Interpretation and modelling of *P-P* and *P-S* seismic data from Lousana, Alberta

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ABSTRACT

Two orthogonal three-component seismic lines were shot by Unocal Canada Ltd. in January, 1987, over the Nisku Lousana Field in central Alberta. The purpose of the survey was to investigate a Nisku patch reef thought to be separated from the Nisku shelf to the east by an anhydrite basin. These data have been reprocessed, analyzed, and used to develop methods for multicomponent seismic data analysis. The data are of overall good quality and major events were confidently correlated between the *P-P* and *P-SV* sections using offset synthetic seismograms. *P-SV* offset synthetic models were also used to extract interval *Vp/Vs* values from the *P-SV* data at well locations.

P-P and *P-S* isochrons were used to calculate *Vp/Vs* values for two intervals containing the reservoir. For both intervals, *Vp/Vs* was lower at two oil well locations than for the rest of the line, including a basinal well location. The decrease is attributed to the facies change from tight basinal anhydrite to porous reservoir dolomite in the Nisku Fm. This trend is in agreement with previous modelling studies.

Misties between the *P-P* synthetic seismogram and the *P-P* seismic data in the zone of interest motivated further forward modelling. The inclusion of intrabed multiples and local conversions in the offset synthetic seimograms resulted in a better tie to the data. *P-P* models from two wells both showed the same travel-time delay on the Nisku event.

INTRODUCTION

In 1987, Unocal acquired two three-component lines across the Lousana Field. Unocal donated these data to the CREWES Project, where they were reprocessed and interpreted. The geology of the Lousana field and the work done to date are described in two previous CREWES Research Reports: Miller et al. (1993) and Miller et al. (1994). This paper is a follow-up paper to the previous two and addresses some of the issues raised in the previous studies.

The seismic survey described here is located over the Lousana field in Township 36, Range 21, West of the 4th Meridian, in central Alberta, Canada. There are two orthogonal 3-C lines; this analysis focuses on line EKW-002 as it has better well control. The producing horizon is a dolomite buildup in the Upper Devonian Nisku Formation. The buildup is separated from the main Nisku carbonate shelf to the east by an anhydrite basin, which forms lateral and vertical seals to the reservoir.

One of the objectives of the survey was to distinguish porous reservoir dolomite from tight basinal anhydrite through the coupled analysis of *P-P* and *P-S* seismic data. The approach was to identify character, amplitude, or time interval variations which coud be associated with productive zones, and attempt to correlate these variations to changes in geology through forward modelling. Forward offset synthetic modelling was also used to study the signal interference caused by intrabed multiples and local *P-S* and *S-P* conversions. Finally, this data set was used as a case study to develop and test techniques for analyzing multicomponent data. The interpretation techniques described in this paper are generic and can be usefully applied to other multicomponent seismic data.

INTERPRETATION

Correlation and *Vp/Vs* extraction

The *P-P* and the *P-S* seismic data were correlated according to the procedure described in Miller et al. (1994). *P-P* and *P-S* offset synthetic seismograms were generated from *P*-wave sonic and density curves using the method described by Lawton et al. (1992). The correlation procedure using synthetic offset gathers and stacks is necessary because of the different bandwidths and dominant frequencies between the *P-P* and *P-S* data.

The synthetic seismograms were generated using the *P*-wave sonic log from the 16-19-36-21W4 well. There was no density curve for this well so the density log from the 8-20-36-21W4 well was edited to match the 16-19 depths and used in the generation of the seismogram. Ricker wavelets were used, with a peak frequency of 40 Hz for the *P-P* seismogram and 25 Hz for the *P-S* seismogram, as determined by spectral analysis of the processed seismic data. The wavelet phase can also be adjusted; in this case zero phase wavelets gave the best tie. The offsets are from 0 to 1782 m, with a receiver interval of 66 m. This compares to the field acquisition geometry of far offsets of 1800 m and a receiver interval of 33 m. Normal moveout corrections and mutes were applied prior to stacking the offset traces. Polarity convention is that a peak on both the *P-P* and the *P-S* data represents an event from an interface across which there is an increase in elastic impedances.

