Preliminary interpretation of *P-P* and *P-S* seismic data from the Blackfoot broad-band survey

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ABSTRACT

A 4.0 km 3C-2D broad-band seismic line was acquired over the Blackfoot Field near Strathmore, Alberta in the summer of 1995. The target rocks are incised valley fill clastic sediments within the Glauconite Formation of the Lower Cretaceous period. The exploration objectives of the survey were to determine if, through coupled analysis of *P-P* and *P-S* seismic data, clean channel sands could be distinguished from shale-plugged channels and regional non-channel sediments.

Preliminary modelling indicates that the channels can be defined seismically by character changes on both the *P-P* and *P-S* sections. *Vp/Vs* analysis of the synthetic *P-P* and *P-S* cross sections showed a clear distinction between sandstone and shale lithologies within the zone of interest. The average interval *Vp/Vs* was lower at the sand channel (1.85) than at either a shale-plugged channel or the regional section (1.93).

The vertical and radial components of the 10 Hz seismic data were correlated using *P-P* and *P-S* offset synthetic seismograms generated from dipole sonic logs. Corresponding horizons were interpreted on the migrated *P-P* and *P-S* sections. In general, the models matched the data quite well, and were useful in developing the interpretation. Both the *P-P* and *P-S* sections showed character changes in the interpreted sand-channel facies which were consistent with the models.

Interval *Vp/Vs* values were calculated from *P-P* and *P-S* isochrons across intervals containing the zone of interest. The *P-P* section is interpreted to have a time-structural low at the Mississippian unconformity which partially coincides with the projected location of the channel. This time structure is much less evident on the *P-S* section. As a result, the interval *Vp/Vs* value is anomalously low at this location, about 1.75 compared to an average value of about 2.00. The trend to a lower *Vp/Vs* value in the channel is in agreement with the model response, although the amplitude of the anomaly is larger than the model predicts. The reason for the large difference in time structure on the Mississippian unconformity is presently unclear. Further processing and modelling are planned.

INTRODUCTION

A 4.0 km 3C-2D broad-band seismic line was acquired over the Blackfoot Field near Strathmore, Alberta in the summer of 1995. The acquisition and processing of the data are discussed elsewhere in this report (Gallant et al., 1995; Bertram et al., 1995; Gorek et al., 1995). This paper discusses the interpretation of the 10 Hz vertical (*P-P*) and radial (*P-S*) components from this seismic line.

The Blackfoot Field is located in Township 23, Range 23, West of the 4th Meridian, in south-central Alberta (Figure 1). The targets are Glauconitic incised valleys in the

Lower Mannville Group of the Lower Cretaceous. The 3C-2D seismic line 950278 crosses one such valley as shown in Figure 1. This map is an isopach of channel thickness based on well control and 3-D seismic data; it indicates gross thickness of the channel fill but no lithologic distinctions (Politylo, A., 1995, personal communication). The channel facies consists primarily of very fine to medium grained quartz sandstone with porosities averaging 18%, though it does shale out in some locations.

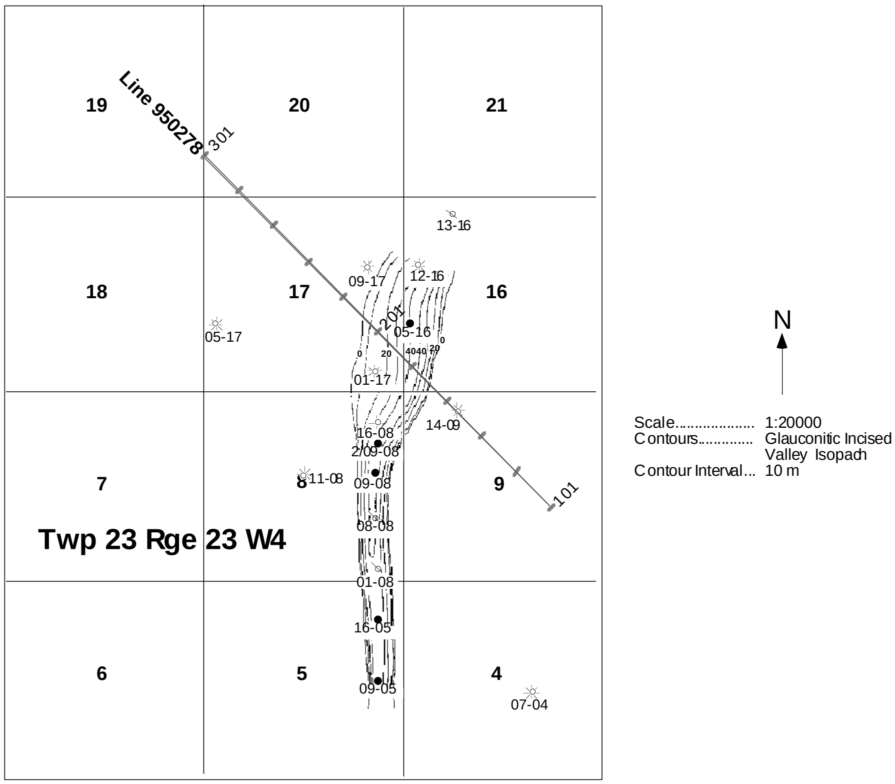

Figure 1. Location map of 3C-3D seismic line 950278, well control and incised valley isopach. (Isopach map from Politylo, A., 1995)

The two primary exploration objectives of the 3-C survey were to: 1) distinguish channel from regional facies, and, 2) determine sand/shale ratios within the incised valley systems. Additionally, this 2-D dataset serves as a template for the acquisition, processing and interpretation of the 3C-3D seismic survey to be conducted over this same field in November, 1995. Other scientific goals of this study are discussed by Stewart (1995) in this volume. Modelling and interpretive studies of the broad-band 3C-2D dataset are ongoing; this interim report describes the work done to date and future plans.

Geology

The target rocks are incised valley fill sediments within the Glauconite Formation of the Lower Cretaceous. For the purposes of this paper, the terms channel and incised valley will be used interchangeably. The Glauconite strata are part of the Upper Mannville Group and represent the maximum transgression of the boreal Moosebar/Clearwater Sea from the north and the early stages of the subsequent regression. South of Edmonton, the Glauconite is a progradational deltaic sequence capping brackish bay sediments of the Ostracod Formation. Numerous incised valleys filled with fluvial and estuarine facies are present in southern Alberta, trending in a northwesterly direction. These range in scale from major valley systems, which can be correlated regionally, to small ones associated with local fluctuations in relative sea-level.

The Glauconite sands are a lucrative target as cumulative production in Southern Alberta has been over 200 MMbbls and 400 BCF gas. Reservoir rocks are generally found in structural and stratigraphic traps where porous channel sands pinch out against non-reservoir regional deposits or low porosity channel sands. The Glauconitic Sandstone varies from zero to over 35 m in thickness and is encountered at a depth of approximately 1550 m in the study area. The stratigraphic sequence near the zone of interest is shown in Figure 2.

