Blackfoot 3C/3D, A VectorSeis ™ Case History

Goodway, W. , PanCanadian Petroleum Ltd., Calgary, Alberta
Tessman, D. J., Input/Output, Inc., Stafford, Texas*

Summary

The Blackfoot field represents a style of stratigraphic trap common in the Western Canadian Basin. In many cases the acoustic impedance of the regional formations is similar enough to the reservoir to make detection through conventional P wave seismic difficult at best. Observations based on log and core analysis suggested that the application of Vp/Vs techniques could provide a seismic method for identifying channel location and evaluating reservoir quality. These considerations lead to the Consortium for Research in Elastic Wave Exploration Seismology (CREWES) acquiring a 3C/3D survey over the Blackfoot field in 1995.

In 1999, PanCanadian volunteered the site for the first pre-commercial test of the VectorSeis™ sensor, a 3 component, solid state, digital accelerometer. A Mega-Bin 3D survey was carried out over a large portion of the legacy CREWES survey. While four years of hydrocarbon production, acquisition, processing, and sensor differences prevented quantitative analysis of VectorSeis™ performance, this paper evaluates several qualitative aspects.

Processing of the compressional and converted wave datasets showed the VectorSeis™ data to be comparable to the legacy geophone data. Further amplitude and Vp/Vs analysis confirmed these conclusions as well as the viability of Vp/Vs techniques as a tool for the identification and evaluation of compound incised valley fill systems in western Canada.

Location

The Blackfoot field is located in south central Alberta, approximately 100km east of Calgary. The 3C/3D VectorSeis™ dataset was acquired over an area previously covered by a 3C/3D survey conducted by the CREWES consortium in 1995 (Figure 1).

The field is a compound incised valley fill system of Lower Cretaceous age. The valley system has three components, Upper valley, Lithic valley, and Lower valley. Of these, the Upper and Lower valleys represent the productive zones. The Lithic valley is generally non porous and is considered to be a permeability barrier between the Upper and Lower valleys. The paleo drainage of the system is south to north.

Within the system, the fluvial and distributary channel facies provide the best reservoir quality. Both the regional stratigraphy and the shale plugs associated with the channel sequences exhibit a Vp range similar to reservoir quality rocks. Examination of core measurements and log crossplot data suggested that it would be possible to discriminate lithology based on Vp/Vs ratio (Figure 2).

Data Acquisition

The 1999 VectorSeis™ 3C/3D survey was acquired over a 2 day time frame in October/November using PanCanadian's patented Mega-Bin technique. This resulted in 70 fold P-P coverage with a natural bin size of 40m by 80m. The stack data were subsequently interpolated to 40m by 40m before migration. Converted wave data was 30 fold with a natural bin size of 26.5m by 53.3m. When binned at the P-P dimensions, this increased to approximately 70 fold.

The 1995 CREWES consortium 3C/3D survey was a conventional orthogonal design that was modified to result in a fractionation bin as per Andreas Cordsen's patented technique. This resulted in 33 fold P-P coverage with a natural bin size of 30m by 30m. The converted wave data were subsequently binned at the same interval which resulted in 36 fold coverage.

Both surveys used the same charge size (4kg) and source depth (18m).

Data Processing

Both datasets were processed to "best of class" standards for their respective time frames. The VectorSeis™ dataset does however benefit from some four years of development in the area of effective γ (V_p/V_s) processing. PanCanadian (as well as other CREWES consortium members) are currently considering the re-processing of the 1995 survey to reflect the current state-of-the-art in converted wave imaging.

The VectorSeis™ data were left in their native acceleration mode throughout the processing sequence. Comparisons after processing through to structural stack indicated a residual phase difference between the velocity and acceleration datasets of only 9°.

In order to promote 4D interpretation of the two datasets, the statics solution from the 1995 survey was applied to the 1999 VectorSeis™ survey. This achieved a satisfactory stack quality despite known long wavelength problems.

Interpretation

A necessary step in validating the performance of the VectorSeis™ 3C sensor was to replicate the previously published Vp/Vs results from the 1995 CREWES survey (Margrave et al). However, given the subjective (interpretive) nature of several of the previously interpreted horizons it was decided that a more simplistic methodology would be employed.