The correlation of the *P-P* offset synthetic seismogram to the *P-P* seismic data is shown in Figure 1. The tie is very good for most of the section. Although a checkshot survey was not available, the sonic and density logs were stretched slightly to match the data down to the Mississippian event. Misties occur below the Mississippian, but the logs were not adjusted to match these events as the misties may be due to short-path intrabed multiple interference. The misties at the Wabamun and Nisku horizons motivated the modelling studies discussed later in this paper.

There are no full-waveform sonic logs available from this area, so the *P-S* seismogram was calculated initially using the *P*-wave sonic curve and assuming a constant *Vp/Vs* of 2.00. The correlation between the *P-P* and *P-S* offset synthetic stacks was straightforward as they were both created using the same depth model. The *P-S* synthetic seismogram was then used to identify events on the *P-S* seismic section.

The use of a constant *Vp/Vs* results in a time-variant mistie between the *P-S* synthetic stack and the *P-S* seismic data. It is the change in *Vp/Vs* which contains geologic information which we wish to extract from the data. As discussed by Miller et al. (1994), the interval *Vp/Vs* can be adjusted to stretch or squeeze the *P-S* synthetic stack in a time-variant manner in order to provide an optimum tie between the synthetic seismogram and the processed data. This procedure was repeated using data which was reprocessed in 1994 for broader bandwidth. Interval *Vp* was available from the *P*-wave sonic log, so *Vp/Vs* was varied by changing *Vs* while keeping *Vp* constant within a particular interval. The resultant *P-S* synthetic seismogram, and the interval *Vp/Vs* values used to generate it, are shown in Figure 2.

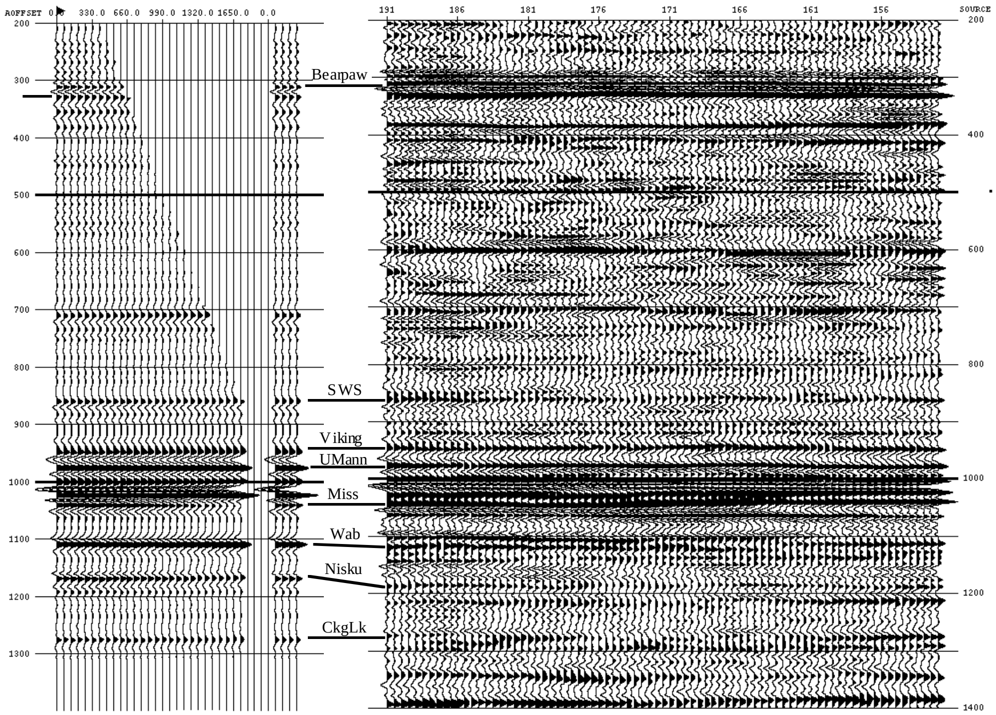

Fig. 1. The *P-P* offset synthetic seismogram and stack from the 16-19 well is tied to the *P-P* seismic data at the well location. The tie is very good down to the Mississippian (Miss), but is poor at the Wabamun (Wab), Nisku, and Cooking Lake (CkgLk) horizons.

