Multicomponent modeling of a conglomerate bar deposit

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ABSTRACT

A multicomponent seismic survey was obtained over the Carrot Creek oilfield of West Central Alberta. The data shows a significant Cardium amplitude anomalies on the radial component corresponding to producing conglomerate bodies. To obtain an understanding of the origin of these anomalies multicomponent modeling was undertaken. By generating and processing P-P (vertical component) and P-Sv (radial component) shot records both a P-P and P-Sv synthetic section were produced. The preliminary results obtained were quite encouraging in that amplitude anomalies corresponding to the location of the conglomerate bar were successfully modeled. Much more modeling must however be undertaken in order to determine the cause of the anomalies.

In addition the results showed the importance of using depth variant mapping, instead of an asymptotic technique, to sort converted-wave data. It was also shown that an improved P-Sv moveout correction for converted-waves is necessary. The velocities derived from the Dix equation for converted-waves overcorrects the data at far offsets.

The modeling results also indicated that AVO effects may be present on both the vertical and radial components of the surface seismic data.

INTRODUCTION

Although the acquisition of multicomponent surface seismic is becoming more prominant, the analysis and interpretation of the additional information obtained is still in its infancy.

This paper deals with the P-P (vertical component) and P-Sv (radial component) modeling of a multicomponent dataset obtained in the Carrot Creek oilfield of West Central Alberta (Figure 1). The motivation for this modeling is to gain a better understanding of this Carrot Creek dataset. More specifically to explain the occurance of converted S-wave amplitude anomalies observed on the radial component of the seismic data corresponding to the position of producing conglomerate bodies. The vertical component (P-P), on the other hand, exhibits only a very slight amplitude increase at these same locations. Figure 2 shows these anomalies for both the vertical and radial components respectively.

The bases of the model in which this modeling was undertaken are; well log, core and surface seismic information. It is hoped that by varying several of the model's parameters (ie. conglomerate thickness, Poisson's ratio) associated with these conglomerate bodies that the origin of these amplitude anomalies can be determined. These results will then be used to make conclusions about the usefulness of multicomponent seismic in identifying other Cardium, or similar clastic, plays.

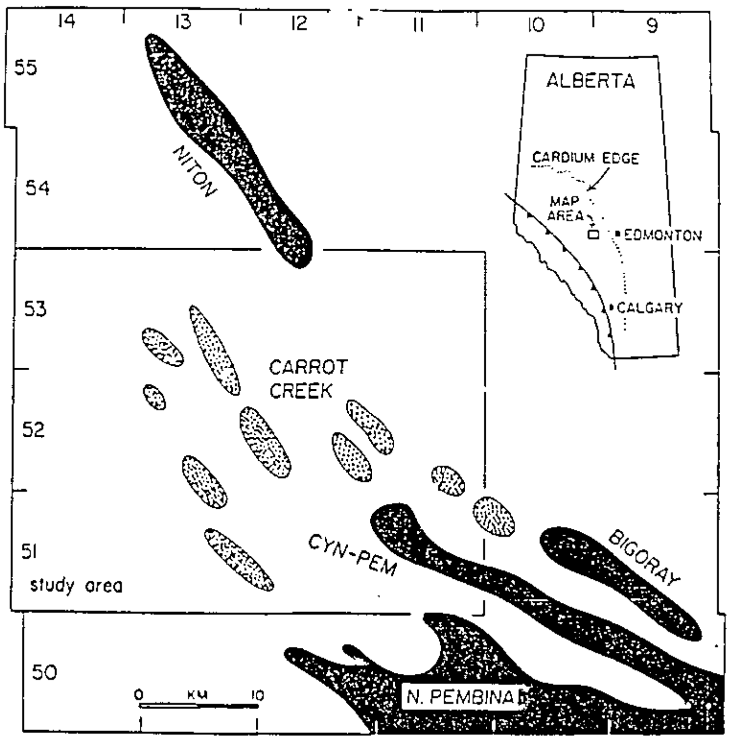


Figure 1: Carrot Creek Location Map (Bergman and Walker, 1987)

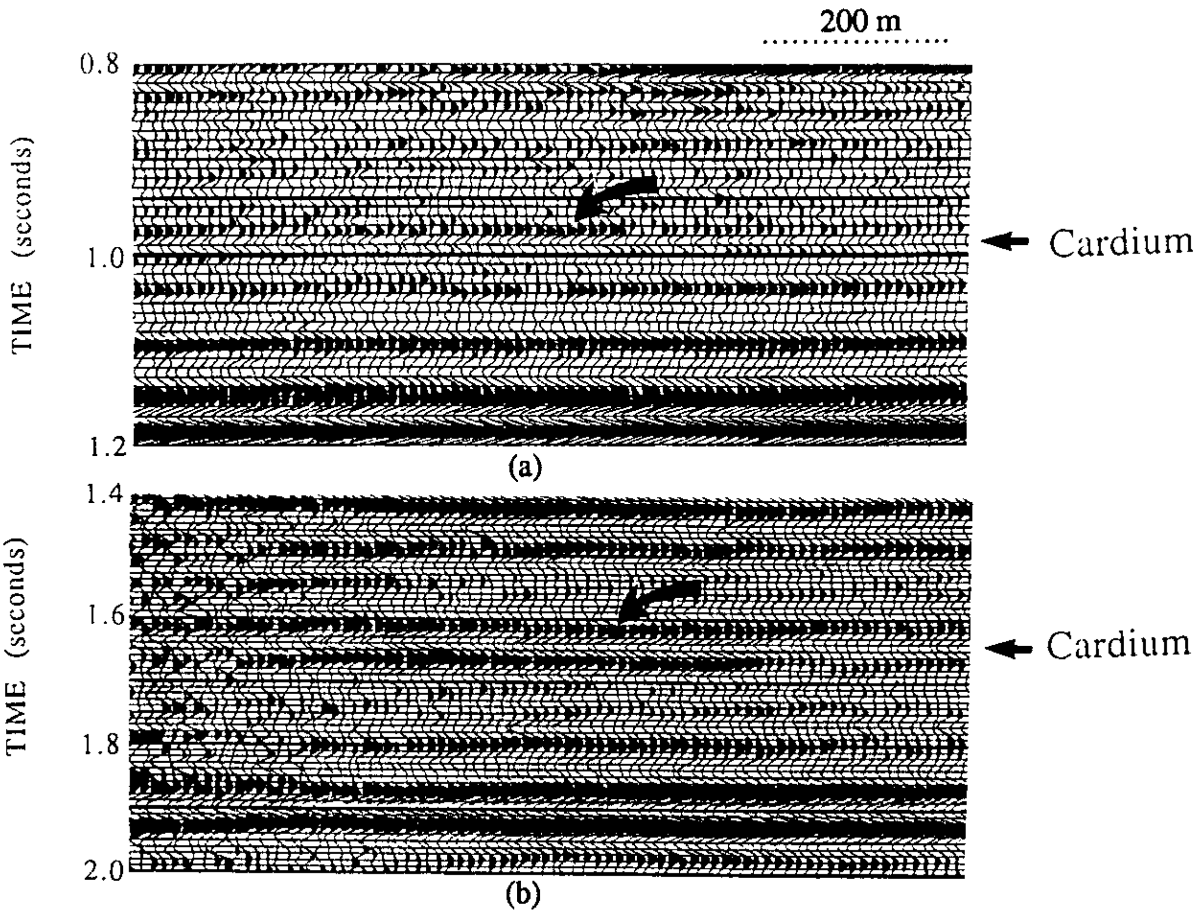


Figure 2: Carrot Creek Cardium amplitude anomalies on (a) the vertical and (b) the radial component of CCSW01

GEOLOGICAL BACKGROUND

The Carrot Creek field of West Central Alberta is located within townships 51-53 ranges 11-14 west of the 5th meridian, just N.W. of the Pembina oilfield (Figure 1). Initially discovered in 1963, it produces from several sandstone and conglomerate bodies of the Cardium Formation.

The Cardium Formation of the Carrot Creek field occurs at a depth of approximately 1550 m. It is underlain by the shales of the Blackstone Formation and overlain by the shales of the Wapiabi Formation (Williams and Burk, 1964). Krause and Nelson (1989) recognize two lithostratigraphic units within the Cardium Formation itself, namely the Pembina River Member and the Cardium Zone Member (Figure 3). Although this stratigraphy is based on the lithologies recorded in the Pembina field, they are consisitent with the lithologies found in the Carrot Creek field.

The Pembina River Member corresponds to a coarsening-upward sequence of sediment. This member is variably thick throughout the Carrot Creek field and may reach a maximum thickness of 30 m. The sediment grades from silty mudstone at the base of the member through sandstone and into conglomerate (Krause and Nelson, 1984). It is these sandstone and conglomerate units which act as the reservoir rock for the field. The conglomerate is found in bodies possessing an asymmetric lensoid shape quite similar to those of modern shelf-sand ridges and is found in thicknesses of up to 20 m.

This geological setting produces an ideal situation for seismic modeling. That is, a conglomerate bar deposit is bounded on both top and bottom by marine shales, producing an isolated structure which can be easily modeled.

SEISMIC DATA

The orientation of the multicomponent seismic lines along with the area's well control can be seen in Figure 4. In this study the models generated will be compared to the final stack of the vertical and radial components of line CCSW01, shown in Figure 5.

