Migration velocity analysis for P-S data

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ABSTRACT

Migration velocity analysis (MVA) in depth (Reshef, 1992) has been successfully applied to P-P data, especially in structural areas where stacking velocity analysis fails. In this paper, the migration velocity analysis technique is investigated in time and is applied to P-S seismic data. This technique is slightly modified for the asymmetrical raypaths of converted wave data. It is assumed that, before the MVA, the P-wave RMS velocity function is known from P-P processing. The rms Vp/Vs value, γ_{rms}, is introduced during the MVA. This time-and-space variant γ_{rms} function is sought rather than the RMS velocity function for S-wave itself during the velocity analysis. However the γ_{rms} value and S-wave velocity are convertible.

INTRODUCTION

Stacking velocity analysis has been a popular tool for use in processing P-P data. Tessmer and Behle (1988) used a similar approach and derived a series expansion of the travel-time curves for horizontal layers and concluded that normal stacking velocity procedure can be applied to P-S stacking velocity, provided those data have limited offset range and sorted into common conversion point (CCP) gather. Hence, some knowledge of S-wave velocity is implied before the velocity analysis. For dipping layers, DMO is required. But even for a constant velocity situation, P-S DMO may be expensive. A normal processing flow for symmetrical raypaths (P-P) becomes awkward and time consuming for asymmetrical raypaths (P-S). However, in prestack time migration, a symmetrical raypath assumption is not important and it can handle larger offset and dips. Furthermore CCP stacking and DMO are avoided and replaced by simple common surface location stacking after migration. In this paper, MVA on an image gather for P-S converted wave is discussed and is tested on a 2-D synthetic data set created by a finite difference elastic modelling

Theory

This section is divided into three parts. In the first part, γ_{rms}, the rms Vp/Vs ratio, is introduced with its physical meaning. It is similar to γ except it is defined in RMS sense. In the second part γ_{rms} is used to relate to the ratios of two-way vertical times among different waves. In last part straight-ray path travel-time for P-S is derived and is in terms of P-wave velocity and γ_{rms}.

a)γ_{rms} is defined as :

$$\gamma_{rms} = \frac{v_p}{v_s}$$

where v_p is RMS velocity for P-wave and v_s is RMS velocity for S wave.

And

$$v_p^2 = \frac{\sum_{i=1}^{n} \alpha_i^2 \Delta t}{\sum_{i=1}^{n} \Delta t}$$

$$= \frac{\sum_{i=1}^{n} \alpha_i^2 \Delta t}{t_{opp} / 2}$$

where α is interval velocity for P-wave.

Δt is sampling rate.

t_{opp} is two-way vertical travel time for P-wave to a given reflector.

$$v_s^2 = \frac{\sum_{i=1}^{m} \beta_i^2 \Delta t}{\sum_{i=1}^{m} \Delta t}$$

$$= \frac{\sum_{i=1}^{m} \beta_i^2 \Delta t}{t_{oss} / 2}$$

where β is interval velocity for S-wave.

t_{oss} is two-way vertical travel time for S-wave to the same reflector.

$$\therefore \gamma_{rms}^2 = \left(\frac{v_p}{v_s}\right)^2$$

$$= \frac{\sum_{i=1}^{n} \alpha_i^2 \Delta t}{\sum_{i=1}^{m} \beta_i^2 \Delta t} \frac{t_{oss}}{t_{opp}}$$

but $\frac{t_{oss}}{t_{opp}} = \gamma_{rms}$ (see below)

$$\therefore \gamma_{rms}^2 = \frac{\sum_{i=1}^{n} \alpha_i^2 \Delta t}{\sum_{i=1}^{m} \beta_i^2 \Delta t} \gamma_{rms}$$

or

$$\gamma_{rms} = \frac{\sum_{i=1}^{n} \alpha_i^2 \Delta t}{\sum_{i=1}^{m} \beta_i^2 \Delta t}$$

$$= \frac{\sum_{i=1}^{n} \alpha_i^2}{\sum_{i=1}^{m} \beta_i^2}$$

Therefore γ_{rms} is a ratio of cumulative velocity square of P and S wave from the surface to a reflector.

b) two-way vertical times

1) P-P reflection

$$t_{opp} = \frac{z}{v_p} + \frac{z}{v_p}$$

$$= \frac{2z}{v_p}$$ where z is the depth to the reflector.