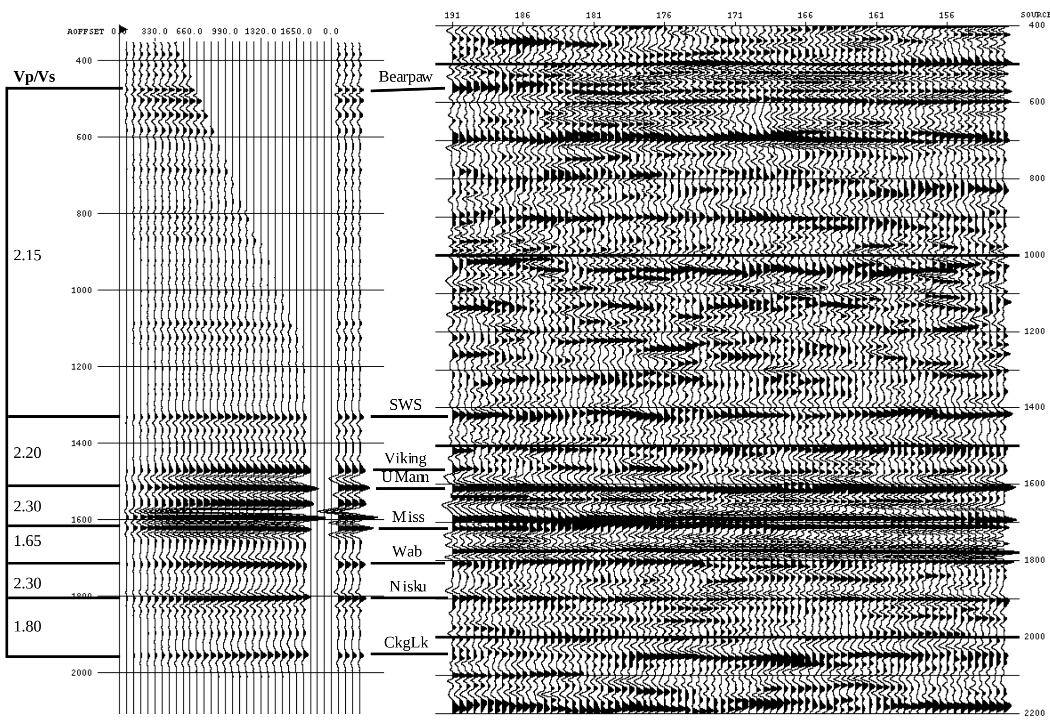

Fig. 2. The *P-S* offset synthetic seismogram and stack from the 16-19 well is tied to the *P-S* seismic data at the well location. *Vp* is taken from the *P*-sonic log, and *Vs* is determined by finding the value which gives the optimum tie to the *P-S* data.

Reservoir *Vp/Vs* analysis using *P-P* and *P-S* isochrons

The interval *Vp/Vs* values shown in Figure 2 apply at the 16-19 well location. The *P-P* and *P-S* seismic data can be used to calculate interval *Vp/Vs* along the length of the seismic line. *Vp/Vs* between any two picked horizons is calculated from the *P-P* and *P-S* isochrons using the relationship (Garotta, 1987):

$$Vp/Vs = (2Is/Ip) - 1 \qquad (1)$$

where Is and Ip are the *P-S* and *P-P* isochrons across the same interval, respectively. If the event correlations between the components are accurate, the dimensionless ratio *Vp/Vs* will be free of the effects of depth or thickness variations, as these will affect both components equally. Lateral variations in *Vp/Vs* may be interpreted as changes in lithology, porosity, pore fluid, and other formation characteristics (Tatham and McCormack, 1991).