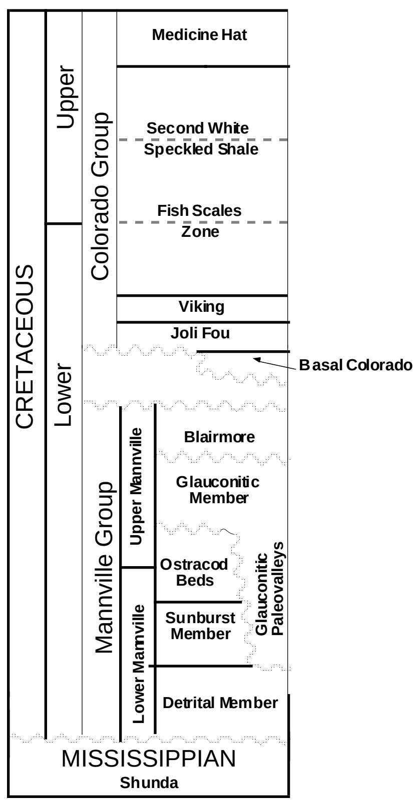

Figure 2. Stratigraphic sequence near the zone of interest. (Modified from Leckie, D.A. et al., 1994 and Wood, J.M. and Hopkins, J.C., 1992)

The Glauconitic consists of very fine to medium grained quartz sandstone in the eastern part of Alberta, and glauconite is only common northwards of central Alberta. The sediments of the channel in this study are subdivided into three units corresponding to three phases of valley incision; all three cuts may not be present everywhere. The lower and upper members are made up of quartz sandstones with an average porosity of approximately 18%, while the middle member is a relatively denser lithic sandstone. The channel sands shale out in some locations, such as at the 12-16 well. The primary hydrocarbon is oil, although gas may also be present in the upper member. The individual members range in thickness from 5-20 m.

The incised valley cuts to varying depths through the underlying strata and thus the base may be found directly overlying one of several formations. The Ostracod beds underlying the Glauconitic are made up of brackish water shales, argillaceous, fossiliferous limestones and thin quartz sandstones and siltstones (Layer, D. B. et al, 1949). The thin, low velocity Bantry Shale Member underlies the Ostracod but is not laterally persistent. The Sunburst Member/Basal Quartz Member contains ribbon and sheet sandstones made up of sub-litharenites and quartzarenites. The Detrital (Deville) Beds make up the basal part of the Mannville Group. This unit has an extremely heterogeneous lithology containing chert pebbles, lithic sandstone, siltstone and abundant shale. Its distribution is largely controlled by depressions in the pre-Cretaceous erosional surface and, as such, its thickness is also highly variable over short distances.

Within the study area, the Mannville Group lies unconformably over Mississippian carbonates of the Shunda Formation. The erosional contact surface has an irregular topography and, as the Shunda is shalier up-section, it cuts into varying lithologies. Lows and highs on the Mississippian seem to have been compensated by the time of deposition of the Glauconitic and do not seem to control the location of the channels (Politylo, A., 1995, personal communication).

Seismic and well data

There are sonic and density logs available for the wells shown in Figure 1. The 14-09 well is on the seismic line and has a *P*-sonic log and a density log. Three of the wells, 08-8, 12-16, and 09-17, have dipole sonic logs and thus have both *P*-wave and *S*-wave sonic curves. These wells were projected onto the seismic line, using the contours from the channel isopach map in Figure 1 as a guide. The dipole logs were only acquired from the top of the Mannville Group to the Mississippian unconformity, an interval roughly 300 m thick. The 08-08 is a productive well with 43 m of incised valley fill sediments, 38 m of which is sandstone. The 12-16 is also in the incised valley, but is primarily shale at the Glauconitic level.

The seismic data used in this interpretation are the migrated vertical (*P-P*) and radial (*P-S*) components from the 10 Hz 3-C geophones from line 950278, shown in Figures 3 and 4. The *P-S* section is plotted at 2/3 the scale of the *P-P* section. Both seismic sections show good coherent reflections which are roughly correlatable. The zone of interest is at about 1050 ms on the *P-P* section and 1700 ms on the *P-S* section.

SEISMIC MODELLING

Cross-section model

Structural cross section models were created using the three wells with dipole sonic logs: 08-08, 12-16, and 09-17. These wells represent each of the sand channel, shale channel, and regional environments respectively, and thus were used to predict the

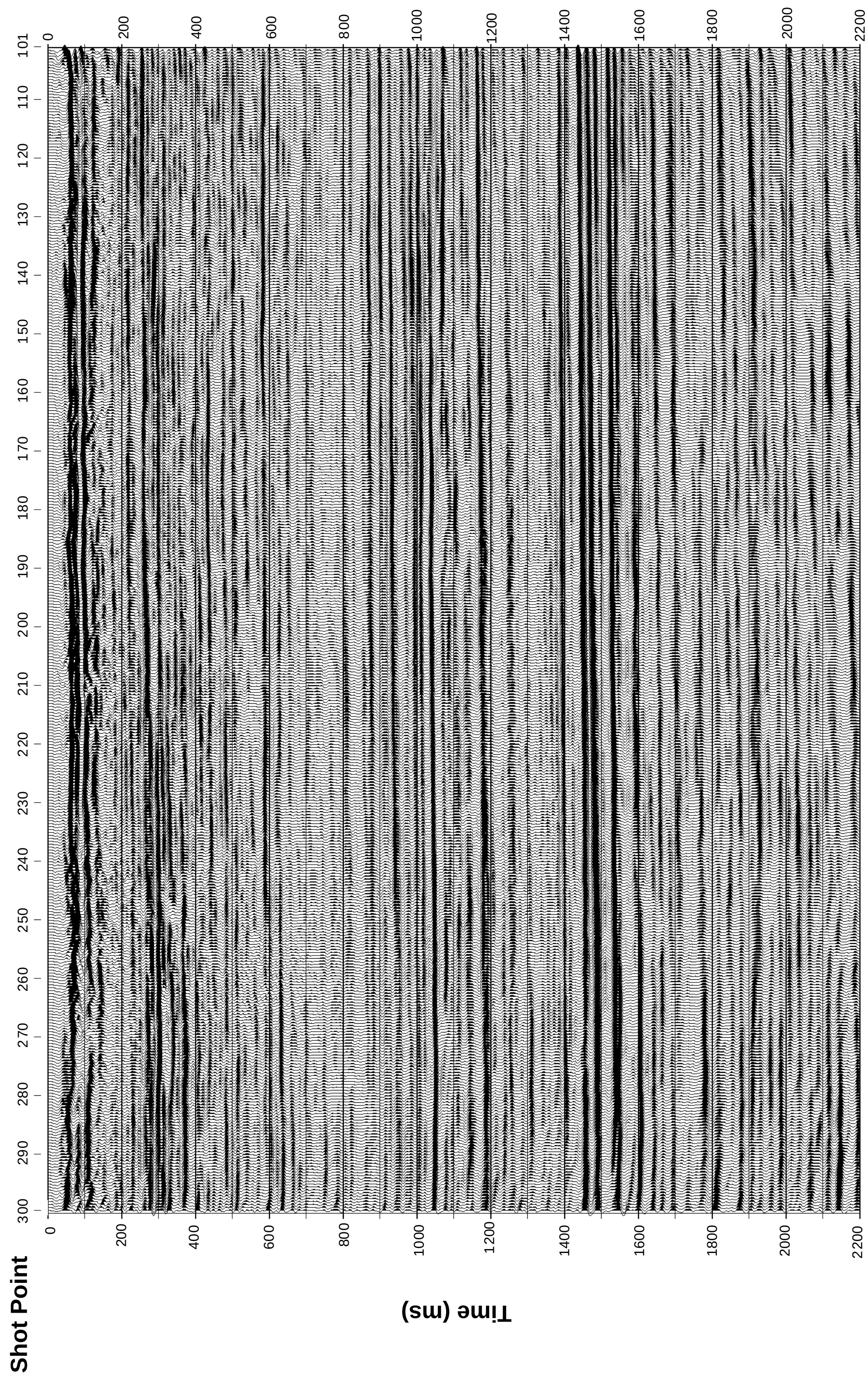

Figure 3. Migrated vertical component of 10 Hz, 3-C geophone data from line 950278.

