A comparison of converted-wave binning methods using a synthetic model of the Highwood Structure, Alberta

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ABSTRACT

Various converted-wave binning methods (CMP, asymptotic CCP, depth-variant CCP, and *PSV* DMO) were applied to a synthetic *PSV* seismic data set, modeled after the Highwood Structure of SW Alberta. The effect of reversing the polarity of the trailing spread is also considered. It is found that depth-variant CCP binning and *PSV* DMO give the best results. Asymptotic CCP binning, with reversal of the trailing spread, is better than CMP binning with no polarity reversals, while being quicker than depth-variant CCP binning and *PSV* DMO.

INTRODUCTION

Early seismic surveys consisted of single-fold coverage, that is, at the location of each reflection point at depth, there is only one raypath which crosses this area. In order to increase the signal-to-noise ratio, the use of multifold data was first attempted starting in 1956 (Mayne, 1956). The advantage of multifold data is that a lot of the random noise should be removed when several traces at the same depth location are combined (stacked) to form one trace. However, in order to combine the correct traces, it is necessary to sort the data based upon common-midpoint (CMP) locations. A CMP location is the location of several reflections of seismic waves at depth. Traces falling into each of these CMP locations actually cover a range of locations on each side of the CMP location, usually the size of one-half of the group interval. Each of these ranges of CMP locations is considered a CMP bin, and all of the traces falling inside a bin make up one CMP gather. This gather is then NMO-corrected and stacked to form one trace, corresponding to one CMP location on a multifold seismic section.

This method of CMP binning and stacking has worked well for *P*-wave data. but with the recent interest in *PSV* data, it has been necessary to reconsider the question of proper CMP location binning (Chung and Carrig, 1985, and Fromm et al., 1985). The reflection point for *PP* seismic data is at the midpoint, halfway between the shot and the receiver, since the upgoing and downgoing raypaths are symmetric (Figure 1). Thus, sorting *P*-wave data from shot and receiver locations into the actual point of reflection is simply a matter of dividing the source-receiver offset by two. However, for converted-wave data, the upgoing and downgoing raypaths are not symmetrical, since the downgoing *P*-wave travels at roughly twice the velocity of the upgoing *S* -wave. Thus, as predicted by Snell's Law, the upgoing raypath will bend toward the normal and will thus be shorter than the downgoing raypath (Figure 1). This offsets the mode-conversion point away from the midpoint and towards the receiver location. Further, the location of this conversion point varies with depth (Tessmer and Behle, 1988, Fromm et al., Key and Wiest, 1985), ranging from an asymptotic value roughly two-thirds of the way from source to receiver, assuming a *Vp/Vs* ratio of 2.0, to almost approaching the receiver location at shallower depths (Slotboom and Lawton, 1989).