To allow for a comparison between the surface seismic and the modeling results the events on both the vertical and radial component section of CCSW01 had to first be identified. This identification was undertaken on the vertical component section through the use of a synthetic seismogram generated using a sonic log from well 1-3-53-13W5 (Figure 6). Events on the radial component section were then identified by correlation with the vertical section (Figure 7).

MODEL DESCRIPTION

Model parameters:

The model used is shown in Figure 8. This model was based upon well log and core information from the Carrot Creek field. The formation depths and their respective P-wave velocities (listed in Table 1) were obtained from the sonic logs of wells 1-3-53-13W5

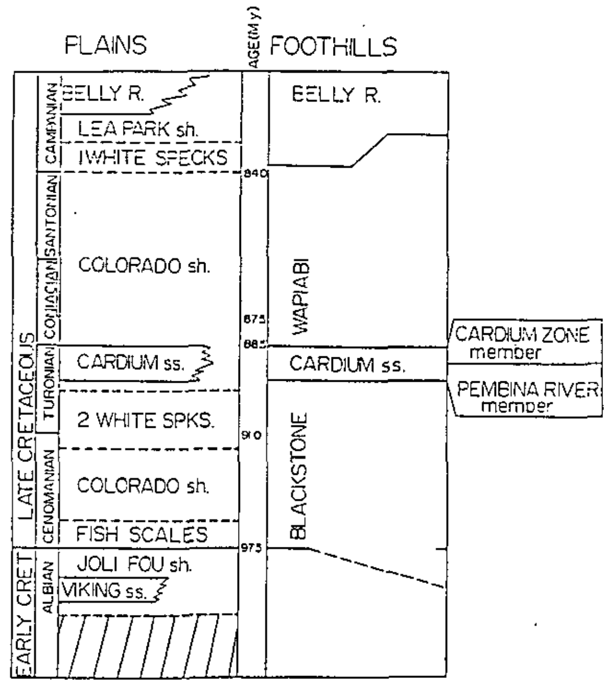


Figure 3: Stratigraphic age and correlation chart for the Carrot Creek field (Krause and Nelson, 1984)

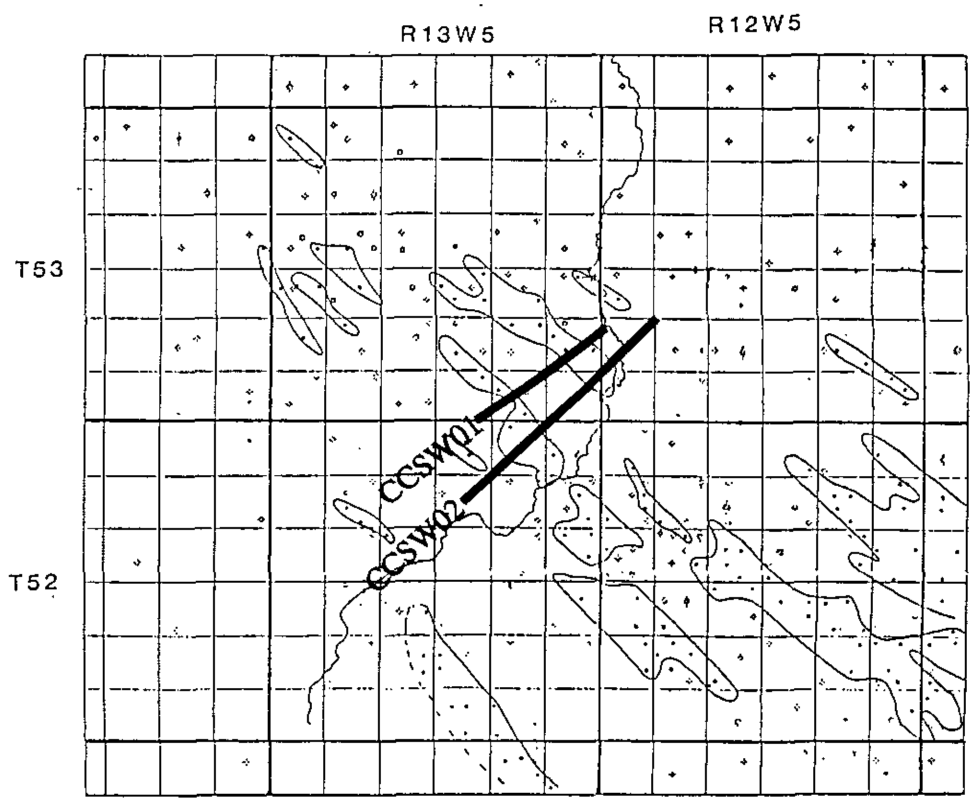
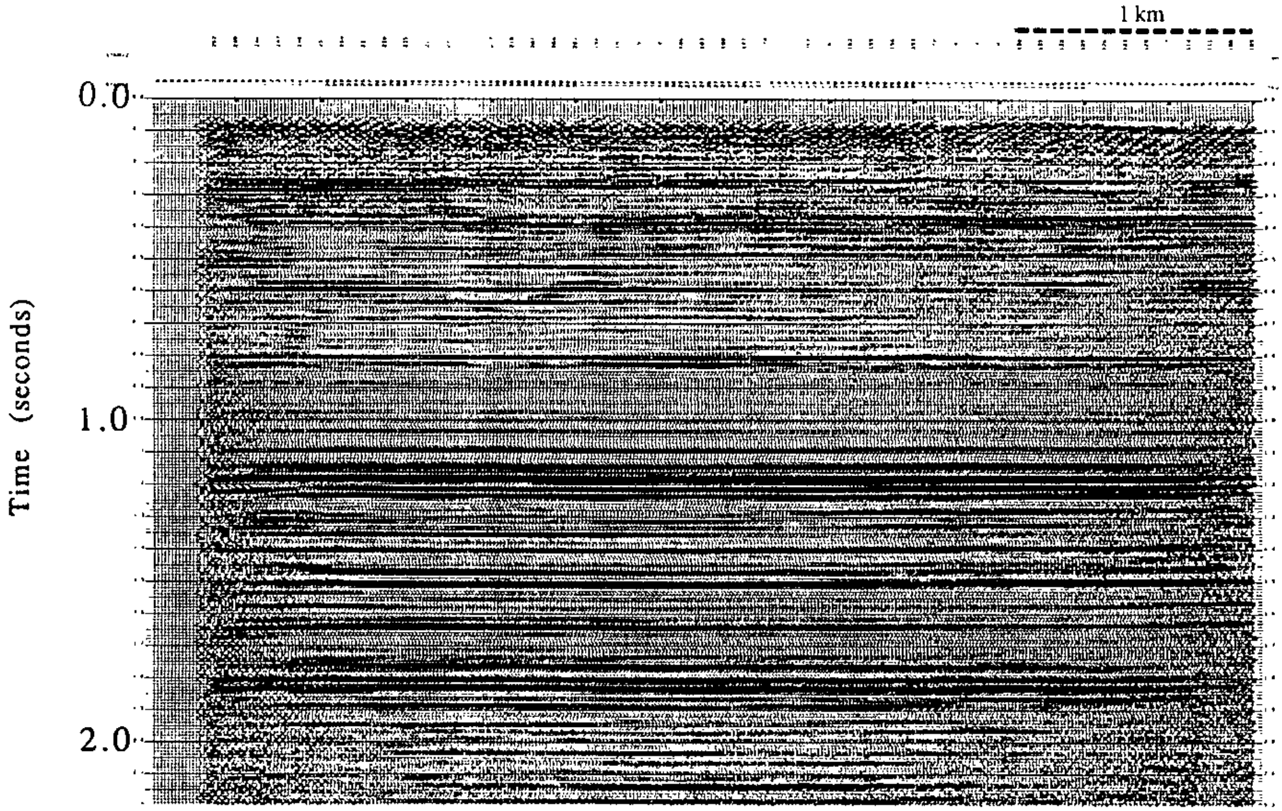
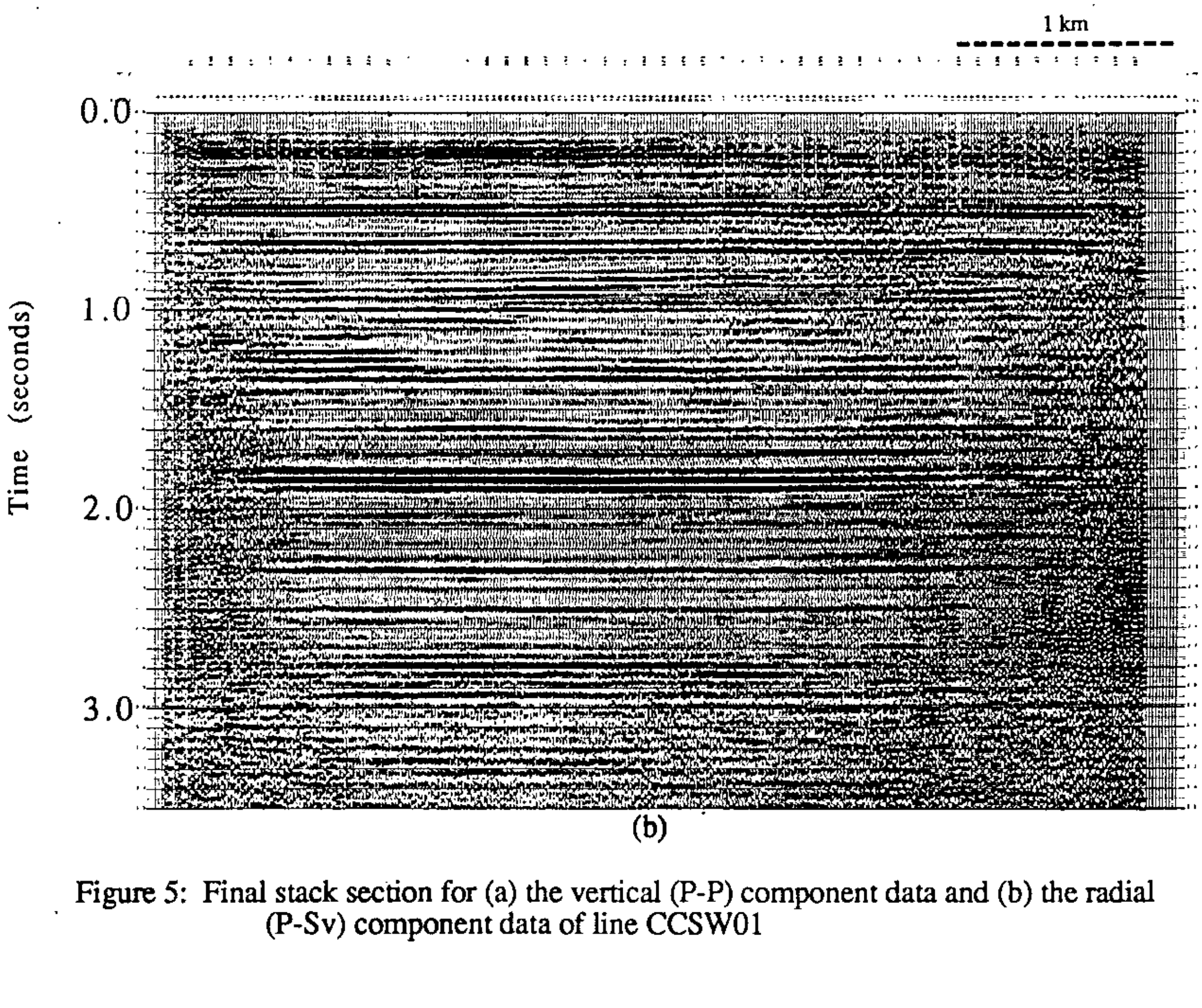