The correlated events were interpreted along both lines using a workstation. Interpretation of the *P-P* and *P-S* sections for the central portion of line EKW-002 is shown in Figures 3 and 4. The *P-S* data are plotted at 2/3 the scale of the *P-P* data, and a robust correlation has been obtained between the two components.

P-P and *P-S* isochrons were used to calculate *Vp/Vs* values for a number of intervals. Lateral *Vp/Vs* variations may be used to interpret facies changes within a horizon. Results for two intervals which contain the reservoir are shown in Figure 5. *Vp/Vs* is lower at the two oil well locations (16-19 and 2-30) than elsewhere on the line. The contrast is the greatest between the oil wells and the basinal anhydrite well (12-20). This trend is in agreement with modelling studies reported by Miller et al. (1994). According to that work, *Vp/Vs* will decrease in these intervals if anhydrite is replaced with porous dolomite.

The *Vp/Vs* curve in Figure 5 shows a substantially greater change than indicated by the 1994 models. In particular, a *Vp/Vs* of 2.3 at the basinal well is higher than the model indicates. Attempts to understand this disparity are discussed in the next section.

P-P MODELLING INCLUDING MULTIPLES

As previously noted, the *P*-wave seismic data ties the *P*-wave synthetic seismogram very well down to the top of the Mississippian (Figure 1). However, there are misties later than this at the Wabamun, Nisku, and Cooking Lake events. The misties occur in the zone of interest and have complicated the travel-time analysis of the Lousana data, including the *Vp/Vs* analysis. Thus far, these misties have been assumed to be due to interference from intrabed multiples, most likely originating within the Mannville coals. To confirm this hypothesis, the data have been modelled using an offset modelling algorithm which can include intrabed multiples, intrabed conversions, or both.

The modelling package used is based on an algorithm which is a hybrid of ray-trace methods and wave reflectivity theory (Frasier, C., 1995, pers. comm.). The algorithm can calculate all intrabed multiples and intrabed conversions for a target zone which is user specified. The input data were blocked *P*-sonic and density logs from the 16-19 and 12-20 wells, which are both situated on line EKW-002. For both wells a target zone was chosen which started above the Mannville coals and ended in the Ireton Fm: 1285 -1840 m for 16-19 and 1290 -1860 m for 12-20. The geometry used was 25 receivers from 0 to 1524 m for a receiver spacing of about 60 m. As currently implemented, this program will zero any traces beyond critical angle; this will be

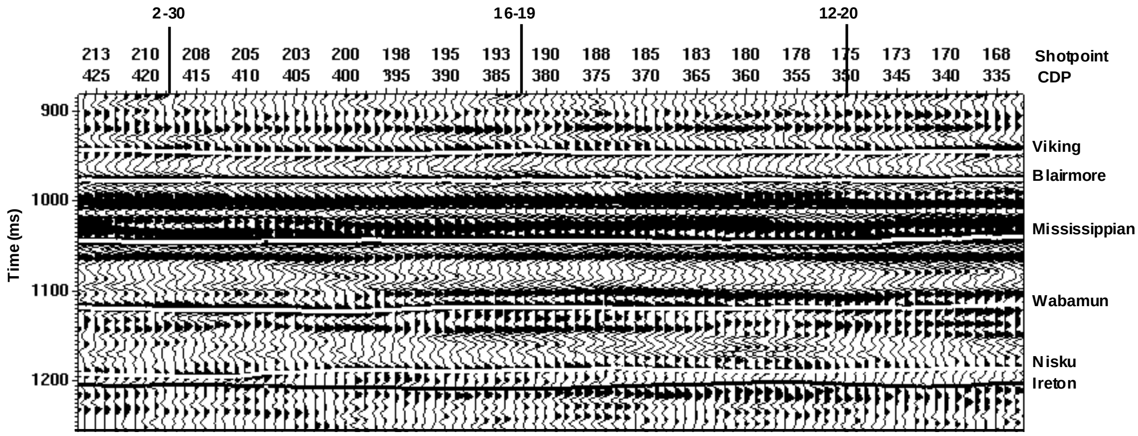

Fig. 3. Interpretation of the central part of *P-P* data from line EKW-002.