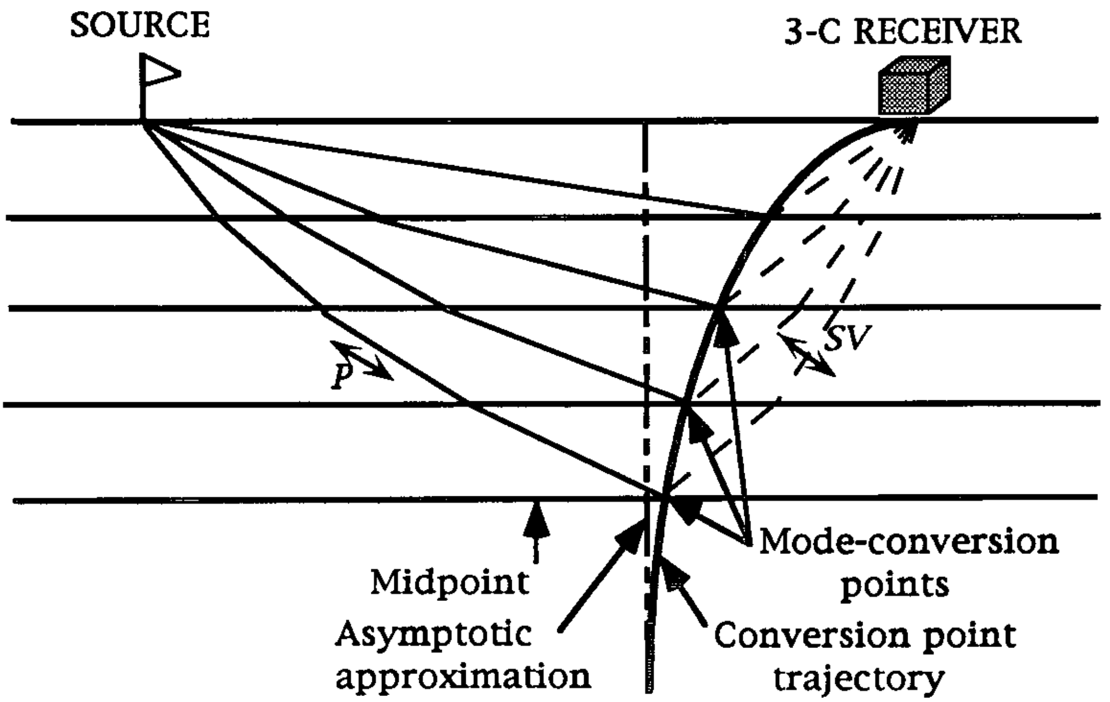


FIG. 1. Schematic diagram showing conversion point trajectory, asymptotic approximation, and converted-wave raypaths.

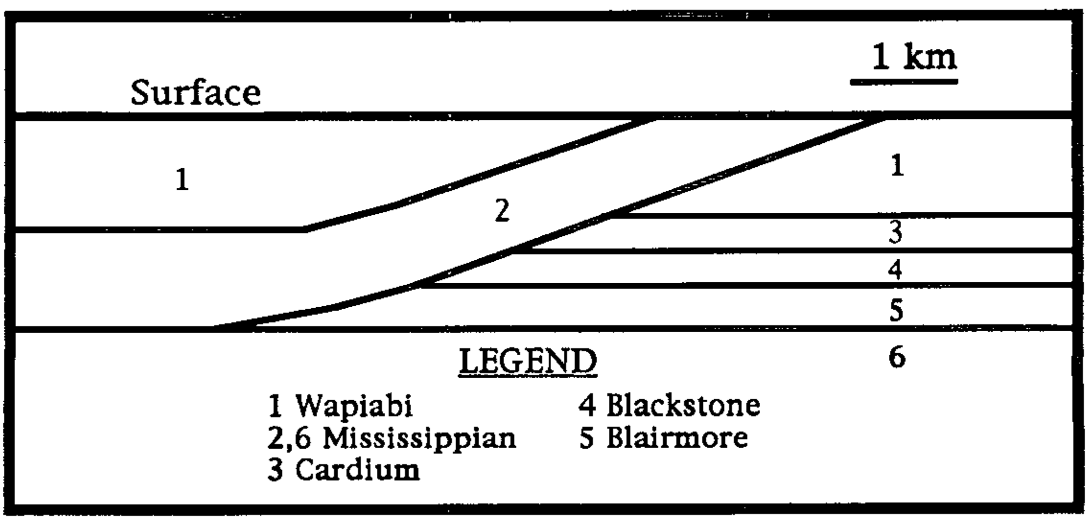


FIG. 2. Thrust fault model of the Highwood Structure, Turner Valley, SW Alberta.

DATA SET

The data set used for this analysis is a synthetic *PSV* seismic reflection data set which simulates a thrust fault, the Highwood structure, in the Turner Valley area of SW Alberta. This model is based on the interpretation of a seismic line in the area by MacKay (1990) and consists of Mississippian carbonates which have been overthrusted and now overlie Mesozoic clastics (Figure 2).