Figure 4: Well and multicomponent seismic line locations in the Carrot Creek field, producing comglomerate bodies outlined (Joiner, 1989)



(a)



(b)

Figure 5: Final stack section for (a) the vertical (P-P) component data and (b) the radial (P-Sv) component data of line CCSW01

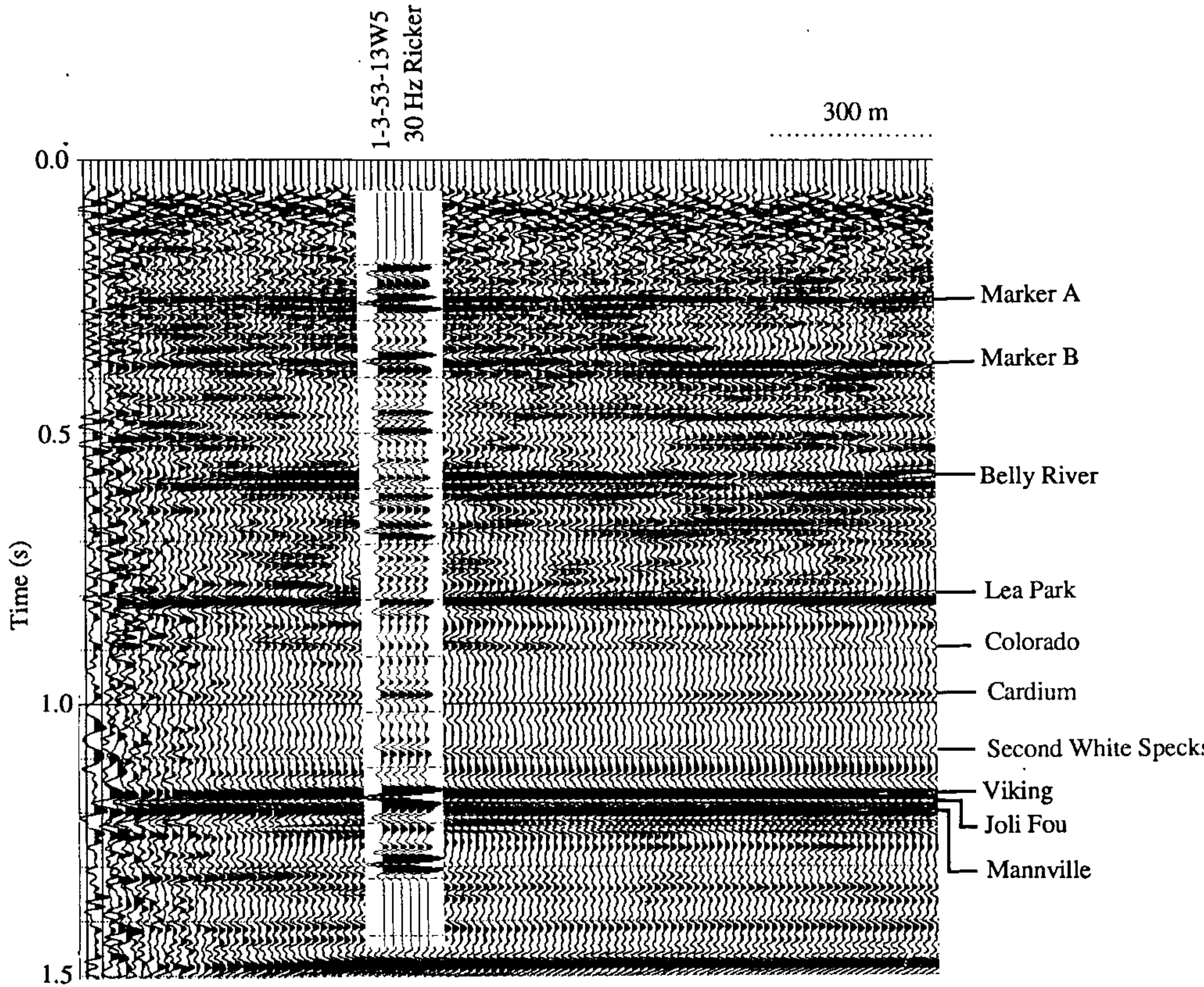


Figure 6: Correlation of a P-wave synthetic with the vertical component of line CCSW01