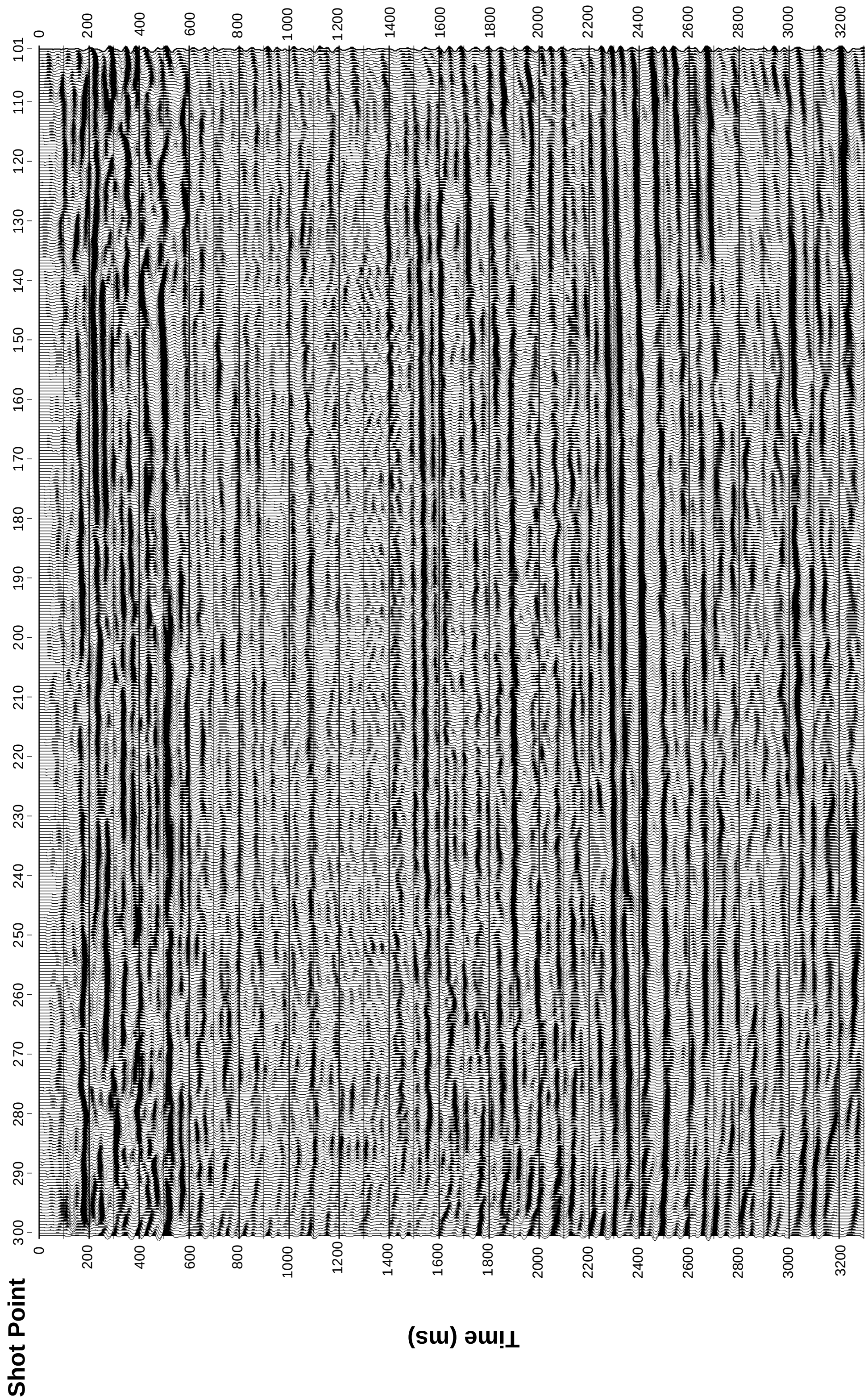

Figure 4. Migrated radial component of 10 Hz, 3-C geophone data from line 950278.

corresponding *P-P* and *P-S* seismic responses. The models were created from the synthetic cross-section program described by Margrave and Foltinek (1995). To create the cross section, well logs are interpolated between the actual logs. This was done for the *P*-sonic, *S*-sonic and density logs; the interpolated log cross sections for the *P*- and *S*-sonic logs are shown in Figure 5.