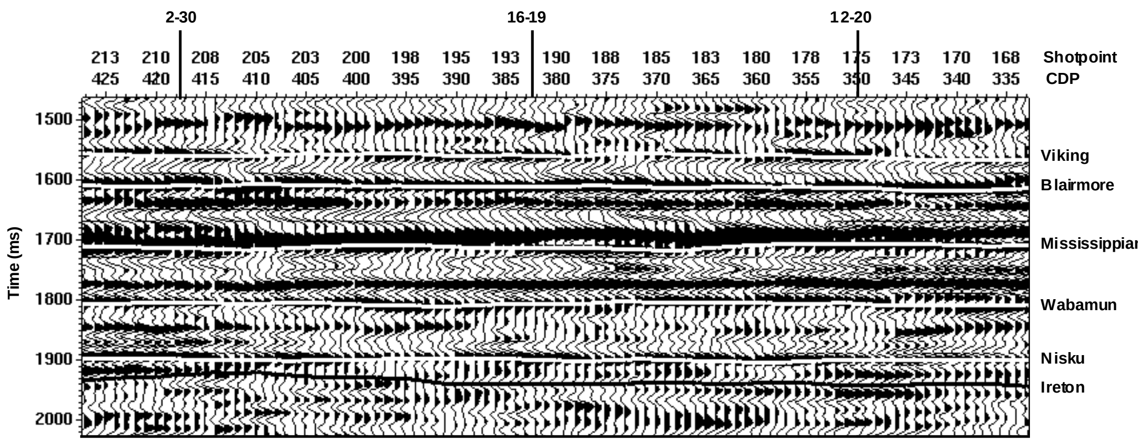

Fig. 4. Interpretation of the central part of *P-S* data from line EKW-002.

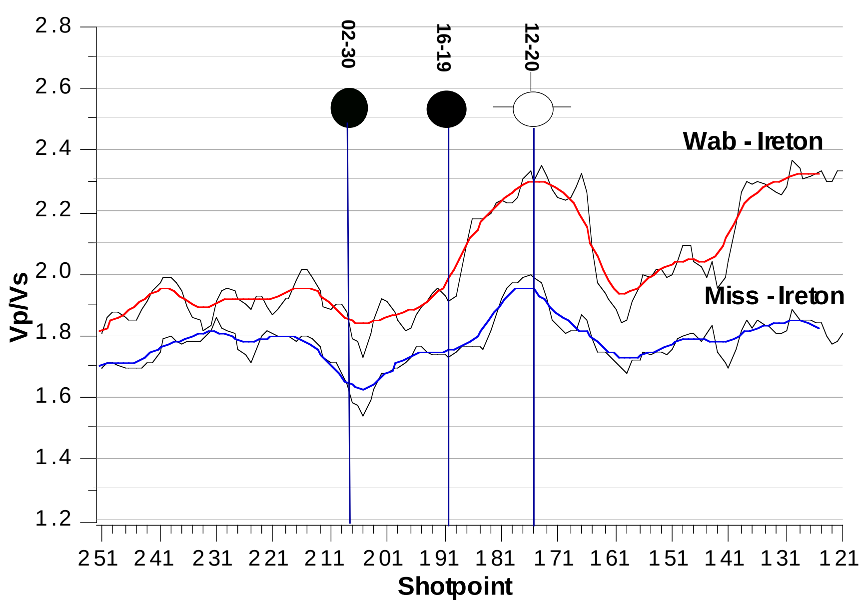

Fig. 5. *Vp/Vs* values for line EKW-002 for two intervals which contain the Nisku reservoir, showing the the actual data picks and smoothed overlays. *Vp/Vs* is lower across the dolomite buildup, where the two oil wells are located.

changed in future versions. Unless otherwise specified, a 40 Hz Ricker wavelet was used for the *P-P* models. All the models have been NMO-corrected.