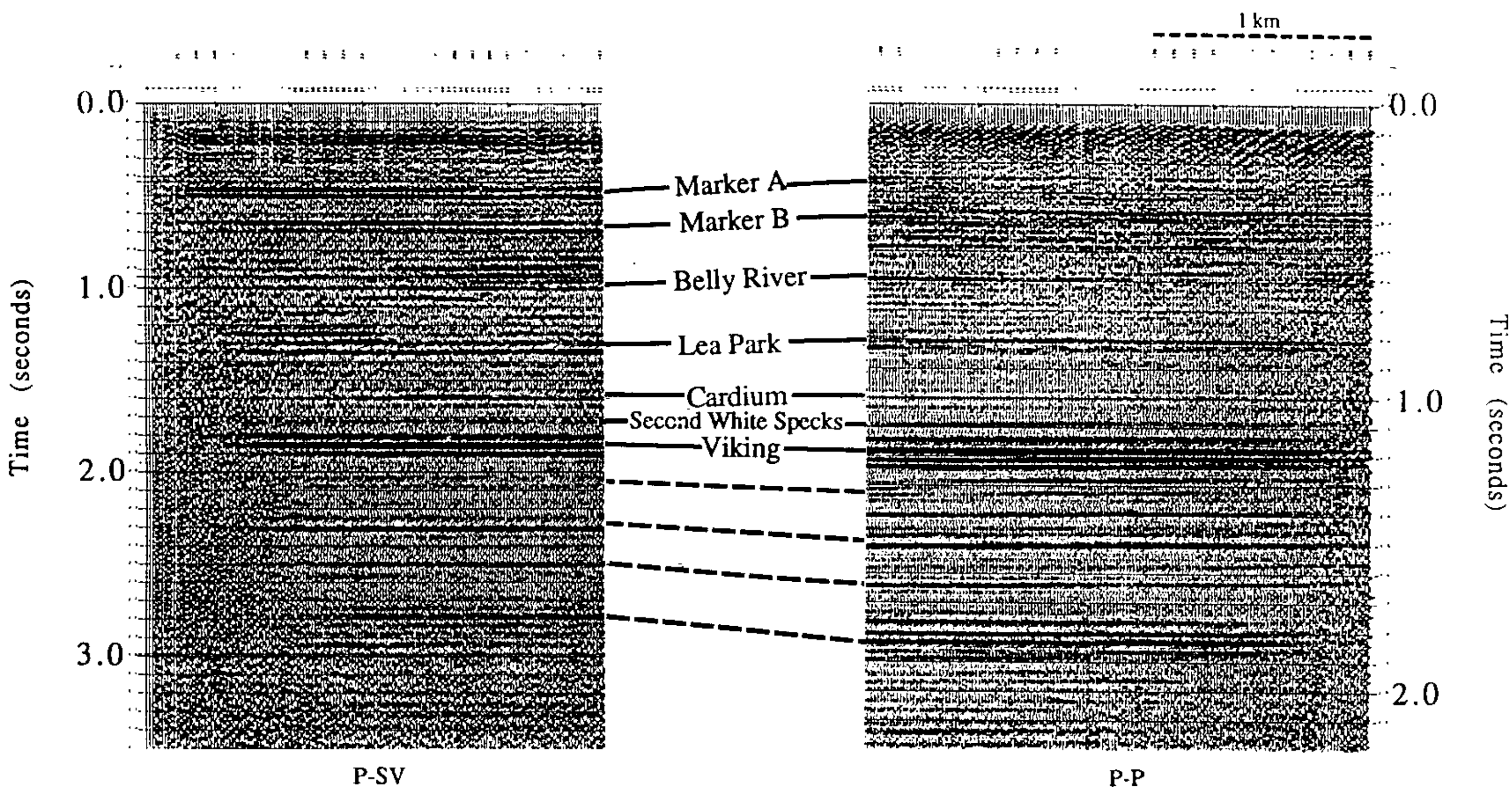


Figure 7: Correlation between P-Sv and P-P stack sections

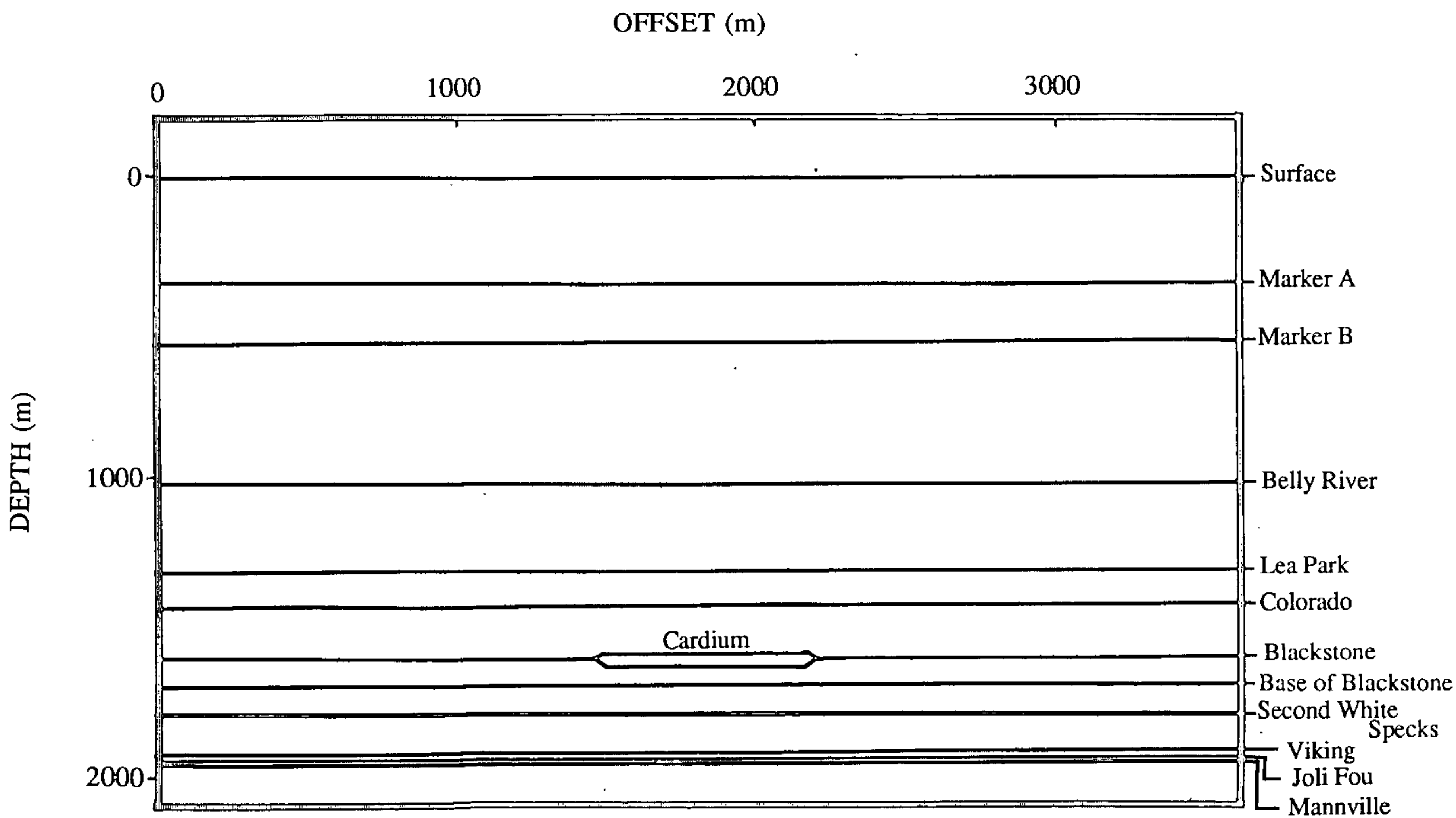


Figure 8: Schematic of the Carrot Creek Geologic Model

and 15-11-53-13W5. The layers overlying , corresponding to and underlying the conglomerate were given densities of 2.37, 2.45 and 2.42 gm/cc respectively. The V_p/V_s for each interval was determined by the following equation:

$$\frac{V_p}{V_s} = 2\frac{\Delta t_{radial}}{\Delta t_{vertical}} - 1 \qquad (1)$$

where Δt = isochron.
Poisson's ratio was then calculated using the following equation:

$$\sigma = \frac{\frac{1}{2}\left(\frac{V_p}{V_s}\right)^2 - 1}{\left(\frac{V_p}{V_s}\right)^2 - 1} \qquad (2)$$

The resulting values from equations (1) and (2) are also listed in Table 1. Constraints on the V_p/V_s of the Cardium (Pembina River Member) conglomerate were provided by petrophysical measurements on a sample of the conglomerate from well 6-12-53-13W5.

Table 1: Carrot Creek Model Parameters

Formaton	**Depth** (m)	**Thickness** (m)	**Vp** (m/s)	**Vs** (m/s)	**Vp/Vs**	**Poisson's Ratio**
Surface	0	355	2800	1040	2.58	0.42
Marker A	355	200	3226	1198	2.58	0.42
Marker B	555	470	3200	1488	2.15	0.36
Belly River	1025	290	3920	2107	1.86	0.30
Lea Park	1315	117	3510	1817	1.93	0.32
Colorado	1432	178	3775	1954	1.93	0.32
Cardium (conglomerate)	1605	20	4700	2781	1.69	0.22
Blackstone	1610	80	4000	2441	1.72	0.245
Base of Blackstone	1690	85	3900	2267	1.72	0.245
Second White Specks	1775	150	3600	1999	1.80	0.28
Viking	1925	33	4400	2666	1.65	0.21
Joli Fou	1958	14	3800	2302	1.65	0.21
Mannville	1972	-	4200	2545	1.65	0.21

Radial component modeling (P-Sv):

Because converted S-waves can only be generated with a source-receiver offset (ie. non-normal incidence) the production of a P-Sv synthetic seismic section is much more complex than that for the P-P case. To gain the offsets required P-Sv shot records had to be generated. These records were produced using Landmark's Uniseis modeling software, which itself uses Knott's-Zoeppritz coefficients (ie. amplitudes are a function of angular incidence) during raytracing. Upon completion of raytracing the resulting reflection coefficient series was convolved with a 20 Hz zero-phase Ricker wavelet. This is the prominant frequency at the Cardium Formation (Harrison, 1989).

Thirty shot records were generated over the model, each consisting of 120 traces. The same receiver spread was used for each shot. The receivers were positioned from 30-3600 m with a spacing of 30 m. The shots were positioned 120 m apart starting at 0 m and rolling into the receiver spread with each progressive shot. This coverage produces an average fold of 15 in the area of the conglomerate deposit. A sample shot record can be seen in Figure 9.

To produce a stacked section these records underwent processing using Western Geophysical's processing software. Flow Chart 1 summarizes the modeling and processing flow needed to produce a final stacked section. Note that the processing flow is more simplistic with model data than that which would be applied to real converted-wave (P-Sv) data (ie. deconvolution, filtering and statics are not necessary).

Unlike conventional P-P processing a couple of additional steps are required to produce a P-Sv stacked section. For instance, since horizontal in-line geophones are being modeled traces on opposite sides of the source have the opposite polarity. Therefore during the application of the geometry traces on the trailing part of the spread had their polarity reversed. Additionally, since converted-waves have asymetric raypaths midpoint gathering cannot be used (Slotboom and Stewart, 1989). In this study the data was sorted using the asymptotic gathering technique, this technique is discussed by Slotboom and Stewart (1989). This procedure is analagous to CMP gathering except that the data is gathered according to the asymptotic value of the conversion-point trajectory. The asymptote itself is defined by the Vp/Vs down to the event of interest. The Vp/Vs used in this study was 1.95 which is the average down to the Cardium (Harrison, 1989). Although this technique will image the deep events well it is a poor approximation for shallow events. This is, however, not considered to be a problem in this study since the zone of interest (Cardium) is located at a depth of greater than 1500 m.