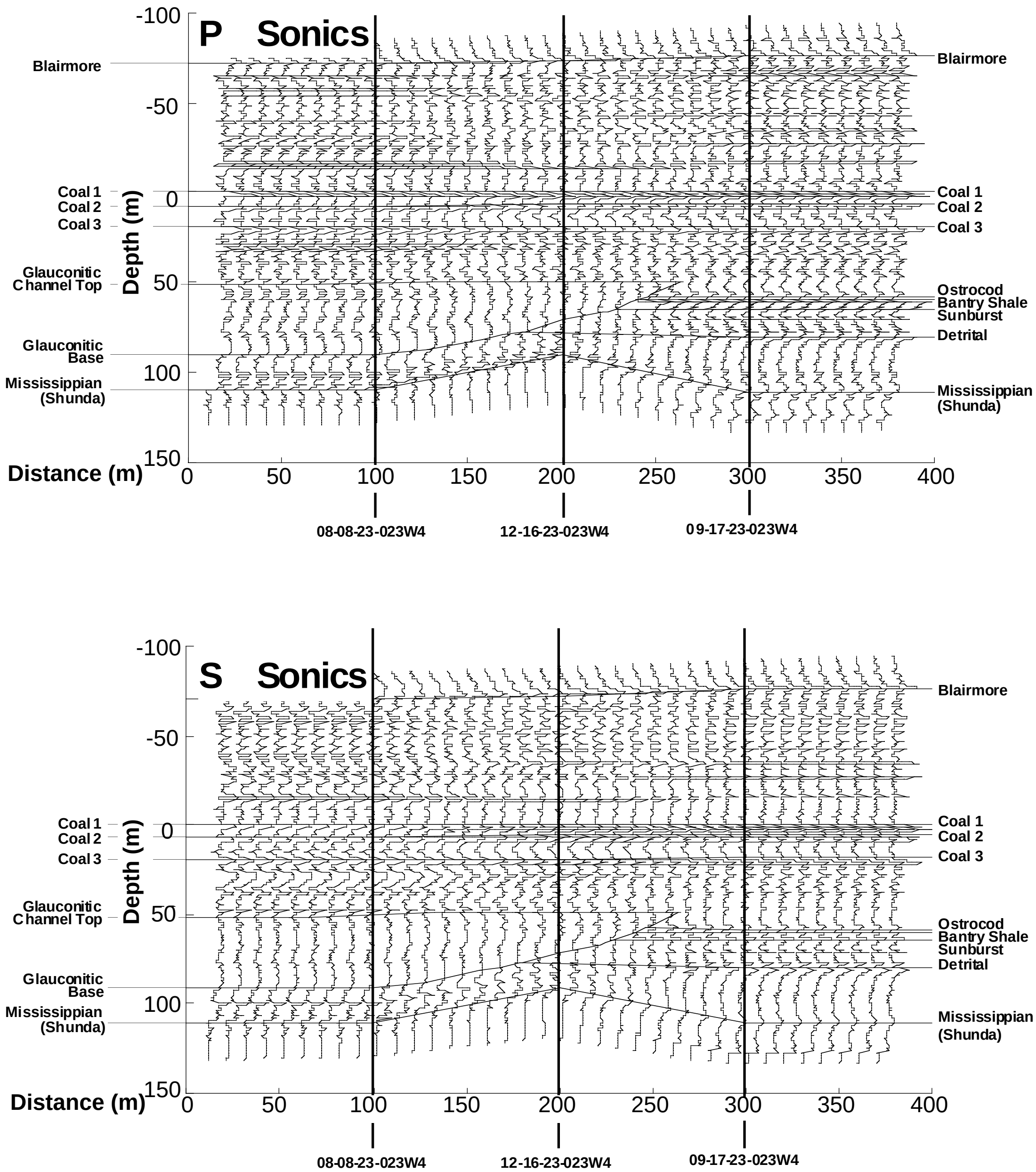

Figure 5. Well log sections using *P*- sonic (above) and *S*-sonic (below) logs interpolated from the three wells 08-08, 12-16 and 09-17. Coal 1 has been used as the datum.

At each log location, an offset synthetic seismogram is generated using the *P*-wave sonic curve, *S*-wave sonic curve, and density curve. The offset seismogram is then stacked and a single trace is displayed at that location. Offsets were 0 to 1500 m with a receiver spacing of 100 m. Bandpass wavelets were used with frequencies of 8-12-75-

85 for the *P-P* model and 5-10-35-45 for the *P-S* model. The log integration interval was 2 ms for the *P-P* model and 3 ms for the *P-S* model. These parameters gave the best match to the data. The *P-S* data have been plotted at 2/3 the scale of the *P-P* data to assist in visual correlation. 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 impedance.

The *P-P* cross section with horizon tops is shown in Figure 6 (it should be noted that the absolute times on the models are not expected to match those on the real data). The upper portion of the model does not change substantially, although tuning affects the character of some events. The zone of interest begins beneath the Mannville coals at about 820 ms. The far right of the model, at well 9-17, represents the regional section. There is a trough at the Ostracod Limestone/Bantry Shale formation tops of the Lower Mannville Group. The Bantry shale is very low velocity (see Figure 5) and thus may be mistaken for channel sands. Beneath this a broad, low amplitude peak occurs at the Sunburst and Detrital tops. The model terminates in the Shunda Fm at the Mississippian unconformity, which is a strong peak.

Moving left toward the 12-16 well the model enters the channel environment. The channel has cut through the Ostracod/Bantry shale and the Sunburst Fms, so that the upper trough now marks the top of the Glauconitic Fm. The 12-16 well is in the channel but has only a thin sandstone and is primarily shale in the Glauconitic Fm. A second trough is developing near the lower part of the channel, but is still low amplitude. There is substantial topography on the unconformity, as indicated by the earlier arrival time of the Mississippian (Shunda) peak. Further left the channel thickens and the lithology changes from shale to porous sandstone. The upper trough continues and increases in amplitude, seismically defining the porous upper member of the Glauconitic channel sands. The peak which begins to develop immediately beneath it is the tight middle member, and the lower trough is the event from the lower porous member. There is only a small amount of Detrital Fm in this well, and the Mississippian is high relative to the regional well. In this *P-P* model, the channel is defined by the brightening of the upper trough and the development of the middle peak and lower trough.

The *P-S* cross section with horizon tops is shown in Figure 7. Above the zone of interest, there are three positive events which continue across the section: the peak whose zero-crossing occurs near the Blairmore top, a second peak at about 1250 ms, and a third peak which occurs beneath the coals and broadens away from the channel. At the regional 09-17 well, there is a broad trough near the Ostracod/Bantry Shale, followed by a low amplitude peak at the top of the Detrital Fm and the Mississippian peak. Entering the channel at the 12-16, the Detrital peak is no longer evident. The upper trough occurs near the Glauconitic Fm top as the channel cuts down through the Ostracod/Bantry Shale and the Sunburst Fm. This trough broadens as the channel thickens and the lithology changes from predominantly shale fill to predominantly sandstone fill. The three channel members are not clearly defined due to the narrower bandwidth of the wavelet. In this *P-S* model, the channel is defined by the broadening of the trough across the Glauconitic Fm.

As mentioned in the geology discussion, development of the channels is thought to be unrelated to the antecedent Mississippian topography. Therefore, although these

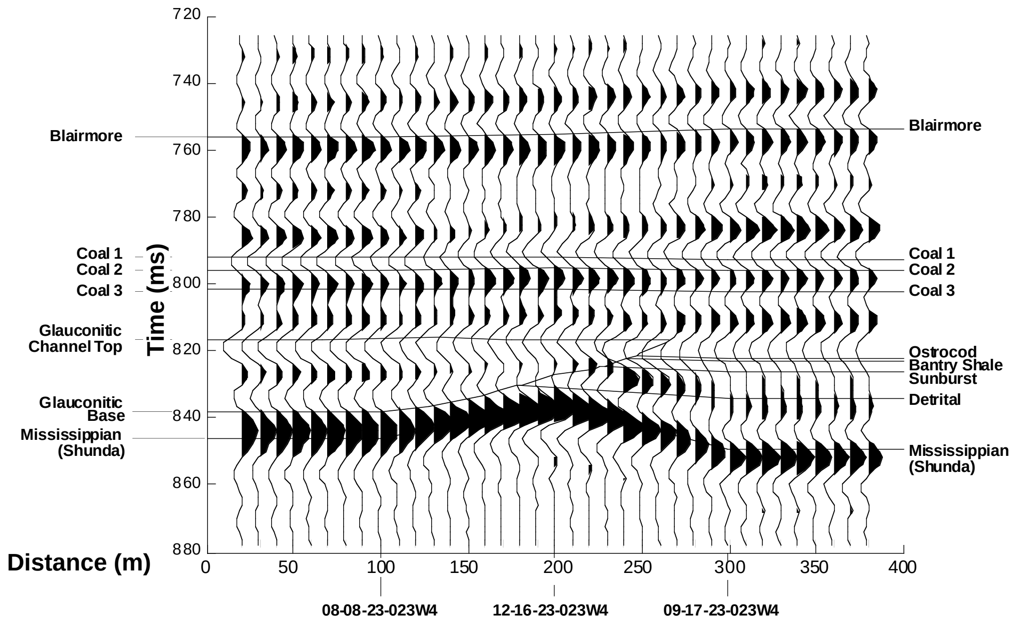

Figure 6. *P-P* synthetic seismogram section generated with a 8-12-75-85 bandpass wavelet. Horizons are flattened on Coal 1.

