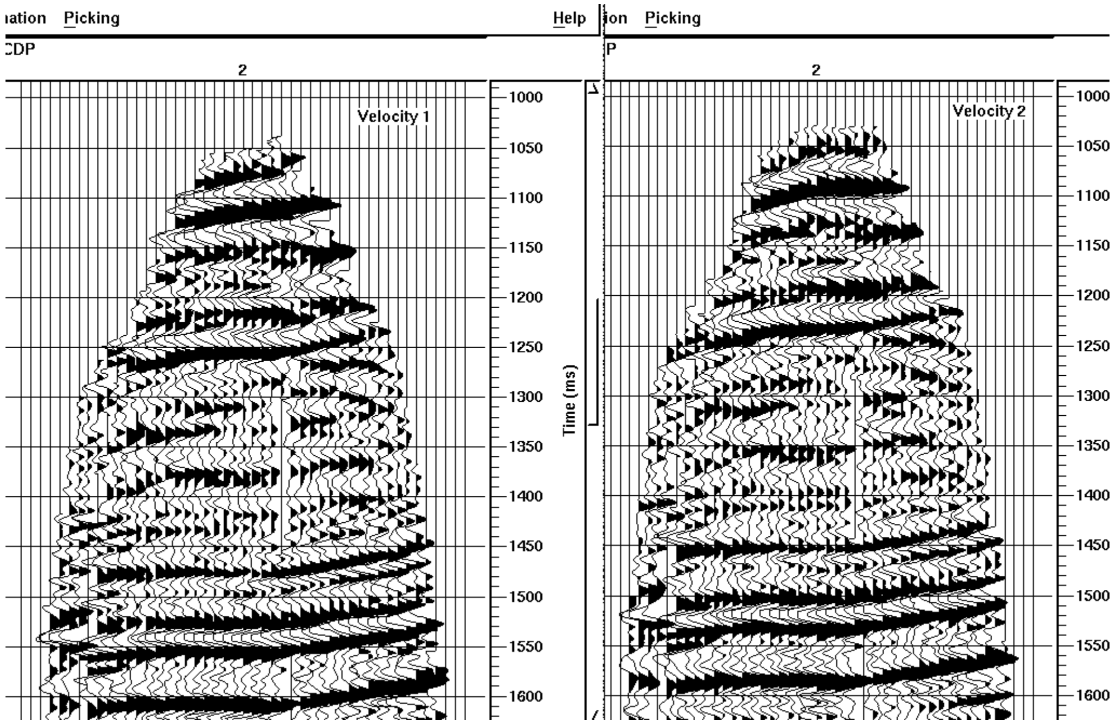
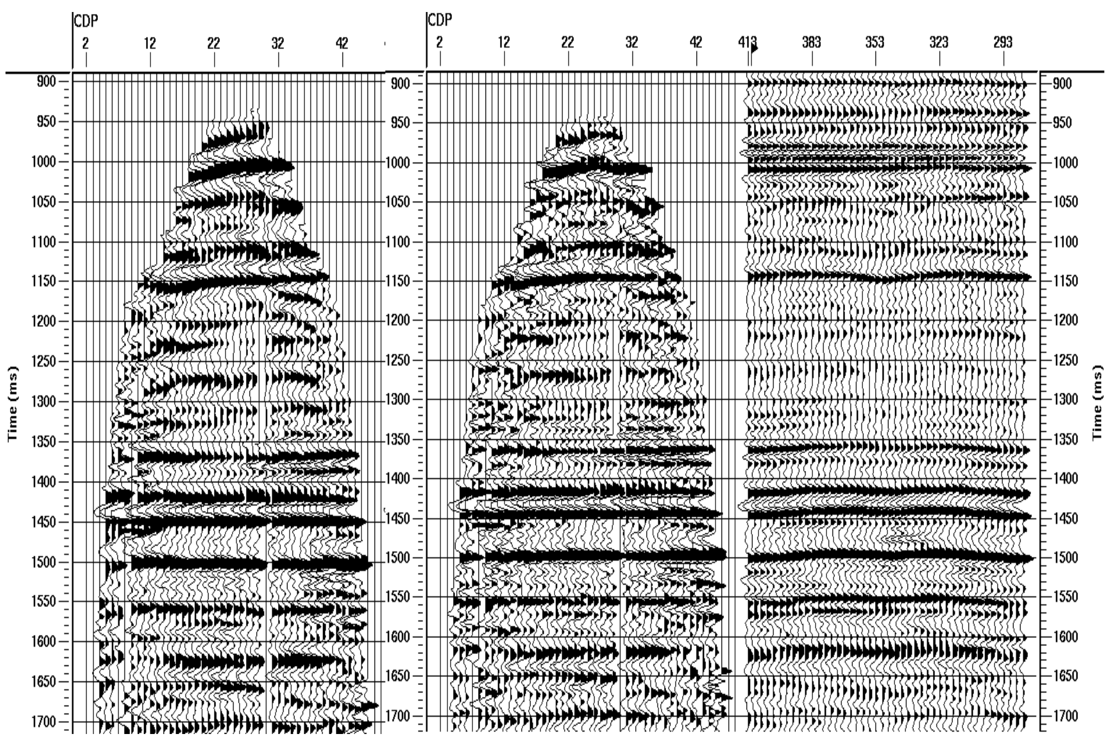