The primaries-only *P-P* offset model from 16-19 is shown on the left in Figure 6. The same model was then run including all intrabed multiples and all intrabed conversions, shown on the right in Figure 6. The effects, primarily evident after the Mississippian event include:

- the subtle peak immediately below the Mississippian shows a significant increase in amplitude,
- the character of the Wabamum event changes; it is more difficult to pick the top,
- additional events appear at 995 and1060 ms (zero-offset time),
- the trough above the Nisku is much brighter,
- character changes on the Nisku event; it becomes a double peak and the porosity trough and base of porosity lower peak are no longer discernable (1100 and 1110 ms on the primaries-only model).
- the Nisku maximum amplitude is delayed, and,
- as offset increases, events exhibit residual moveout due to local conversions; this will degrade the stack.

In order to better understand the source of the intrabed multiple interference, the target zone was progressively thinned from the top. The output seismograms suggested that the primary source of multiple interference is from the low-velocity coal beds in the Upper Mannville.

Effect of Wavelet

The choice of wavelet when modelling can have a substantial influence on interference effects. Figure 7 shows a comparison of four wavelets on stacked offset synthetic seismograms modelled with all intrabed multiples and conversions. The bandpass wavelet has the same passband as the filtered stacked *P-P* seismic data. The next wavelet was extracted from the data using the 16-19 and 12-20 sonic logs. The statistically extracted wavelet did not utilize well logs and has a constant phase of zero. The 40 Hz zero-phase Ricker wavelet is shown for comparison The first three wavelets have more side lobes than the Ricker wavelet and thus produce seismograms with a ringier appearance. These side lobes contribute significantly to the interference effects from intrabed multiples and conversions.

The seismograms with the statistically-extracted wavelet and the 40 Hz Ricker are very similar and best match the seismic section. The stacked seismogram with the 40 Hz Ricker wavelet is spliced into the *P-P* seismic line at the 16-19 well location in Figure 8. This seismogram contains intrabed multiples and local conversions. As mentioned in the correlation discussion, the input well log was not stretched below the Mississippian, and there is still a time mistie; the synthetic seismogram has been aligned to match at the Nisku. The high amplitude peak just after the Mississippian event on the seismogram also appears in the data. The Wabamun is less ringy on the seismogram than on the data, but there is a good character match at the central event. The character match is also good at the Nisku. This seismogram, containing intrabed multiples and local conversions, matches the data better than the primaries-only seismogram shown in Figure 1. This supports the hypothesis that misties between synthetic models and the *P-P* seismic data are due to short-path multiple interference.

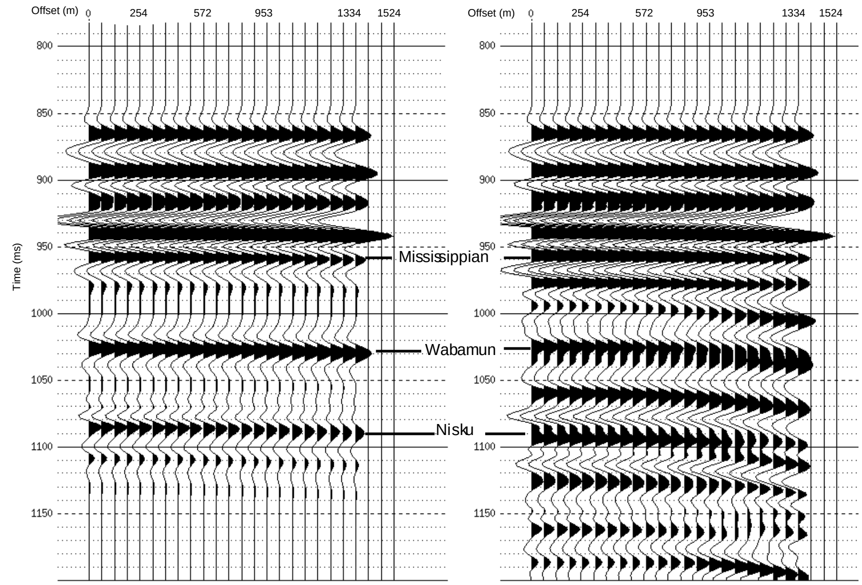

Fig. 6. *P-P* offset synthetic seismograms are created from the 16-19 well using *P*-sonic and density logs. The seismogram on the left is modelled with primaries only, whereas the seismogram on the right is modelled with primaries and all intrabed multiples and conversions.