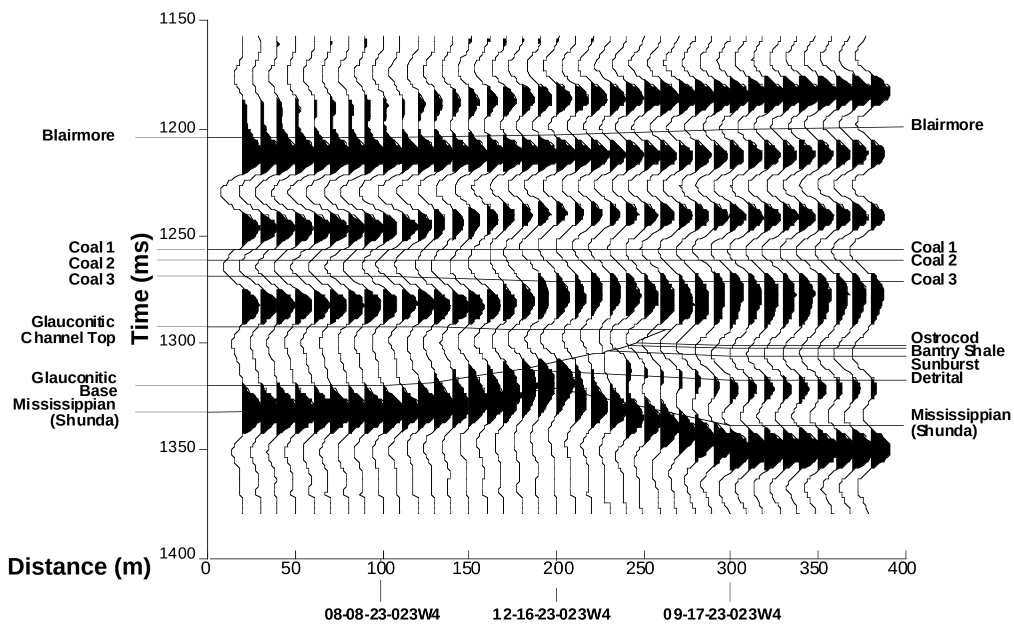

Figure 7. *P-S* synthetic seismogram section generated with a 5-10-35-45 bandpass wavelet. Horizons are flattened on Coal 1.

wells are examples from the three stratigraphic environments of interest, they are not necessarily representative of the seismic signature for each of these environments. That may vary depending on the topography of the Mississippian, the thickness of the Detrital sediments beneath the Glauconitic Fm, and the thickness of the channel sediments. In the channel, all three members may be present, as in the 08-08, or the middle and/or lower members may be absent. It should also be noted that this cross section does not represent an actual geological cross section across the channel. As shown in Figure 1, none of these wells are on the seismic line, nor does their line of section cross the channel.

Vp/Vs analysis of cross-section model

The cross section models were used to calculate average interval *Vp/Vs* values across the zone of interest. The measured interval extends from the peak which occurs immediately below the Mannville top to the Shunda peak at the bottom of the model, which is at the Mississippian unconformity. *P-P* and *P-S* isochrons were calculated from each of the models, and the average *Vp/Vs* across this interval was calculated using the relationship (Garotta, 1987):

$$Vp/Vs = (2Is/Ip) - 1 \tag{1}$$

where Is and Ip are the *P-S* and *P-P* isochrons across the same interval, respectively.

The results of this analysis are plotted in Figure 8. The dotted line shows the exact values, with a smoothed solid line overlay. *Vp/Vs* is significantly lower across the sand channel, about 1.85, than across either the shale-plugged channel or the regional section, where it averages about 1.93. Both seismic models were created from the same depth model, therefore such lateral variations in *Vp/Vs* may be due to velocity changes, which in turn are a result of changing facies in the zone of interest. This result is in agreement with the literature, which suggests that *Vp/Vs* will increase in clastics as shale or clay content increases (e.g. Castagna et al., 1985; Han et al., 1986, Eberhart-Phillips et al., 1989, Miller and Stewart, 1990). According to the modelling results, *Vp/Vs* analysis should assist in distinguishing between sandstone and shale lithologies in the zone of interest.

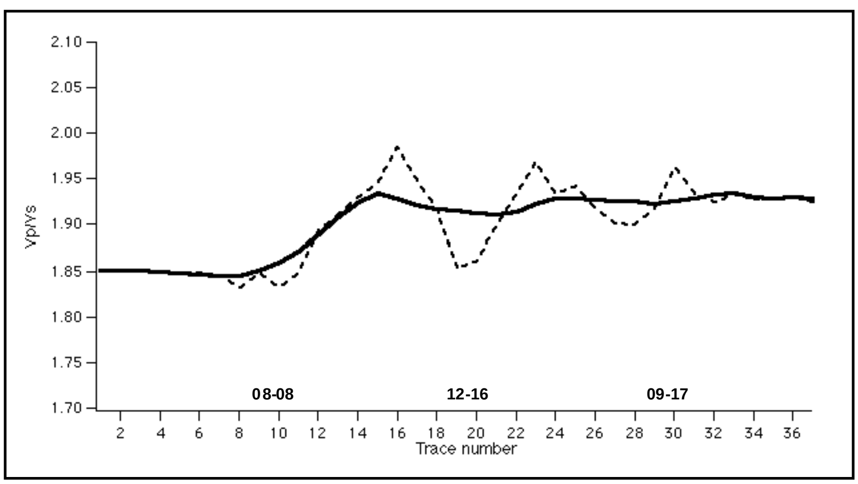

Figure 8. *Vp/Vs* values from the cross-section model for the interval from the Blairmore peak to the Shunda peak. The dotted line shows the actual picks and the solid line the smoothed version. Traces numbers are equal to the distance divided by 10 on the models. *Vp/Vs* is lower at the sand channel well (08-08) than at the shale channel well (12-16) or the regional well (9-17).

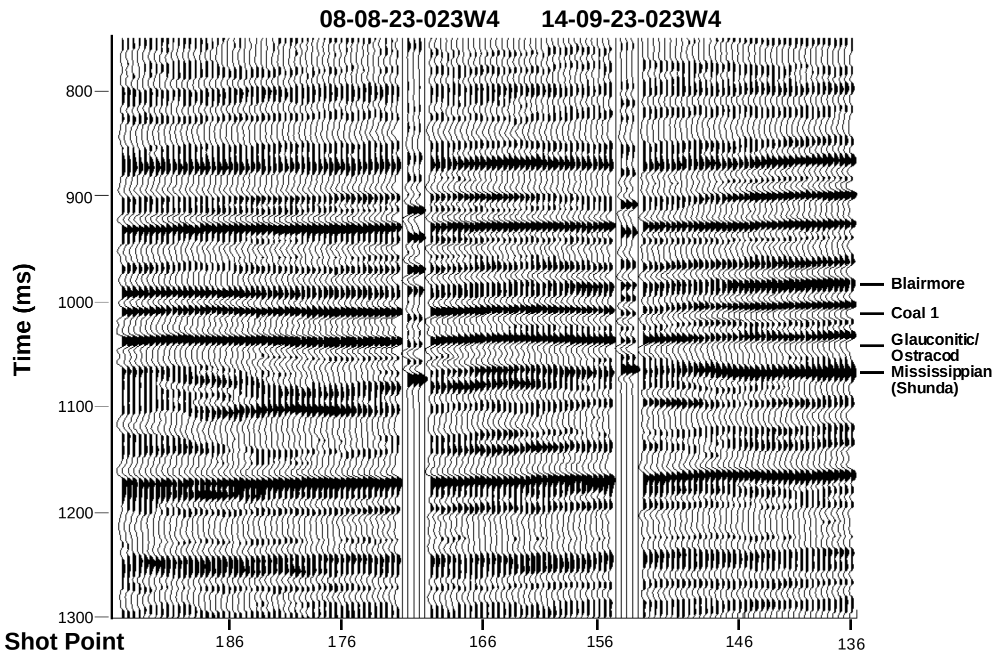

Figure 9. Blow-up of the migrated vertical section in the zone of interest showing the tie to the 08-08 and 14-09 *P-P* synthetic seismograms.