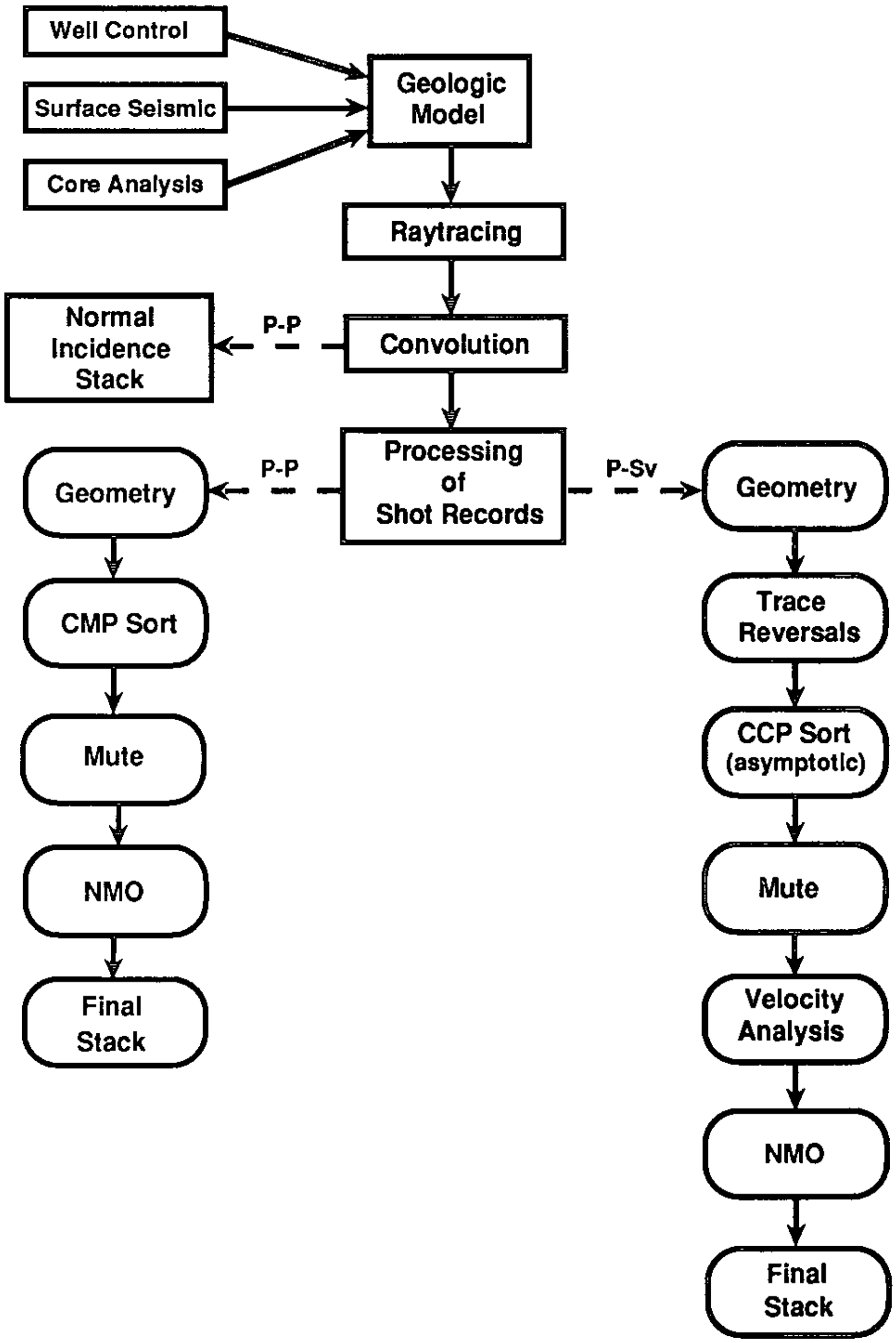
Once the data has been sorted it had to undergo an NMO correction. The velocity function used for this model was calculated using the Dix equation for P-Sv waves:

$$V_{P\text{-}Sv_i}^2 = \frac{\sum (V_{p_i}^2 t_{p_i} + V_{s_i}^2 t_{s_i})}{\sum (t_{p_i} + t_{s_i})} \qquad (3)$$

where, V_{p_i} = P-wave velocity
V_{s_i} = S-wave velocity
t_{p_i} = one-way P-wave traveltime
t_{s_i} = one-way S-wave traveltime
i = interval.

P-Sv interval velocities can therefore be calculated using:

$$V_i = \sqrt{V_{p_i} V_{s_i}} \qquad (4)$$



Flow Chart 1: Modeling and Processing Flow

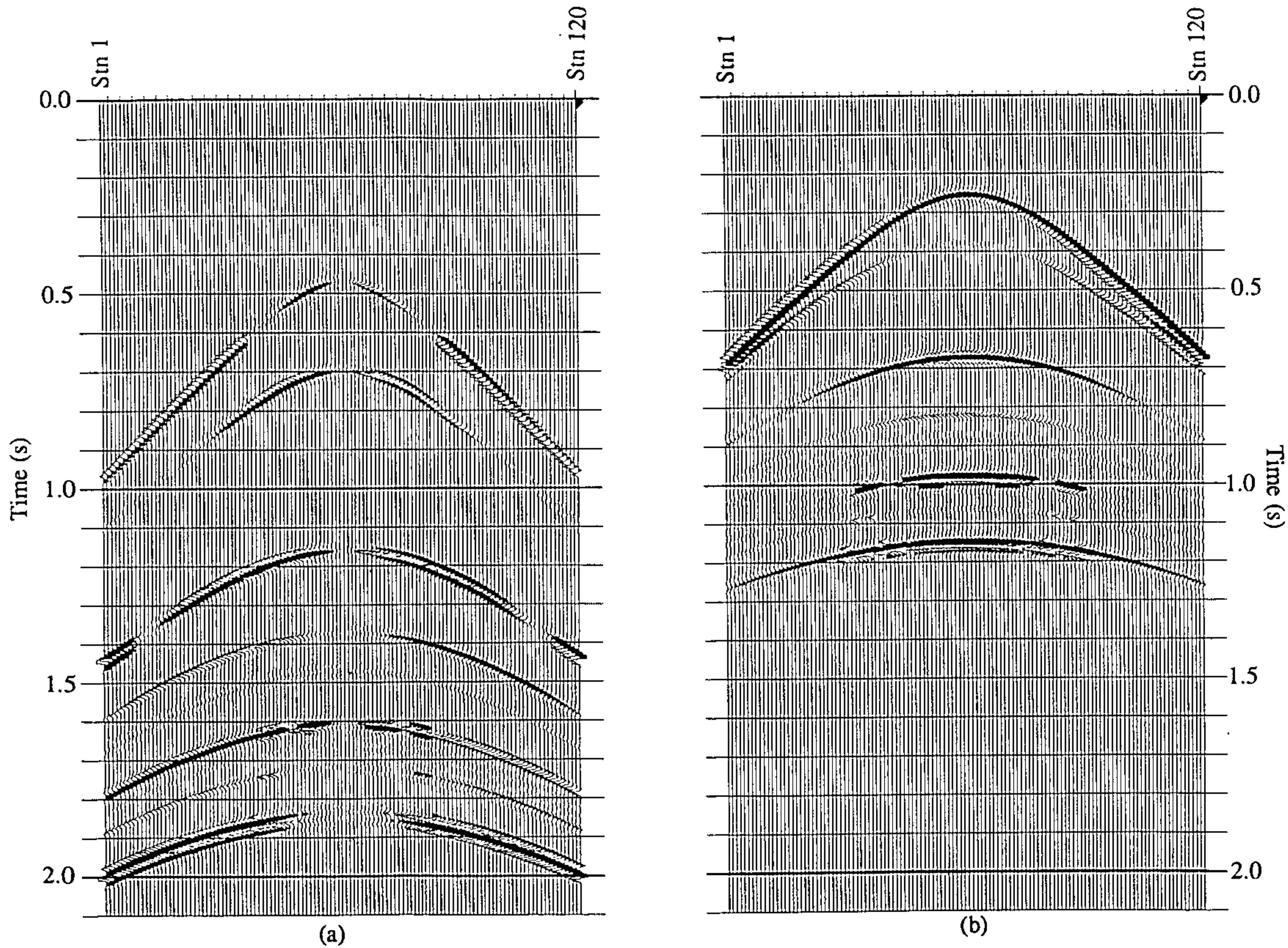


Figure 9: Radial (a) and vertical (b) component synthetic shot records (shot 15) from the Carrot Creek Model

Note that the velocity function produced using (3) is only an approximation, it becomes less reliable at far offsets (Slotboom and Stewart, 1989) causing an overcorrection of events. This effect can be easily seen on the common offset gather of Figure 10. To minimize the detrimental effect this, a mute was chosen (Figure 10) to remove the overcorrected data. A velocity analysis of the muted data was undertaken with the results shown in Figure 11.

Stacking produces the result shown in Figure 12. Note that the conglomerate thickness in this model was 20 m. The resulting Cardium anomaly from this modeling along with that observed on the surface seismic are shown together in Figure 13.

Vertical component modeling (P-P):

Vertical component modeling was undertaken by again generating shot records and processing them into a stacked section. Using the same source-receiver geometry as the P-Sv case 30 shot records were generated. A sample shot record can be seen in Figure 9. The processing flow for these records is summarized in Flow Chart 1.