Both datasets are interpreted to create 3 horizons for each dataset (P-P and P-S). The horizons were chosen for their proximity to the reservoir as well as their regional continuity. These horizons are:

- Upper Mannville: coal/shale sequence associated with a peak immediately above the reservoir interval. This represents the upper surface for subsequent Vp/Vs work (HOR A, Figure 3 & 4).
- Top Upper Valley: fluvial sequence associated with the trough immediately below the Upper Mannville horizon. This horizon has a characteristic amplitude response associated with the presence of the Upper Valley channel sequence. This surface is used for amplitude extraction work (HOR C, Figure 3 & 4).
- Top Wabamun: a regional marker associated with the transition from Carboniferous to Devonian age carbonates. This represents the lower surface for subsequent Vp/Vs work (HOR B, Figure 3 & 4).

These horizons result in the following maps for both the 1999 and 1995 datasets;

- Top Upper Valley amplitude extractions for P-P and P-S datasets
- Upper Mannville to Top Wabamun isochrons for P-P and P-S datasets

The amplitude extractions would be compared to evaluate their similarity while the isochron datasets are used to calculate Vp/Vs using the methodology prescribed by Margrave et al.

Discussion

Four years of hydrocarbon production as well as different acquisition & processing methodologies will undoubtedly prevent quantitative conclusions as to VectorSeis™ performance. However, the results do offer some qualitative insight as to the performance of the sensor.**Amplitudes:**

Both datasets result in credible amplitude extractions from the Top Upper Valley horizon. The P-P datasets show the amplitude response characteristic of the presence of an Upper Valley channel system. These results correspond closely with the historical drilling results. The VectorSeis™ amplitudes produce a narrower, more compact anomaly consistent with the depositional environment while the 1995 results appear more diffuse. The P-S amplitudes results are similar in that neither dataset produces an amplitude response associated with the channel lithology (Figure 5).

Isochron(s):

P-P isochron data are able to provide some limited resolution of channel location. This is primarily associated with the differential compaction observed over the thickest sand sequences. While this correlates well with several wells, it is not necessarily indicative of channel location or reservoir quality.

P-S isochron data provide a very different view of the channel system. Both datasets show a systematic thinning of 6 – 10ms over the channel system. This is interpreted as the shear wave response to the presence of reservoir quality rocks. While both datasets exhibit similar results, the results from the VectorSeis™ data appear more continuous and less diffuse. The P-S isochron data correlate closely to the channel location as mapped from the well data but offer little insight as to reservoir quality.

Vp/Vs:

Vp/Vs data calculated from both datasets produce results that correspond closely to those predicted from the log data. The sands associated with the channel system are cleanly separated from the regional shale formations. The best sand intervals as identified from the logs correspond to mapped Vp/Vs values of 1.65 to 1.80 while the regional shales correspond to mapped Vp/Vs values of >1.90. As was the case with the other datasets, the VectorSeis™ data appear more continuous than the 1995 results (Figure 6).

The Vp/Vs data as mapped over this gross stratigraphic column provide definitive indications of both channel location and reservoir quality. The similarity between the Vp/Vs maps and the Net Sand maps from log data are conclusive (Figure 7).

Conclusions

- VectorSeis™ seismic data acquired using the Mega-Bin technique are comparable to those obtained from conventional coil geophones in the 1995 CREWES survey.
- On a purely qualitative basis, the maps produced from VectorSeis™ data were more consistent with the known morphology of these compound incised valleys.
- Vp/Vs results from both datasets matched log based measurements and provide accurate indications as to channel location and reservoir quality.
- P-S isochron accurately identified the channel fairway.
- P-P isochron was complicated by other phenomena and was of limited use in this application

• P-P and P-S amplitude extractions preformed as expected but were not considered sufficient by themselves. Historically, many dry holes have been drilled on non reservoir related P-P amplitude anomalies.

Acknowledgments
The authors would like to thank PanCanadian Petroleum Ltd., and especially Dave Cooper, for their support in the testing of VectorSeis™. Also, we would like to thank the management of Input/Output, Inc. and finally those field personnel from both I/O and Veritas DGC Land without whom the field test would not have been possible.