Fig. 9 Comparison of CDP sections using velocity 1(left) and velocity 2(right). Events are not flat.



Fig, 10. Comparison of VSP CDP maps with 2D migrated section. Left: VSPCDP map flattened after stack by the event at 1450ms. Middle: VSPCDP map flattened before stacking by same event. Right: 2-D migrated section.

Next, a RBIN_NUM stack is performed. It means all 5 traces in every shot gather are stretched and split into the t-x domain with two-way traveltime before being stacked back into ONE trace. One trace represents one shot. Figure 11 shows this procedure. Waveform within 1050 ms to 1200 ms at far-offset traces is muted due to stretching. The final section is shown in Figure 12. It is not a complete image section. The upper part close to receiver can be thought one or several adjacent common reflection point gathers for various shot offsets, which might show some AVO anomalies.

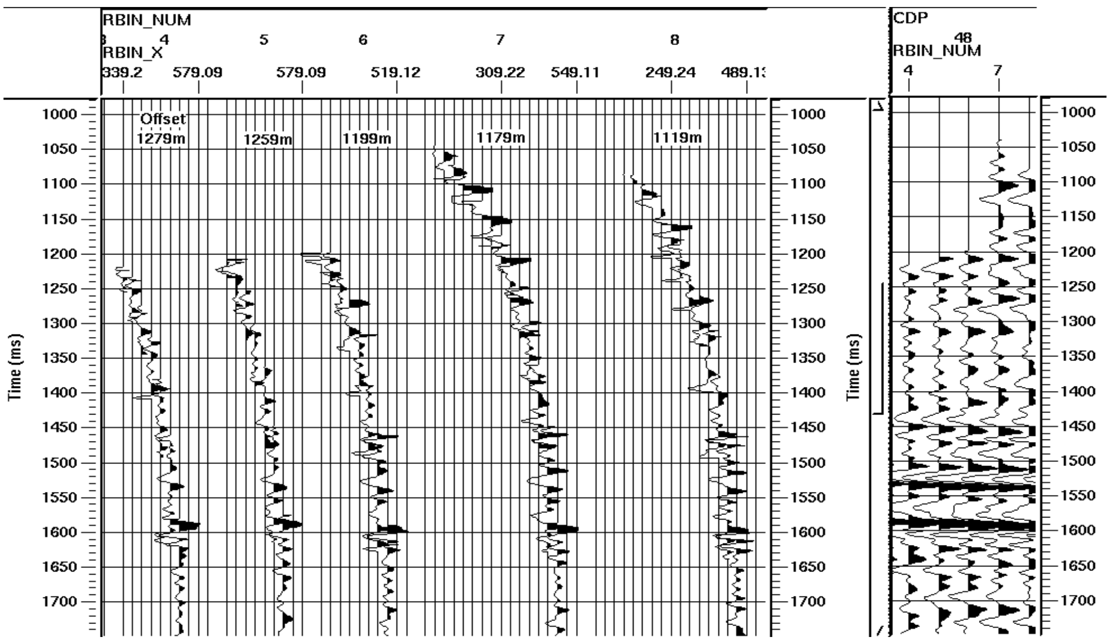


Fig. 11. Shot gather is transformed to t-x domain by VSPCDP mapping, then stacked back to one trace shown in two-way time.