The velocity function used for this P-P models was calculated using the Dix equation for P-P waves:

$$V^2_{P\text{-}P_i} = \frac{\sum V^2_{P_i} t_{P_i}}{\sum t_{P_i}} \qquad (5)$$

As in the P-Sv case an NMO corrected common offset gather was produced (Figure 10) Unlike the P-Sv case however, the resulting velocity function was very effective in flattening the events. The final stacked section produced can be seen in Figure 14.

DISCUSSION

Radial Component Modeling (P-P):

At present only one P-Sv model (conglomerate thickness of 20 m), has been processed. Although this modeling is in its preliminary stages several features of P-Sv data become apparent. The first of which is that the sorting of the data can be improved. Although the asymptotic technique used in this study produces coherant results, it causes a periodic fluctuation in the stacking fold (Eaton and Lawton, 1990). This fluctuation can be easily seen in the final P-Sv stack of Figure 12. This figure shows that for shallow events every fourth CCP bin is empty. At greater depths however, as the asymptotic approximation becomes more applicable, the fold appears to become more evenly distributed (ie. no empty CCP bins). These results can be improved upon by applying the depth varient mapping technique proposed by Eaton and Stewart (1989). This technique is quite similar to the mapping employed to process offset VSPs, except in this case each point would be repositioned to its correct conversion point location.

As mentioned earlier there is also a problem utilizing the Dix equation for P-Sv waves, this problem does not however arise in the P-P case. This is clearly shown by the NMO corrected common offset gathers of Figure 10. Slotboom et al (1990) states that this overcorrection occurs with P-Sv data when the offset to depth ratio is 1:1.5 or more. Although this can be resolved by muting the far offsets, as was done in this study, this is a

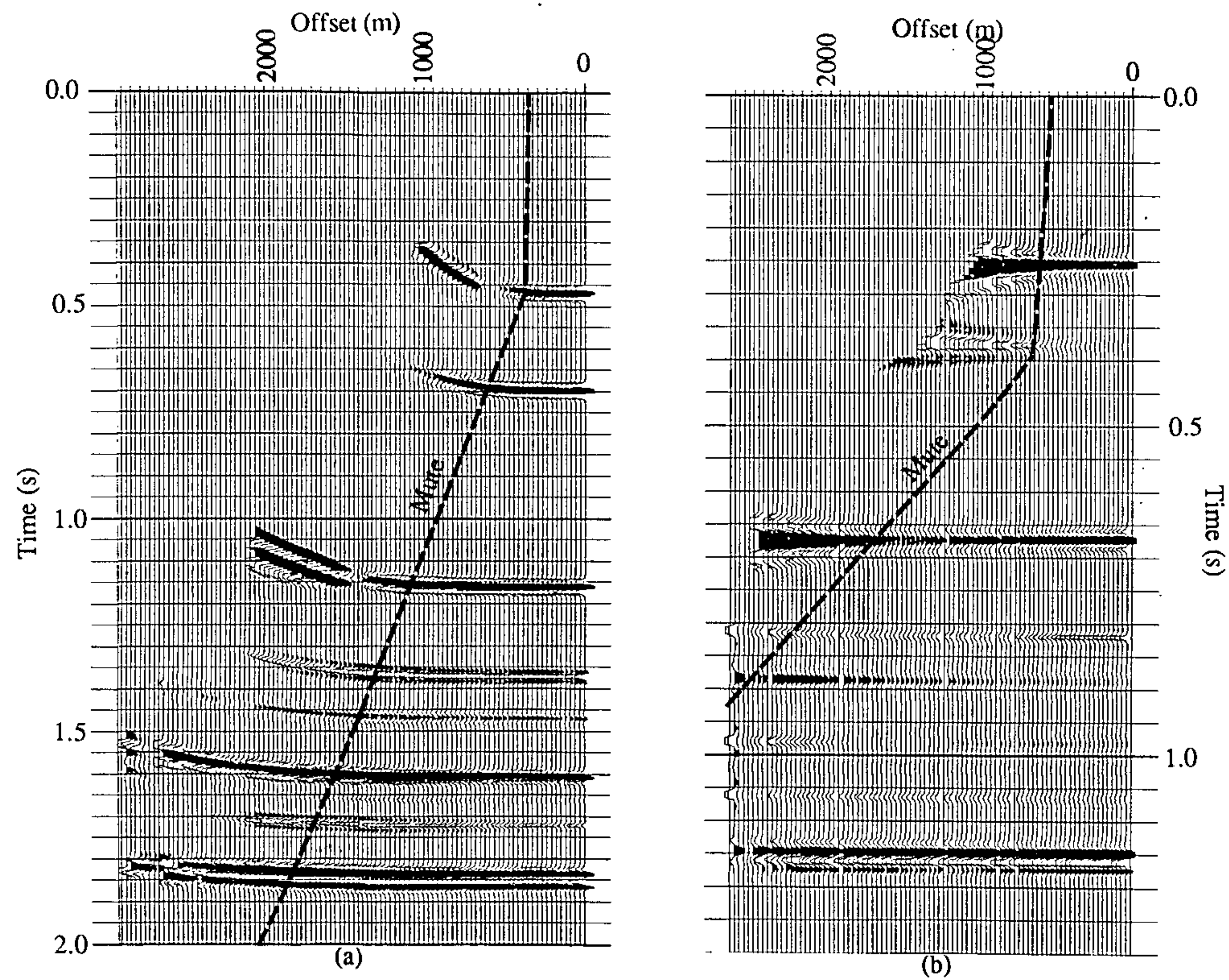


Figure 10: P-Sv (a) and P-P (b) common offset gathers of the synthetic Carrot Creek data