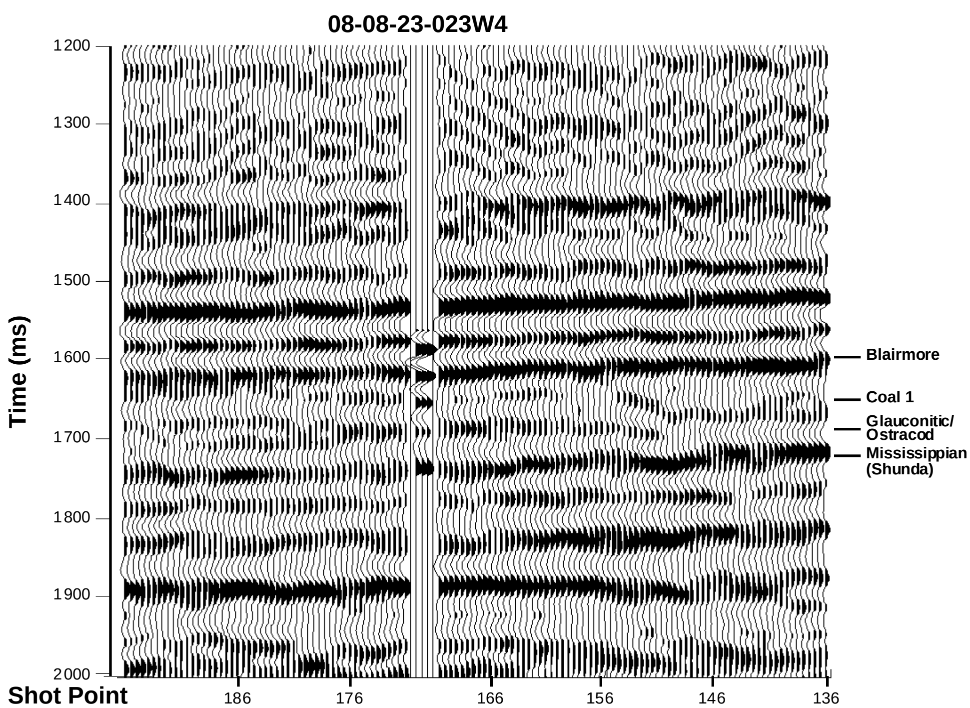

Figure 10. Blow-up of the migrated radial section in the zone of interest showing the tie to the 08-08 *P-S* synthetic seismogram.

PRELIMINARY SEISMIC INTERPRETATION

Correlation of *P-P* and *P-S* Seismic data

The identification of seismic events on the *P-P* data is shown in Figure 9. Two *P-P* synthetic seismograms are spliced into the line: 14-09 which is on the line, and 08-08, which has been projected onto the line at S.P. 171 using the channel isopach and the arrival time of the Mississippian as guides. Both zero-offset synthetic seismograms were created using a bandpass wavelet with frequencies 8-12-75-85, which is the bandpass filter applied to the *P-P* seismic data. The seismograms are not check-shot corrected, but a good tie between both synthetic seismograms and the data is evident. The seismograms were used to identify the seismic horizons.

To correlate the *P-P* and *P-S* seismic sections, offset synthetic seismograms were generated using the *P*-wave sonic curve, *S*-wave sonic curve, and density curves from the 08-08 well. *P-P* and *P-S* seismograms were created using the algorithm described in this volume by Margrave and Foltinek (1995). The parameters used were the same as for the *P-P* and *P-S* cross-section models. The 08-08 *P-S* synthetic seismogram is spliced into the *P-S* seismic section in Figure 10. The *S*-sonic log only covers a thin interval, but the events tie well. The peak after the Blairmore and the peak at the base of the coals are lower in amplitude than on the seismogram, and discontinuous across the seismic section.

The correlation of the *P-P* and *P-S* synthetic seismograms is shown in Figure 11. Although there is greater detail on the *P-P* seismogram because of the broader bandwidth, the major events correlate well.

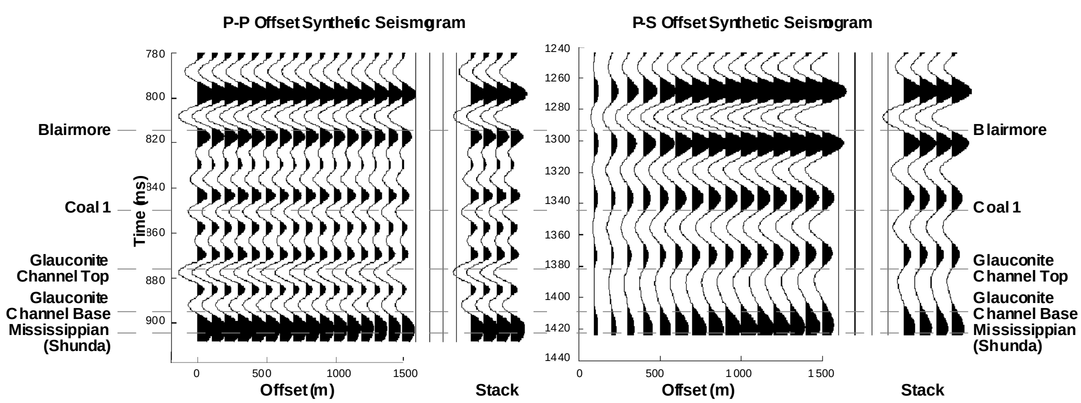

Figure 11. Correlation of *P-P* and *P-S* offset synthetic seismograms. Time scale of *P-S* seismogram is 2/3 that of *P-P*.

Data interpretation

After the *P-P* and *P-S* data were correlated and matching events were identified, the migrated sections were interpreted on a workstation. The *P-P* interpretation for part of the line over the zone of interest is shown in Figure 12. The eastern edge of the Glauconitic channel is interpreted to cut through the Ostracod and into the Detrital at about S.P. 161. The Detrital peak just above the Mississippian is replaced by a trough, which increases in amplitude westward. The central peak, indicative of the tight central member, also begins to develop at this point and increases in amplitude westward. The