This model was designed by Sukaramongkol (1991) to examine the effects of near-surface high-velocity material on *PSV* seismic reflection data. The velocities and densities of each layer (Table 1) were obtained from the well 6-19-19-3W5M, which ties the seismic line, taken from Miller and Stewart (1990).

Formations	V_p (m/s)	V_s (m/s)	Density (g/cm^3)
Mississippian	5500	2894	2.80
Wapiabi	3884	2044	2.55
Cardium	4300	2529	2.65
Blackstone	4000	2139	2.60
Blairmore	4200	2545	2.65

Table 1. Physical parameters of the Highwood Structure *PSV* synthetic seismic model

ACQUISITION AND PROCESSING

Acquisition of the model is done on the UNISEIS modeling software on a Landmark RT. The model was first entered into UNISEIS by hand, and then ray-traced such that only conversion to *SV* is allowed at interfaces. The ray-tracing method uses the Knott-Zoeprittz coefficients to allow for amplitude variations as a function of angular incidence. The resulting reflection coefficient series was then convolved with a Ricker wavelet with a maximum center frequency of 20 Hz to generate the synthetic *PSV* seismic reflection data. To make up the model, forty-six shot gathers were acquired using split-spread geometry, with 240 groups at a 20-m group interval and 200-m shot interval, giving an anticipated fold of twelve.

In order to process the data, it must be written to tape for transferring to the SUN SPARC II workstations. The data are then converted from SEGY to ITA's INSIGHT format using IT&A software. Once the headers are modified to contain the acquisition geometry, subsequent processing such as CCP binning, sorting, NMO application and stacking can be performed.

Most of the *PSV* processing steps are similar to *PP* processing steps and thus can use the same software. However, due to the asymmetric raypaths, new programs must be written for CCP binning. *PSV* DMO is also not identical to *PP* DMO and had to be written (Harrison, 1990). Further, the non-hyperbolic nature of the *PSV* moveout curve would require an NMO correction to be applied (Slotboom and Lawton, 1990), but since for moderate offset the error between *PP* and *PSV* move out curves is small, regular *PP* NMO correction can be used to approximate the *PSV* move out correction. Since the polarity of the trailing spread is opposite to that of the leading spread, it is also necessary to reverse the polarity of the trailing spread for *PSV* data. Since this is synthetic data, there is no need for either deconvolution or any statics corrections, which simplifies the processing somewhat. The data are simply corrected for geometry, sorted into CCP location, the polarity of the trailing spread is reversed, the CCP gathers are NMO corrected, muted and stacked. Finally, for display purposes, an AGC gain was also applied.

BINNING THEORY

Asymptotic Approximation

As an initial attempt at converted-wave binning, the asymptotic value of the conversion-point trajectory was used. This is the value of the curve at a sufficiently large enough depth so that it can be assumed that the offset-to-depth ratio approaches zero. The general form of the formula for the asymptotic correction has the following form:

$$X_P = \frac{X}{1+\frac{V_s}{V_p}}$$

where Xp is the offset from the source to the conversion point, X is the total source-to-receiver offset, and V_S/V_P is the shear-to-compressional wave velocity ratio in the area. The advantage of this method is that it is not depth variant and thus each shot-receiver pair requires only one simple calculation to be binned into the proper subsurface location.