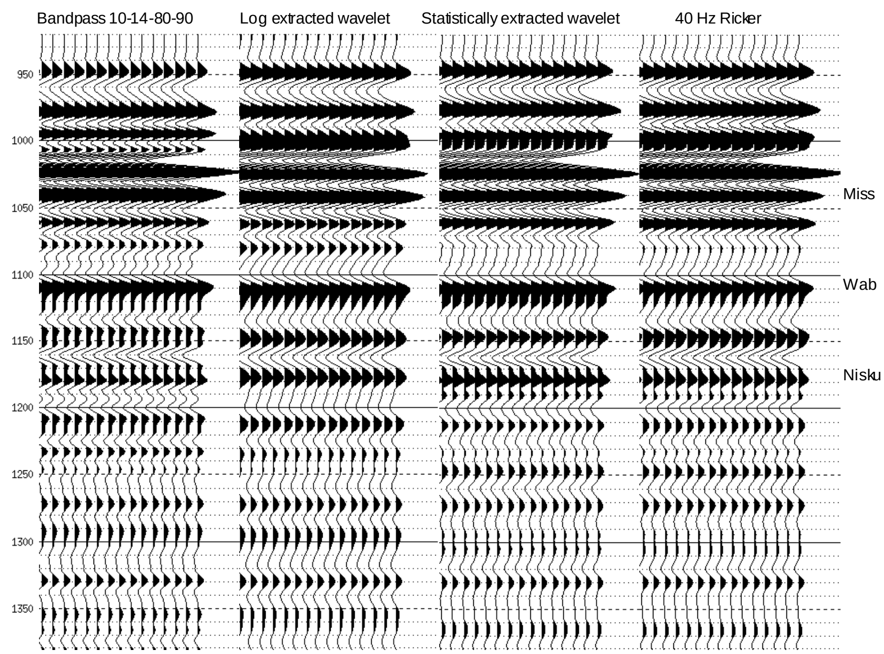

Fig. 7. Comparison of four wavelets on *P-P* offset synthetic stacked seismograms modelled with all intrabed multiples and conversions.

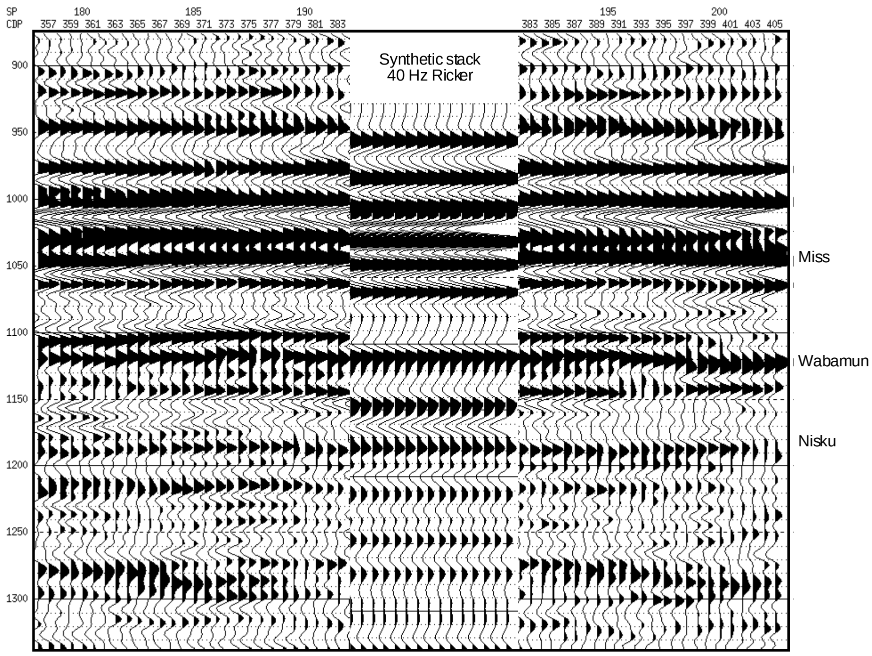

Fig. 8. The *P-P* offset synthetic stack with all intrabed multiples and conversions is spliced into the *P-P* seismic line at the 16-19 well location.