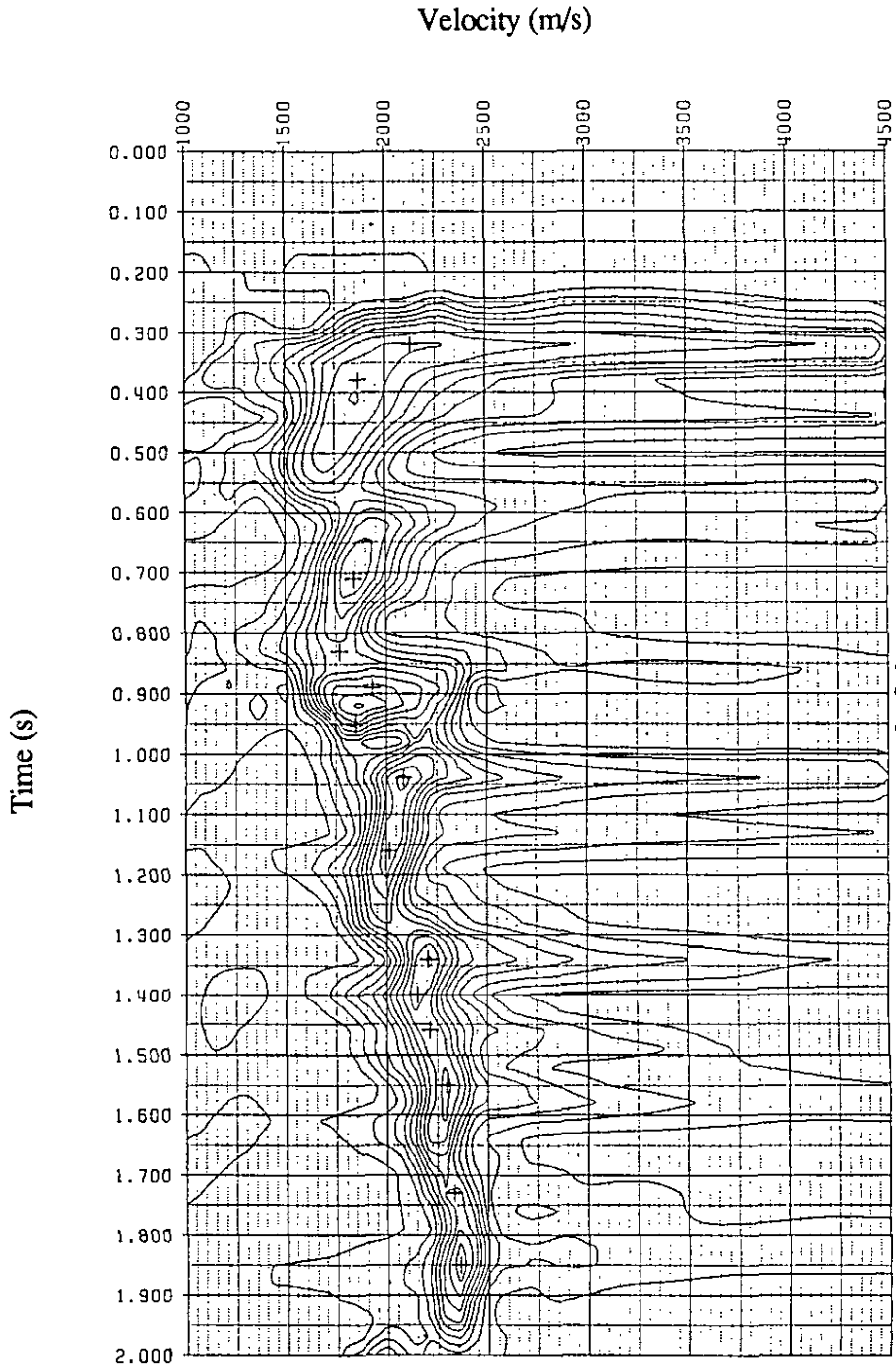


Figure 11: Velocity analysis of the P-Sv synthetic data

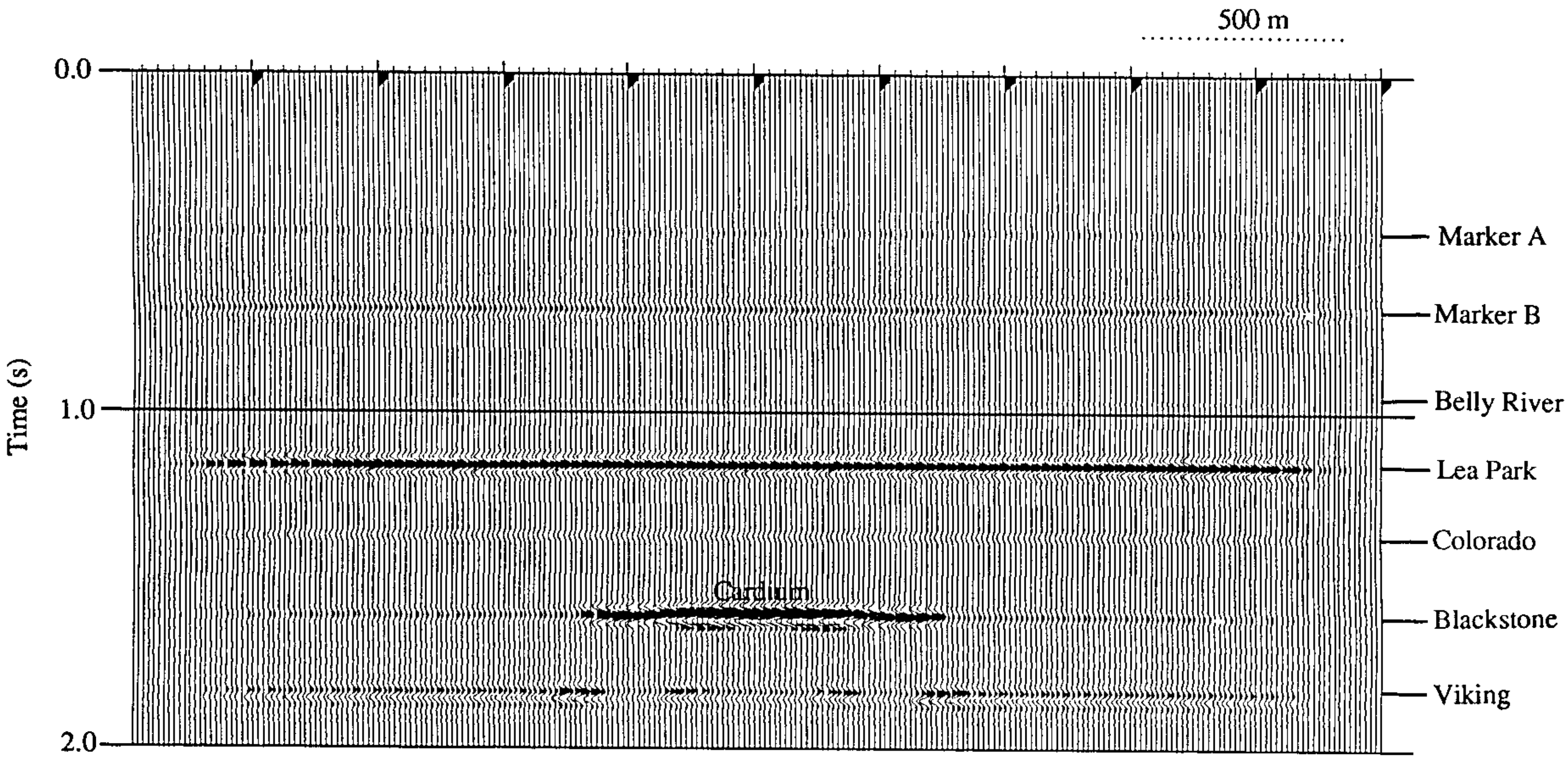


Figure 12: Final P-Sv synthetic stack section

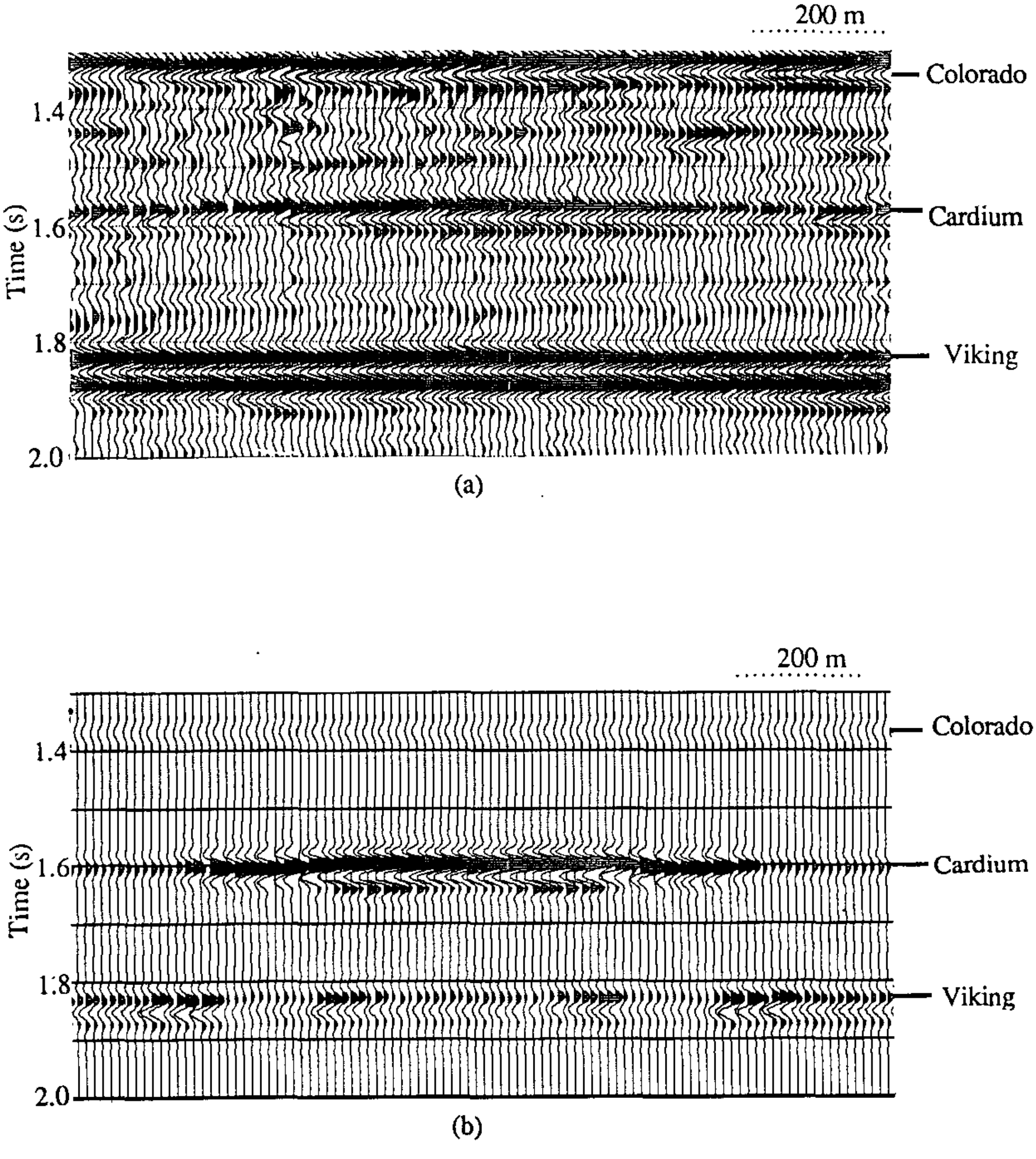


Figure 13: Comparison between (a) the surface seismic P-Sv anomaly and (b) the modeled P-Sv anomaly