Depth-variant Common Conversion Point

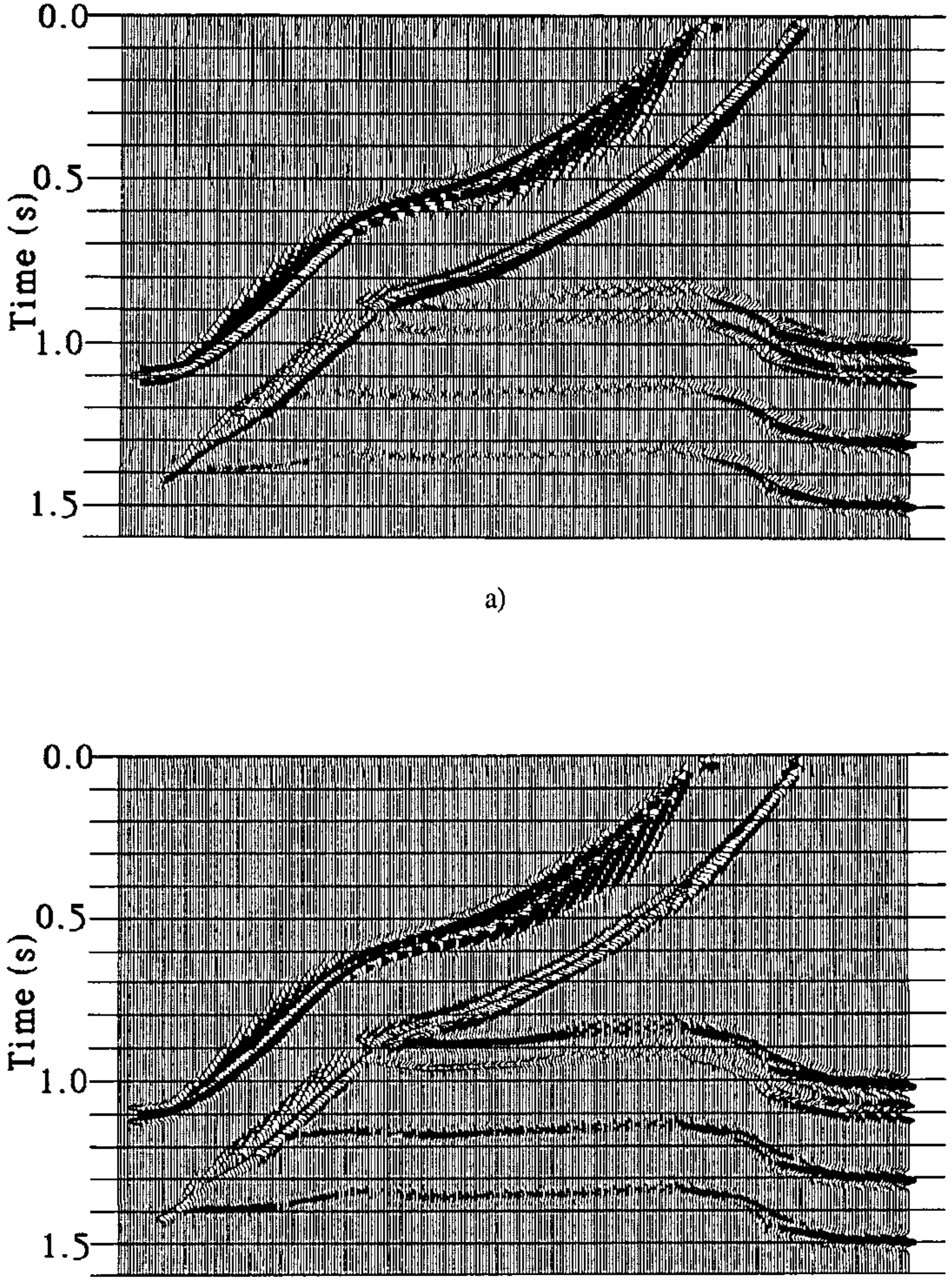
In order to improve upon the quick and simple asymptotic method, it is necessary to account for the depth-variance of the conversion-point trajectory. Tessmer and Behle (1988) have shown that the difference, D, between Xp and the source-receiver midpoint satisfies the fourth-order polynomial equation:

$$D^4 + (Z^2 - X^2)\, D^2 \;\; Z^2kXD + 1/16(X^4 + 4X^2Z^2) = 0$$

where Z is the layer thickness, X is the source-receiver offset, and $k = (1+V_S/V_P)/(1-V_S/V_P)$. There are four solutions to this equation, of which only two are real and of these the correct solution satisfies the relation $D \leq X/2$. The solution of the exact single-layer formula is used to reposition each sample point in depth to its correct conversion-point location.