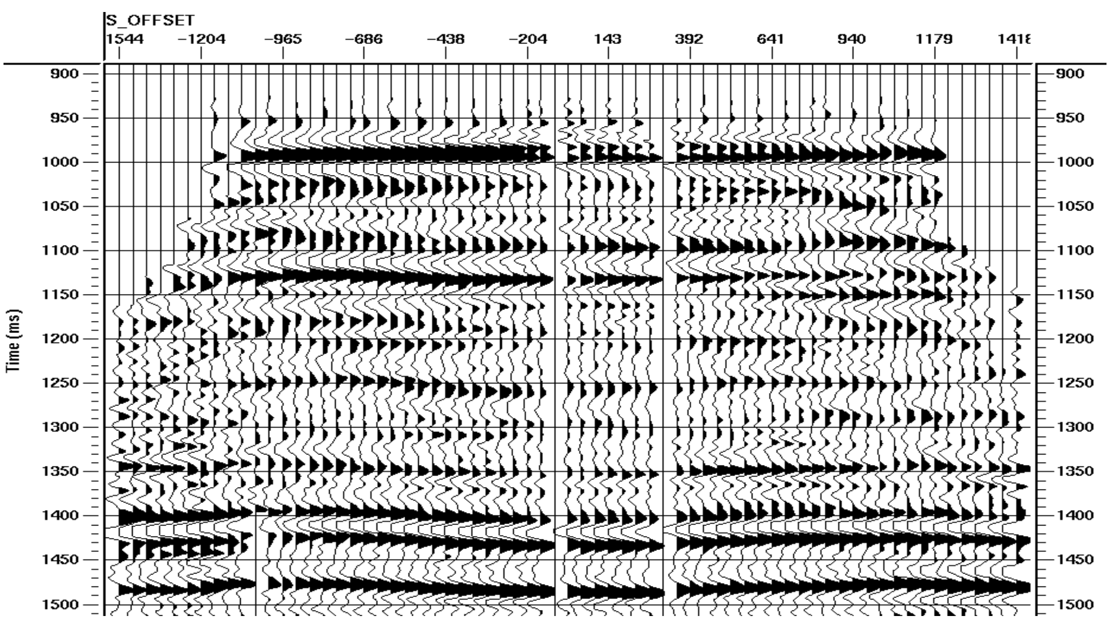


Fig. 12. AVO gather of 67 sources.

ANALYSIS AND DISCUSSION

Although they are all reflection seismology, VSP processing has some specific characteristics and techniques which are different from normal surface seismic.

Statics

Generally, only shot statics are applied for VSP processing. In this case, both the walkaway VSP and a 2-D surface seismic survey are recorded simultaneously using same dynamite sources. So, the shot statics from surface seismic are directly applied to the VSP data. Figure 13 (a) shows that the statics application looked reasonable for the 5-level tool string position of 1425 m to 1485 m, but not as good for the second receiver group (Figure 13 (b)). The statics will change the traveltime, and affect the final spatial position by VSPCDP transforming. These two receiver groups are transformed into CDP maps respectively and shown in Figure 14. Regardless the velocity error, unreasonable statics disturb the final image of receiver group 6 ~ 10.

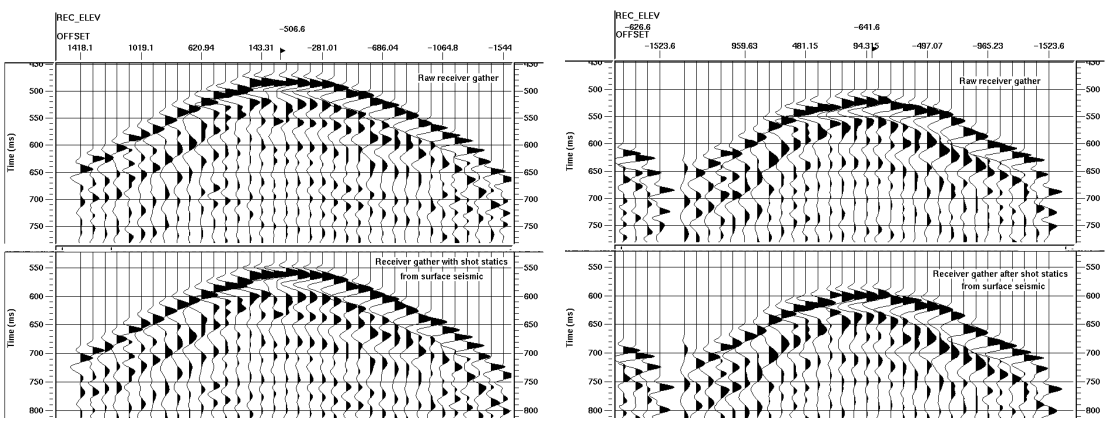


Fig. 13. Comparison of applying shot statics to receiver 1 (left) and 10 (right).