References

Goodway, W. N., Ragan, B. R., U. S. Patent 5,787,051, Three-Dimensional Seismic Acquisition, July 28, 1998.
Cordsen, A., U.S. Patent 5,487,052, Three-Dimensional Seismic Data Acquisition Using A Repeating Offset Arrangement of Source and Receiver Lines, January 23, 1996.
Margrave, G. F., Lawton, D. C., Stewart, R. R., 1998, Interpreting Channel Sands with 3C – 3D Seismic Data, The Leading Edge, 17, 04 (509-513).
Dufour, J., Squires, J., Edmunds, A. and Shook, I., 1998, Integrated geological and geophysical interpretation of the Blackfoot area, Southern Alberta: Annual Meeting Abstracts, Society Of Exploration Geophysicists, 598-601.
Stewart, R. R., Gulati, J. S., Zhang, Q., Parkin, J. M. and Peron, J., 1998, Analysing 3C-3-D VSP data: The Blackfoot, Alberta survey: Annual Meeting Abstracts, Society Of Exploration Geophysicists, 381-384.

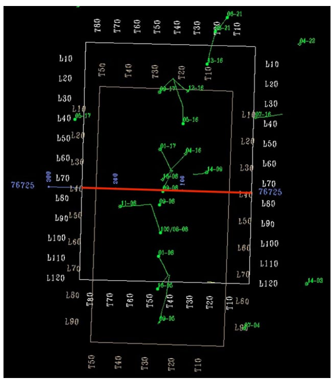


Figure 1 Map view showing the outline of the 1995 CREWES survey to the north (top of page) and the 1999 VectorSeis™ survey overlapping to the south. Wells are in green and the red line identifies the location of the extracted 2D profiles that follow.

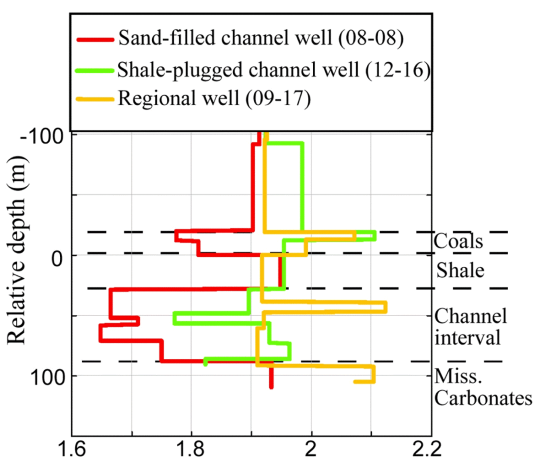
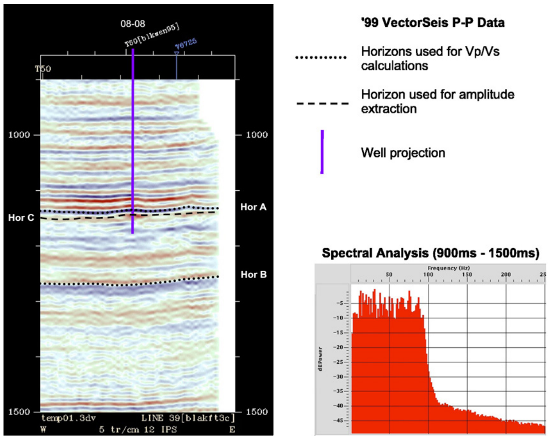


Figure 2 Comparison of Vp/Vs values for reservoir and non-reservoir rocks suggesting discrimination is possible with the use of multicomponent seismic data (Margrave et al, 1998). Values were obtained by blocking dipole sonic logs from the three wells identified.