Dip Move out (DMO)

The method of common-conversion-point binning works well for symmetric, flat layers. However, it is well known for the *PP* case that, once dipping layers are considered, there is smearing or dispersal of data within a common-midpoint gather, since the reflection point for data from a dipping interface is displaced away from the midpoint (Levin, 1971). Dispersal within a common-midpoint gather causes an increase in the apparent velocity necessary to properly flatten the dipping event, and thus the dipping data is attenuated by stacking (Judson et al., 1978). In order to avoid this problem, dip move out (DMO) is used to place the reflection in the proper location for dipping data. For the *PP* case, this method has been successfully used for over a decade ever since its introduction in 1978 (Judson et al., 1978).



a)

b)

FIG. 3. Result using common midpoint (CMP) binning for Highwood Structure *PSV* synthetic seismic section, a) without polarity reversals and b) with polarity of trailing spread reversed.

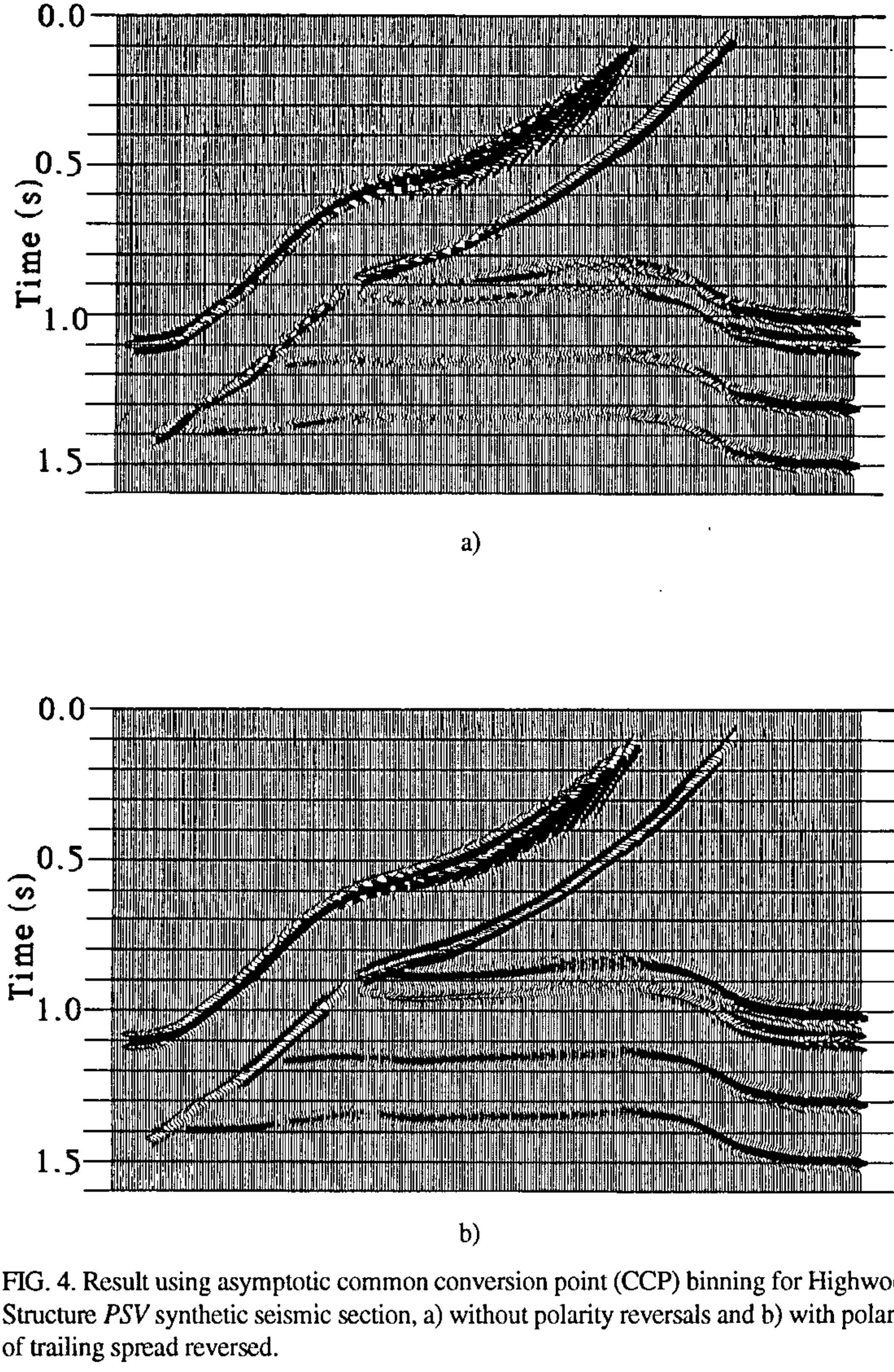


FIG. 4. Result using asymptotic common conversion point (CCP) binning for Highwood Structure *PSV* synthetic seismic section, a) without polarity reversals and b) with polarity of trailing spread reversed.

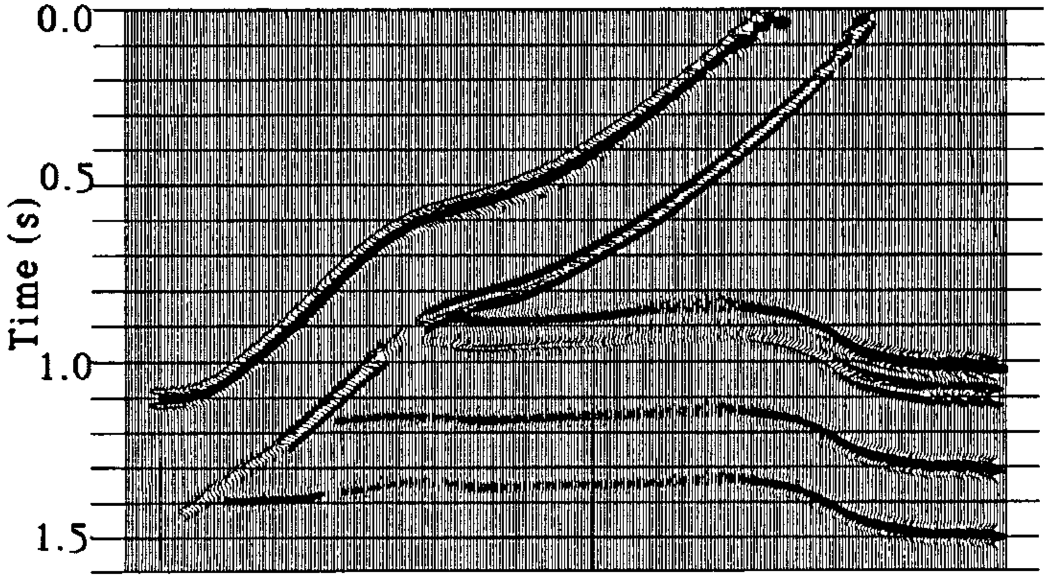


FIG. 5. Result using depth-variant common conversion point (CCP) binning for Highwood Structure *PSV* synthetic seismic section.