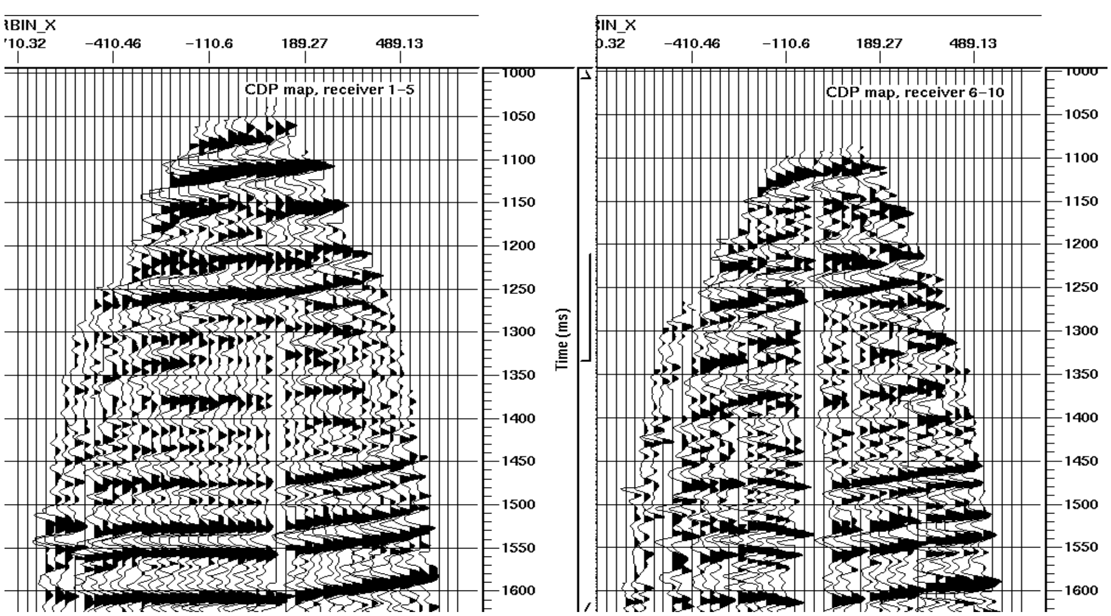


Fig. 14. Comparison of VSPCDP stack of receiver 1~5 (left) and receivers 6~10 (right).

Velocity in VSPCDP transform

How can we attempt to improve the image resolution of the area just beneath receiver? Given the simple one layer geometry shown in figure 15 with source A, receiver C, reflection point B, and travel time t along the path ABC with constant velocity v, the two-way vertical time from the surface to point B is calculated by the following equation

$$t_v = \frac{Z}{v} + \sqrt{t^2 - \frac{x^2}{v^2}} \quad , \tag{1}$$

and the horizontal distance from image point B to well is computed by

$$x_B = \frac{x}{2}\left(\frac{vt_v - 2Z}{vt_v - Z}\right) \quad . \tag{2}$$

For a multiple-layer model with velocity varies in depth, v should be the RMS velocity. As depth increases, the reflection point moves away from the well borehole. The moveout correction in VSP is not exactly like the symmetric NMO of surface seismic. However, it is a transition procedure from one-way NMO to near two-way NMO, corresponding to reflections that move from positions just below the receiver to deeper points. The reflection points beneath the receiver from all offset sources are so close even they might be stacked into one CDP. If the moveout corrections are not correct, the reflections will not be flat. Consequently, stacking will make this reflection smearing and show lower resolution. A reasonable VSP NMO velocity is therefor necessary to create an accurate, high resolution walkaway VSP image section. Residual statics may also be needed.

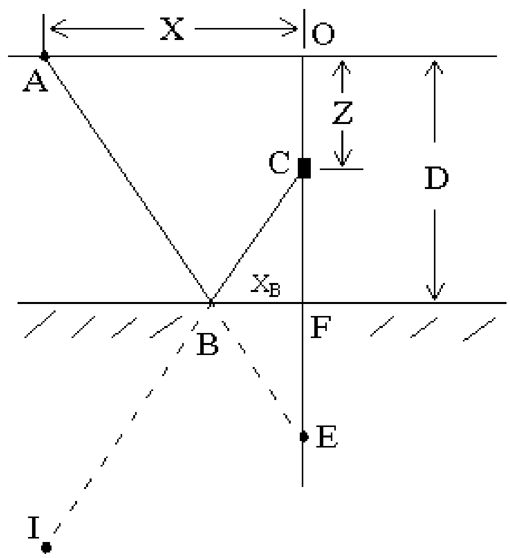


Fig. 15. Schematic of simple one layer VSP geometry (from SEG Course Notes).