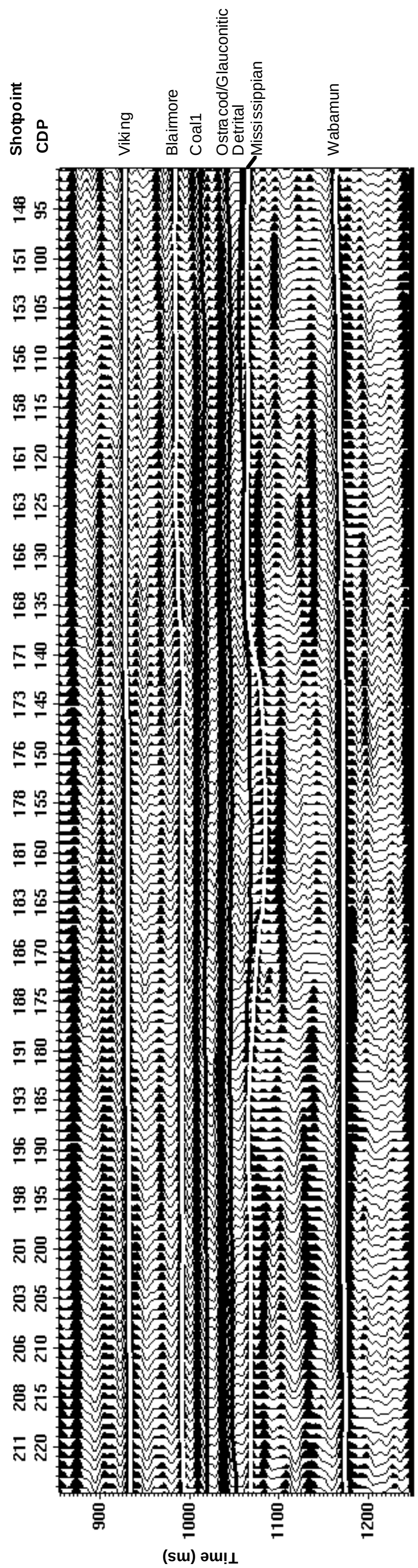

Figure 12. Interpretation of 10 Hz P-P data showing horizons of interest.

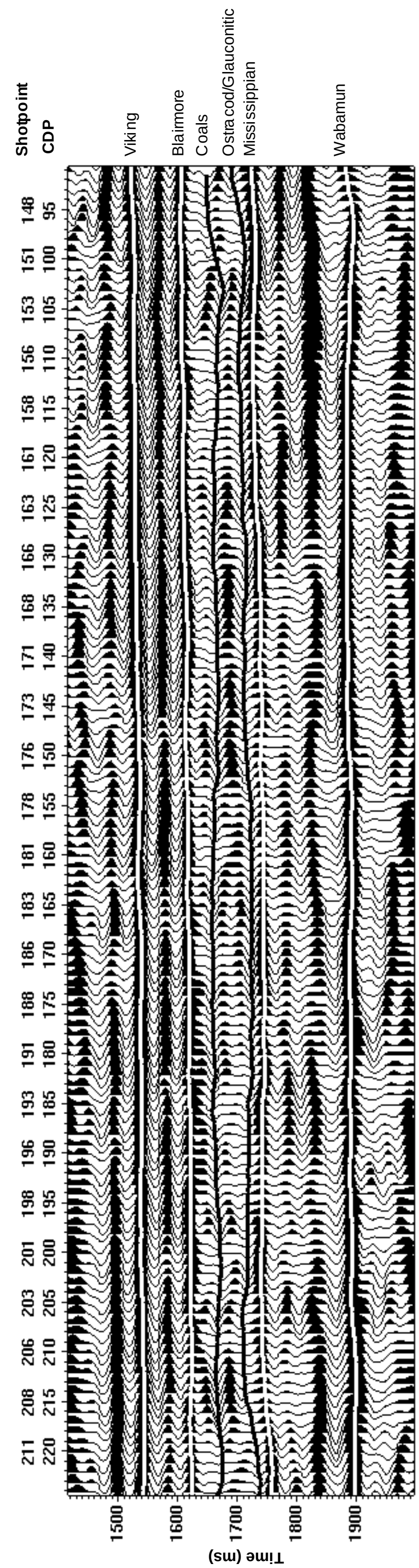

Figure 13. Interpretation of10 Hz P-S data showing horizons of interest.

trough-peak-trough pattern closely matches the seismic model in the sandstone channel (Figure 6). Coincident with the channel development is the Mississippian low from shotpoint 166 to 191. The Detrital then thickens sufficiently for the top of Detrital peak to appear above the Mississippian. The Detrital horizon overlay is not is not shown where the Detrital peak tunes with the Mississippian peak. The Mississippian is high at the 8-8 well and the Detrital is very thin, so the model matches the data best at about S.P. 171, where the Mississippian is shallower.

The western edge of the channel is harder to define, but may extend out to S.P. 211. The lower trough of the Glauconitic sandstone loses amplitude at about S.P. 186, where the Mississippian time structure appears shallower. The change in seismic character suggests that the channel may become shalier towards the western edge of the channel. The 12-16 well, which is shale at the Glauconitic, can be projected onto the seismic line at about S.P. 195. The upper trough is quite strong, and the central peak detectable, but the lower trough is poorly defined.

The 9-17 regional well should tie the line anywhere west of S.P 211, however, the tie is poor, both across the zone of interest and also above the coals, where the isochron between the first two peaks in the Mannville is much thicker on the seismogram than on the data. This well ties the data best on the easternmost part of this line, near S.P. 101, suggesting that 9-17 may not be truly representative of the regional stratigraphy as imaged along this line.

The *P-S* interpretation of the same portion of the line for the same interval is shown in Figure 13. The Blairmore event is clearly identifiable, as is the Mississippian event, although there are some amplitude variations on the latter. On the model (Figure 7) there are two strong and continuous peaks between these two events: one in the Upper Mannville (1250 ms) and a second just below the coals (1280 ms). These two events are discontinuous on the seismic data and appear only intermittently, as between shotpoints 219 to 238 and shotpoints 121-176. The cause of this dimming is unknown to date, as both the *S*-wave sonic curves and the model generated from them indicate otherwise. There is less time structure on the Mississippian event from shotpoints 166 to 191 than on the *P-P* section.

As with the *P-P* data, the channel portion of the model ties the *P-S* data best at about S.P. 171, where the broad trough indicates the channel sands. The two peaks between the Blairmore and the Mississippian are present here and match the synthetic model very well. The Glauconitic trough brightens at S.P. 162 at the interpreted eastern edge of the channel, broadens in the centre of the channel, and brightens again out to about S.P. 188, where the channel may be becoming shalier. The 12-16 well ties the data quite closely and shows the narrowing of the Glauconitic trough as the channel thins. The 09-17 ties well to the base of the coals, but the tie at the Mississippian is poor.

Vp/Vs **analysis of seismic data**

Interval *Vp/Vs* values were calculated for several intervals using the *P-P* and *P-S* isochrons and equation (1). Plots of these results are shown in Figure 14. The Viking to Mississippian (referred to in the figures as the Shunda) interval was preferred to the Blairmore to Mississippian interval as it showed the same trends but was less noisy. There is a *Vp/Vs* anomaly from shotpoints 167 to 191. This *Vp/Vs* anomaly is not apparent for the interval from the Viking (or the Blairmore) to the Wabamun; any effects from the zone of interest may have been averaged out over these thicker intervals. The *Vp/Vs* anomaly coincides with the time structural low on the Mississippian event on the *P-P* data; the *P-P* isochron thickens significantly, whereas the *P-S* isochron thickens only slightly (Figure 15).