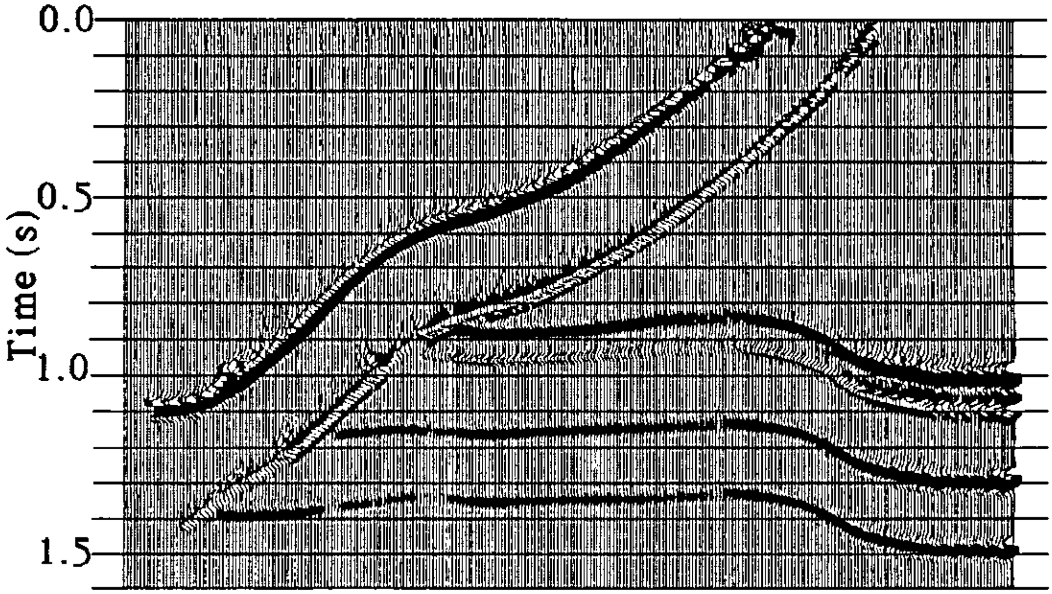


FIG. 6. Result using *PSV* dip movout (DMO) for Highwood Structure *PSV* synthetic seismic section.

PP DMO has recently been extended for use in the *PSV* case by Harrison (1990 and 1992). The equations for *PSV* dispersal, *PSV* apparent velocity, and the *PSV* constant-velocity DMO operator are much more complicated than those for the *PP* case, and it would not be appropriate to go into detail in this paper. However, the method can be summarized as being an algorithm that first constructs the time-domain DMO operator for each input trace, then sums the operators to get the final DMO result, similar to the integral summation technique for *PP* DMO (Deregowski,1985).

RESULTS

The result of applying common-midpoint (CMP) sorting to *PSV* data, without reversing the polarity of the trailing spread is shown as Figure 3a. This is equivalent to treating the *PSV* data as *PP* data, since *PP* data is sorted into the common midpoint and has no need for polarity reversals. Note that the horizons are not sharp, due to smearing of traces in CMP bins, and that events are not continuous.

Next, the polarity of the trailing spread is reversed for the CMP-sorted data (Figure 3b). This results in a slight improvement in continuity of the deeper reflectors, but the smearing of traces in CMP bins is still evident, particularly in the shallow section.

Applying asymptotic CCP binning helps to remove some of the smearing of the CCP bins (Figure 4a) and finally also reversing the polarity of the trailing spread improves the continuity of reflections throughout (Figure 4b). However, there are a few blank traces due to the irregular distribution of traces in the asymptotic CCP bins (Eaton and Lawton, 1990).

Finally, application of depth-variant CCP binning (Figure 5) and DMO (Figure 6) serve to remove the smearing of CCP location and further improves the continuity of reflections. However, these two programs take about thirty minutes to run, while asymptotic CCP or CMP binning takes only five minutes.

CONCLUSIONS

•*PSV* DMO or depth-variant CCP binning provides the best result for structurally complex *PSV* seismic data.

•Asymptotic CCP binning is still a considerable improvement over CMP binning, and is much quicker to run than depth-variant binning or *PSV* DMO

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