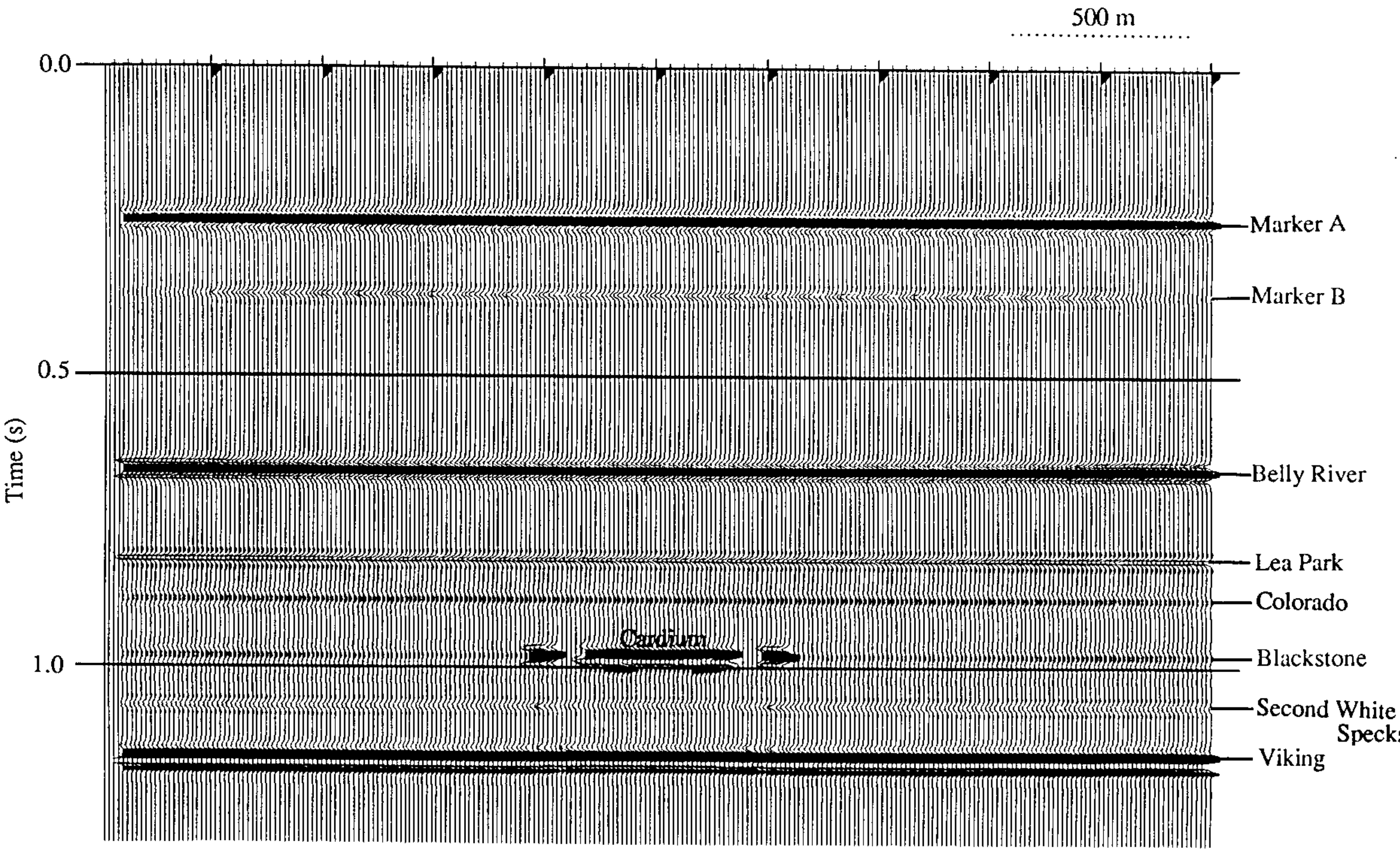


Figure 14: Final P-P synthetic stack section

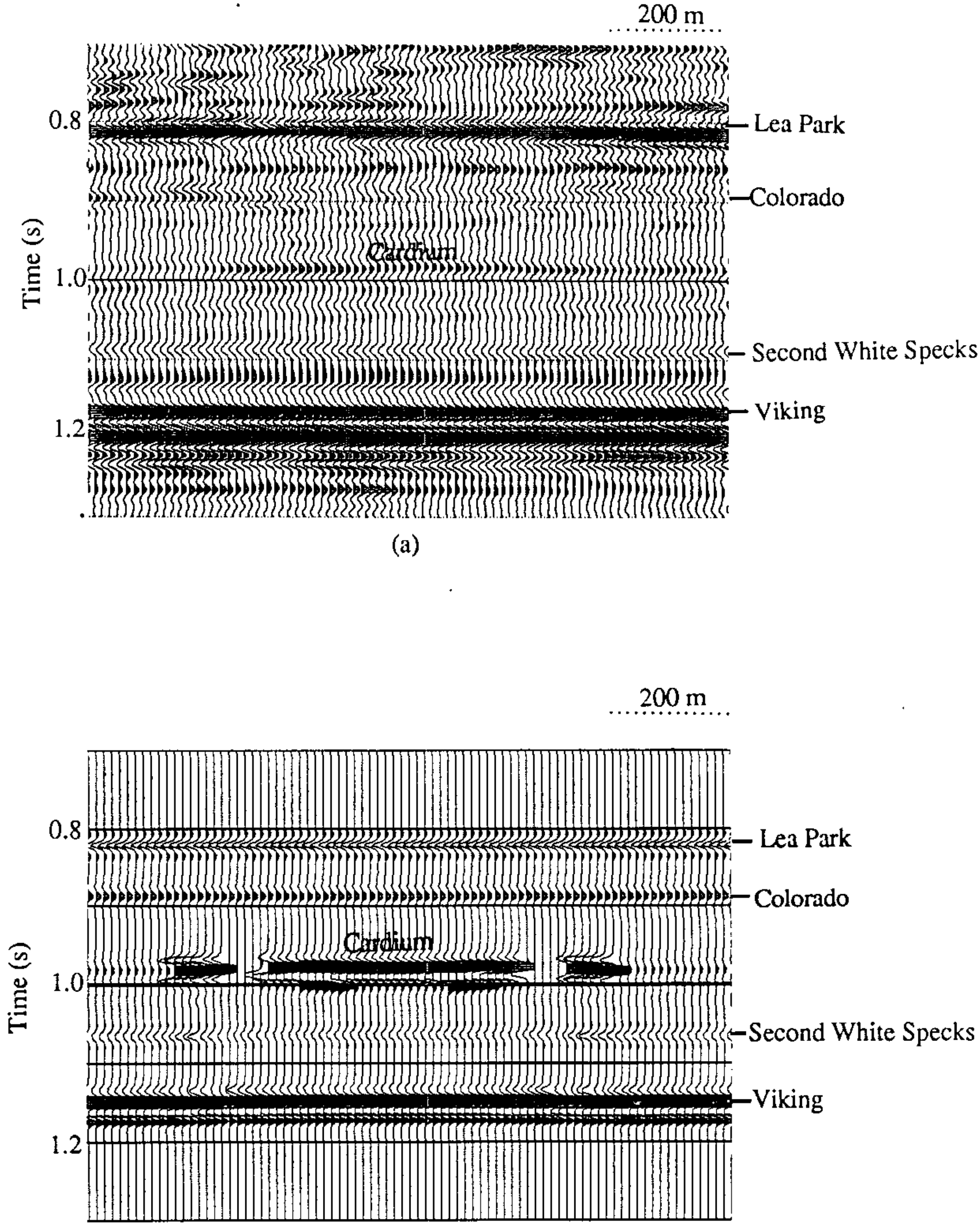


Figure 15: Comparison between (a) the surface seismic P-P anomaly and (b) the modeled P-P anomaly

loss of information and thus is not desirable. To remedy this Slotboom et al (1990) derived an improved converted-wave moveout estimation formula which would better flatten the events at far offsets.

Although AVO effects are not clearly seen on the P-Sv common offset gather of Figure 10 they should still be considered in future modeling.

Events on the P-Sv model correspond well in terms of time with the surface seismic the relative amplitudes of the events do not. This indicates that the geological model still has to undergo further modifications. Several factors can be attributed to this difference, the first of which is that the models velocity structure consists of a blocked sonic log. This would produce more abrupt velocity contasts between layers than would actually be present. For example the amplitude of the Cardium anomaly on the model data is significantly greater than on the surface seismic. This is due to the assumption that the bar deposit in the model contains only conglomerate, which has a very high velocity. In actual fact however the velocity contrast is most likely more subtle because the bar itself grades from one rock type to another.

Vertical component modeling (P-P):

The main advantage of modeling shot records instead of using normal incidence raytracing is the ability to show AVO effects. An example of this from this model can be seen, at 1.0 second (Cardium event), on the P-P common offset gather of Figure 10. This therefore indicates that an AVO study may be useful in the analysis of the Cardium amplitude anomalies.

Figure 15 shows a good correlation between the modeling results and the surface seismic. An exception to this however is a significantly larger Cardium anomaly in the modeling results. This, as in the P-Sv model, indicates that the velocity contrast between the conglomerate and the surrounding formations (Colorado and Blackstone) is too great and should therefore be decreased. It should also be noted that the discontinuities in the modeled Cardium anomaly are due to the geometry of the bar model itself and are not naturally occuring events.

CONCLUSIONS

Although both the P-P and P-Sv modeling of the Carrot Creek dataset is still in its preliminary stages there appears to be significant promise in the ability to model the vertical and radial component Cardium amplitude anomalies. The results however show that a significant amount of work must still be undertaken in adjusting the geologic model in order to gain a better correlation with the surface seismic.

The modeling results also show the importance of obtaining an improved CCP sorting technique and a P-Sv moveout correction for converted-wave data. These problems are easily observed on the P-Sv model by periodic fluctuation in fold and the overcorrection of events at far offsets, respectively.

Preliminary results also indicate the presence of AVO effects on the vertical (P-P) component and possibly on the radial (P-Sv) component. At present, however, no additional work has yet been undertaken in this area.

FUTURE WORK

The modeling of the Carrot Creek conglomerate will be continued. Various P-P and P-Sv models will be produced with different conglomerate thicknesses and values for Poisson's Ratio, in order to obtain an understanding of the origin of the amplitude anomalies observed on the surface seismic.

In addtion Eaton and Stewart's (1989) CCP depth variant mapping program and the improved P-Sv moveout correction of Slotboom et al (1990) will be applied to both the surface data and the P-Sv model data, to help improve the quality of the final stacks.

AVO modeling shall also be undertaken on both the vertical and radial component data.

ACKNOWLEDGEMENTS

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