AVO

When locating the geophone just above the reflector, the same reflection point could be imaged into one CDP bin by each source position, thus, the AVO response of a reflector can be observed. From the acoustic log curve of well 09-08 (Figure 16), it can be seen that both upper channel sands (1560 m to 1575 m) and lower channel sands (1585 m to 1600 m) have low acoustic impedance, corresponding to two troughs on the synthetic seismogram. In Figure 12, all five levels in every shot gather are transformed into t-x domain and stacked into one trace. The trough at 1010 ms is the top channel, which shows that amplitude increase from the middle to the two sides. At 1020 ms to 1030 ms, the amplitude of the peak event has a trend of increment along the source offset increase. However, the trough corresponding to the lower channel is not obvious due to resolution. The further possible improvements might be achieved by: 1) increasing image resolution by adjusting NMO velocity for VSPCDP transform; 2) improving deconvolution and enhancing upgoing wave; 3) carefully using trace equalization.

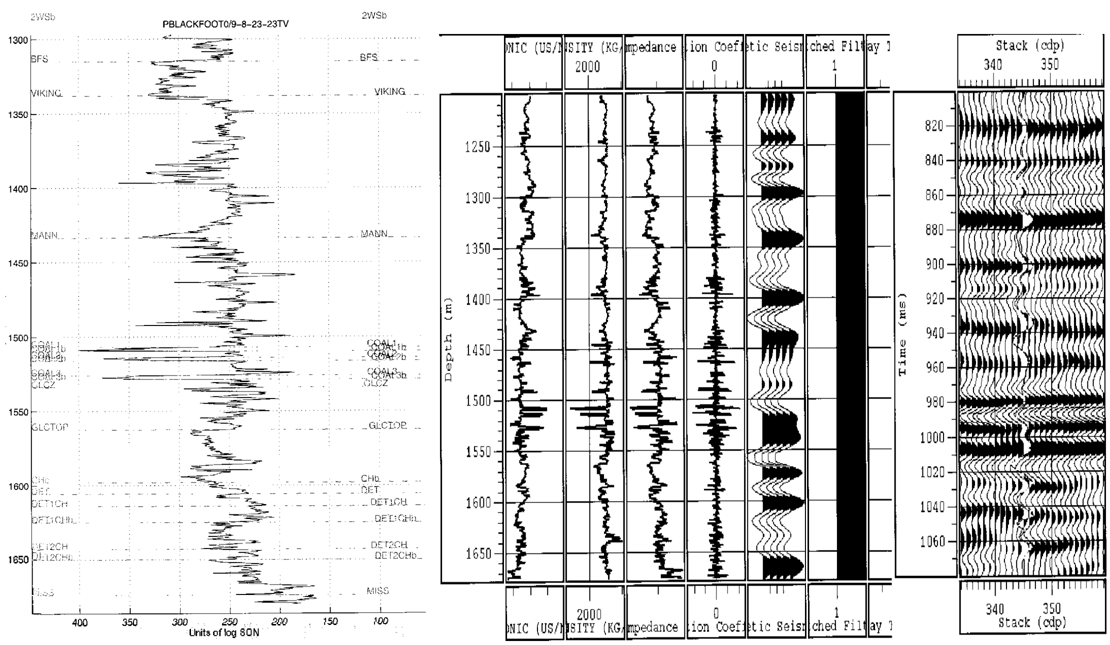


Fig. 16. P-wave acoustic log curve of well 09-08 is displayed on the left side, as well as the synthetic seismogram from well logs shown on right side.

CONCLUSION

Ten levels of vertical-component data of a walkway VSP survey in Blackfoot well 09-08 are processed here. The final CDP map provides a correlatable match with the simultaneously acquired 2-D surface seismic. The velocity used in VSPCDP transforming is not the same NMO velocity used in surface seismic due to the asymmetric VSP geometry, and velocity adjustment is required in avoiding smearing. This may be the main reason that AVO response is not obvious in this processing.

FUTURE WORK

1) Try to work out the method of getting correct NMO velocity for walkaway VSP, in that way, a clearer stacked image section can be obtained.

2) Improve processing procedures for AVO studies.

3) Complete and integrate converted-wave processing.

4) Process the10 shallow levels (250m~385m).

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