Modelling of the 12-20 well

The full-elastic wave modelling results have important implications for *Vp/Vs* analysis. This procedure incorporates *P-P* isochrons, which will be altered if multiple interference is causing events to have an apparent time delay. Since the goal of this analysis is primarily to detect lateral variations in *Vp/Vs*, the modelling was repeated at the 12-20 well to see if a comparable delay was observed on seismic events. Figure 9a shows the 16-19 stacked synthetic seismogram with primaries only on the left, and all intrabed multiples and conversions included on the right. The top line shows the correct Nisku pick from the primaries-only model, and the lower line is the pick made on the model with multiples and conversions. The inclusion of multiples and conversions delays the pick by 10 ms. In Figure 9b, the 12-20 well is modelled without intrabed multiples and conversions (left) and including them (right). The Nisku pick on the left uses the well log top and is correct, whereas the pick on the right is the peak amplitude of the Nisku event. Again, there is a 10 ms delay between the two. This suggests that multiple interference may introduce a systematic error to the *Vp/Vs* analysis. Althought this will affect absolute values, lateral variations in *Vp/Vs* will remain intact provided that the delay on the picked horizon is laterally constant.

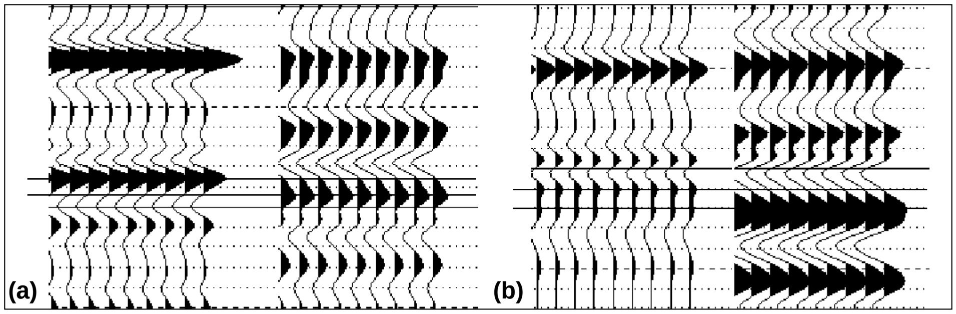

Fig. 9. (a) The 16-19 stacked synthetic seismogram with primaries only on the left, and all intrabed multiples and conversions included on the right. (b) The 12-20 stacked synthetic seismogram with primaries only on the left, and all intrabed multiples and conversions included on the right. The bold lines indicate the Nisku picks, which have been delayed by multiple interference by about 10 ms for both wells.

DISCUSSION

Two orthogonal three-component seismic lines were shot by Unocal in January, 1987, over the Nisku Lousana Field in central Alberta. The purpose of the survey was to investigate a Nisku patch reef thought to be separated from the Nisku shelf to the east by an anhydrite basin. These data have been reprocessed and are currently being analyzed and used to develop methods of multicomponent seismic data analysis. Several techniques which are useful in the analysis of multicomponent data are described and applied in this study. The data are of overall good quality and major events were confidently correlated between the *P-P* and *P-SV* sections using offset synthetic seismograms. *P-SV* offset synthetic modelling was also used to extract interval *Vp/Vs* values from the *P-SV* data.

The inclusion of intrabed multiples and local conversions in the *P-P* offset synthetic seimograms resulted in a better tie to the data. This modelling will next be extended to the *P-S* case to better understand how intrabed multiples differ between *P-P* and *P-S* seismic data, and the effect of *Vp/Vs* on multiple interference.

ACKNOWLEDGMENTS

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