3a)



3b)

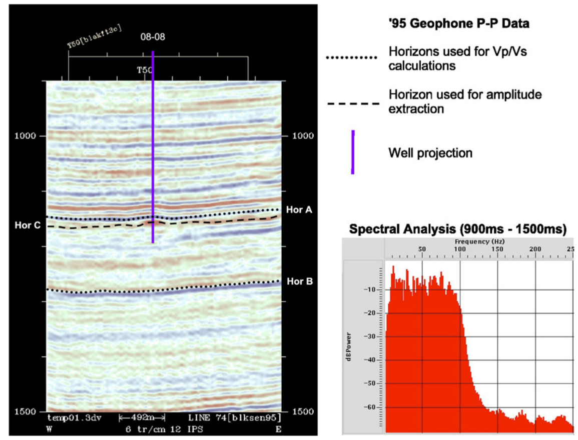
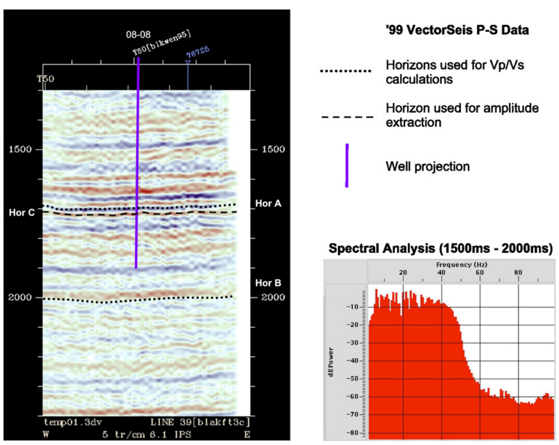


Figure 3a and 3b P-P Comparison: VectorSeis™ data (3a) and 1995 geophone data (3b). Spectral response curves are included for each in the lower right corner and are similar for both datasets. Horizons chosen for subsequent mapping are identified as is the 08-08 well.

4a)



4b)

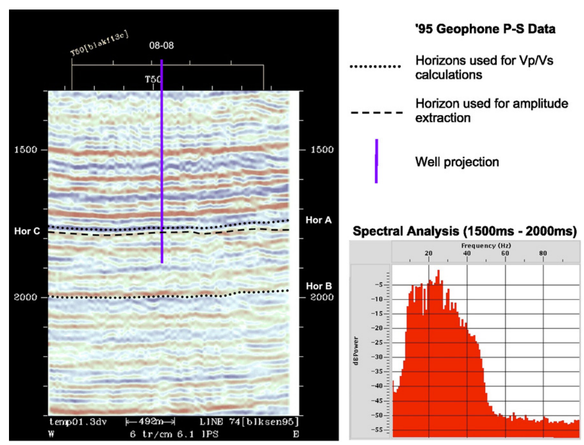


Figure 4a and 4b P-S Comparision: VectorSeis™ data (4a) and 1995 geophone data (4b). Spectral response curves are included for each in the lower right corner. Note the increased low frequency content of the VectorSeis™ data. Horizons chosen for subsequent mapping are identified as is the 08-08 well.

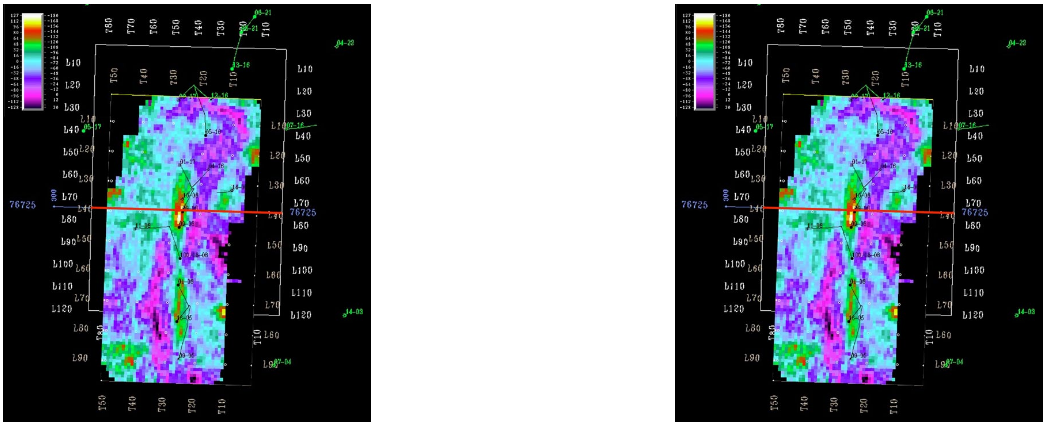


Figure 5 Amplitude Comparison: VectorSeis™ amplitude extraction (left) from “Hor. C” compared to equivalent 1995 3C geophone data (right). Red line indicates the location of the extracted 2D profiles.