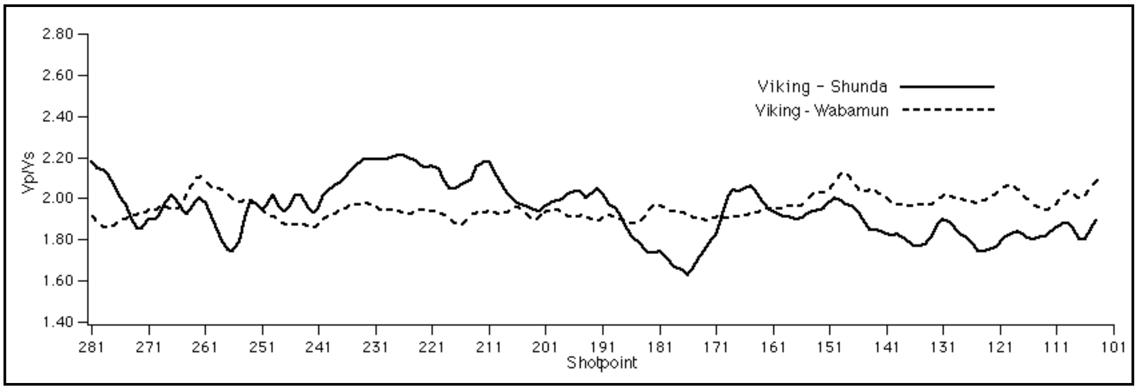

Figure 14. *Vp/Vs* values calculated for line 950278. *Vp/Vs* for the Viking to Shunda (Mississippian) interval was calculated from the isochrons in Figure 15 and shows a *Vp/Vs* low from shotpoints 167 to 191. The anomaly is no longer present when *Vp/Vs* is calculated for a thicker interval, from the Viking to the Wabamun.

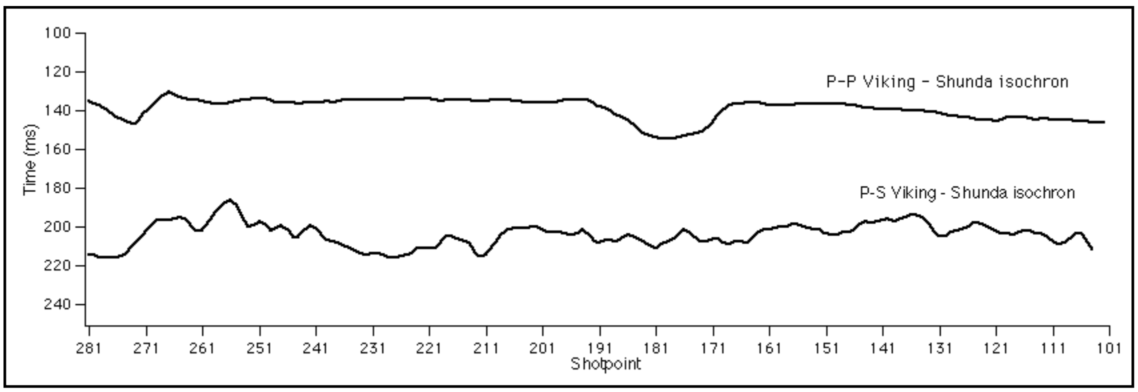

Figure 15. *P-P* and *P-S* isochrons measured from the line 950278 for the Viking to Shunda (Mississippian) interval. The time structure anomaly from shotpoints 165 to 191 on the *P-P* isochron is not present on the *P-S* isochron.

The decrease in *Vp/Vs* agrees with trend from the model, although the anomaly does not extend westward as far as the isopach map in Figure 1 indicates. According to our model, higher *Vp/Vs* values on the west portion of the channel indicates a transition to a shalier environment. This interpretation is supported by the change in seismic character on both sections. In addition, the shaley 12-16 well may tie the data on the western extent of the channel.

These results raise some questions. The underlying assumption of *Vp/Vs* analysis is that geological structure will affect both components equally and thus not affect the *Vp/Vs* ratio. In this case, the time structure on the *P-P* Mississippian event is responsible for the *Vp/Vs* anomaly on this data. If the Mississippian low is a *P*-wave velocity effect, it should affect later reflections, but there is no evidence of this. This raises two additional possibilities: 1) the *P*-wave Mississippian pick is incorrect, and should be higher, perhaps at what is currently identified as the Detrital, or 2) there is a true structural low on the Mississippian which is not being properly imaged on the *P-S* data.

The first explanation is possible in that the topography on the Mississippian complicates the interpretation. Wells which are projected onto the line have highly variable Mississippian tops. For example, using the channel isopach map, three wells can be projected onto the line at about S.P. 181: 09-08, 2/09-08, and 08-08. Each of these wells has a significantly different Mississippian elevation. The 08-08 synthetic seismogram puts the Mississippian peak where the Detrital is now interpreted to be, the 2/09-08 confirms the current Mississippian interpretation, and the 09-08 locates the top at the high amplitude peak below the current interpretation, at 1100 ms. Acquisition of the 3C-3D survey over this field should help to resolve this issue, as the wells can be tied at their correct locations.

The second explanation, that the Mississippian structure is not being properly imaged on the *P-S* seismic data, is also possible. The Mississippian event dims from S.P. 167 to 183 on the migrated section, whereas the amplitude is quite strong on the stacked unmigrated section. On the stacked section, the Mississippian event is also slightly lower in time over this shotpoint range. It may be possible to improve the imaging of this event by additional processing.

The *Vp/Vs* anomaly in Figure 14 is larger than the anomaly predicted by the model, shown in Figure 8. Thus, if either of the explanations given above is correct, it might reduce the anomaly somewhat to be more consistent with modelling results and yet still indicate the presence of sandstone channels.

CONCLUSIONS

Preliminary modelling and interpretation of the 10 Hz *P-P* and *P-S* seismic data from the Blackfoot survey has been presented. The exploration objectives of this survey were to determine if, through coupled analysis of *P-P* and *P-S* seismic data, clean channel sands could be distinguished from shale-plugged channels and regional non-channel sediments. Preliminary modelling indicates that the channels can be defined seismically on both the *P-P* and *P-S* sections. *Vp/Vs* analysis of the synthetic *P-P* and *P-S* cross sections showed that the average interval *Vp/Vs* was lower at the sand channel (1.85) than at either a shale-plugged channel or the regional section (1.93).

The vertical and radial components of the 10 Hz seismic data were correlated using *P-P* and *P-S* offset synthetic seismograms generated from dipole sonic logs. Corresponding horizons were interpreted on the migrated *P-P* and *P-S* sections. In general, the models matched the data quite well, and were useful in developing the interpretation. Both the *P-P* and *P-S* sections showed character changes in the interpreted sand-channel facies which were consistent with the model.

Interval *Vp/Vs* values were calculated from *P-P* and *P-S* isochrons across intervals containing the zone of interest. The interval from the Viking to Shunda Fm at the Mississippian unconformity shows a decrease in *Vp/Vs* which partially coincides with the projected location of the channel. This trend is in agreement with the model results, although the amplitude of the anomaly is larger than predicted. The *P-P* section is interpreted to have a time structure low on the Shunda horizon at this location which is less evident on the *P-S* section. This may result in a lower *Vp/Vs* than predicted by the model. The reason for the difference in the Shunda time structure between the *P-P* and *P-S* data is presently unclear. Further processing and modelling are planned.

FUTURE WORK

Several questions raised in this analysis which may be resolved by the 3C-3D survey. For example, the topography on the Mississippian complicates the interpretation. The pick should be more clear on the 3-D dataset, which will tie all the wells at their proper locations. Further processing may help to resolve some issues.

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