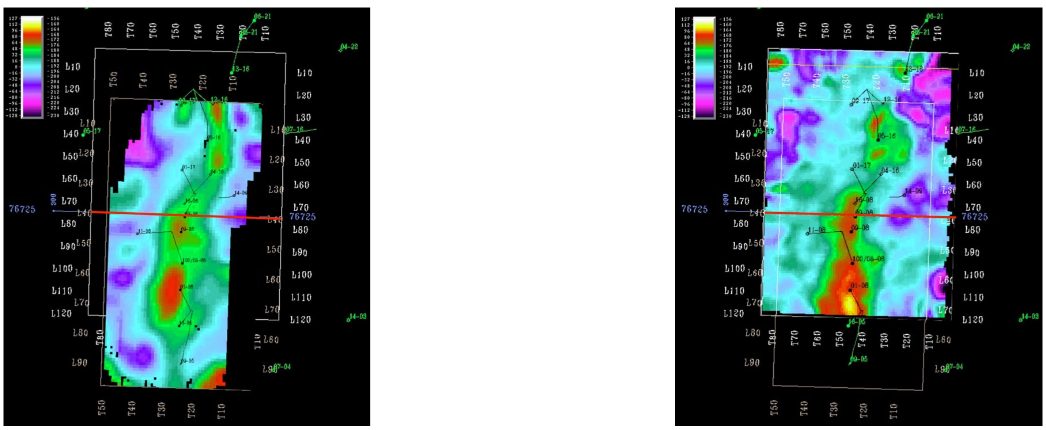


Figure 6 Vp/Vs Comparison: VectorSeis™ derived Vp/Vs (left) compared to equivalent 1995 3C geophone data (right). Red line indicates the location of the extracted 2D profiles.

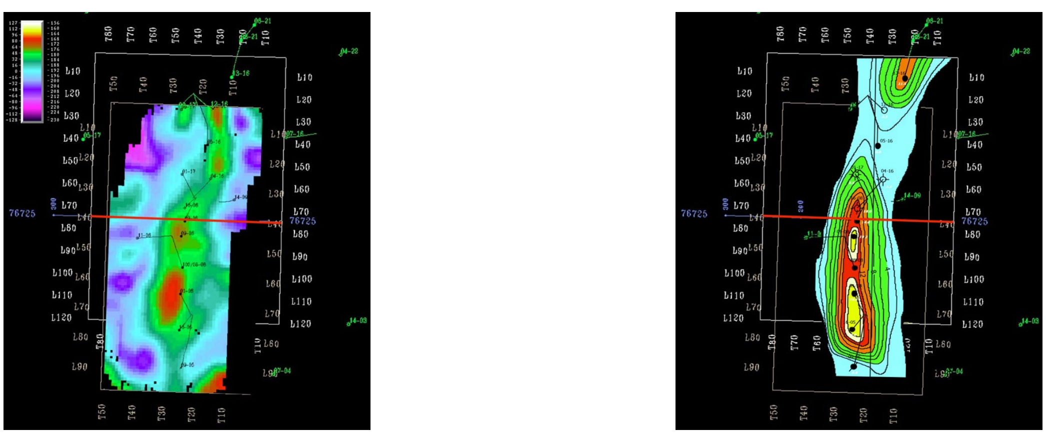


Figure 7 Vp/Vs to Net Sand Comparison: VectorSeis™ Vp/Vs (left) compared to contour map of net sand derived from log data (right). Note that the two thick zones mapped from log data appear visible in the Vp/Vs data. Also, the pronounced thinning between the upper and lower sand lobes also appears on the Vp/Vs map. Vp/Vs values calculated are as predicted from logs in Figure 2 (1.6 – 1.8 for reservoir, >1.9 for shales).