2) S-S reflection

$$t_{oss} = \frac{z}{v_s} + \frac{z}{v_s}$$

$$= \frac{2z}{v_s}$$

3) P-S reflection

$$t_{ops} = \frac{z}{v_p} + \frac{z}{v_s}$$

$$= \frac{z}{v_p} + \frac{z}{v_p / \gamma_{rms}}$$

$$= (1 + \gamma_{rms})\frac{z}{v_p}$$

$$\therefore\ \frac{t_{opp}}{t_{ops}} = \frac{2}{1 + \gamma_{rms}}$$

$$\frac{t_{opp}}{t_{oss}} = \frac{v_s}{v_p}$$

$$= \frac{1}{\gamma_{rms}}$$

$$\frac{t_{oss}}{t_{ops}} = \frac{2\gamma_{rms}}{1 + \gamma_{rms}}$$

c) P-S travel-time

Consider the diagram in Figure 1.

$$t_{sr} = \frac{\overline{sp}}{v_p} + \frac{\overline{pr}}{v_s}$$

$$= \sqrt{\left(\frac{x_s}{v_p}\right)^2 + \left(\frac{z}{v_p}\right)^2} + \sqrt{\left(\frac{x_r}{v_s}\right)^2 + \left(\frac{z}{v_s}\right)^2}$$

$$= \sqrt{\left(\frac{x_s}{v_p}\right)^2 + \left(\frac{1}{1 + \gamma_{rms}}\right)^2 t_{ops}^2} + \sqrt{\left(\frac{x_r}{v_s}\right)^2 + \left(\frac{\gamma_{rms}}{1 + \gamma_{rms}}\right)^2 t_{ops}^2}$$

$$= \sqrt{\left(\frac{x_s}{v_p}\right)^2 + \left(\frac{1}{1 + \gamma_{rms}}\right)^2 t_{ops}^2} + \sqrt{\left(\frac{x_r}{v_p / \gamma_{rms}}\right)^2 + \left(\frac{\gamma_{rms}}{1 + \gamma_{rms}}\right)^2 t_{ops}^2}$$

If v_p is known, the above equation can be use for velocity analysis by migrating the P-S data with different γ_{rms} and form an image gather at the selected location.

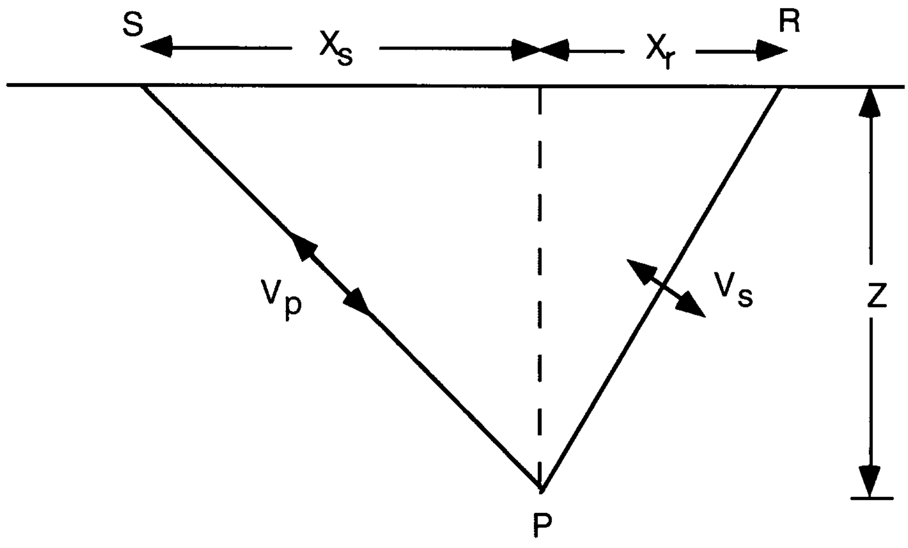

FIG. 1. Schematic diagram for P-S raypath.

Procedure

The steps for MVA are as follows:

1) select a few locations based on a time stacked or migrated P-P section for MVA.
2) RMS velocities for P-P waves at the same locations are estimated (obtained either from the stacking velocity or from MVA for P-P data).
3) for each selected surface location, collect all shots that contributed to the location.
4) select a range of γ_{rms}.
5) migrate the shots to the same surface location for each selected γ_{rms} with $v_p(t_{opp}) = v_p\left(\frac{2}{1+\gamma_{rms}} t_{ops}\right)$
6) an image gather is then formed at the surface location for each selected γ_{rms}.
7) γ_{rms} function at the surface location is picked based on the maximum flatness of the events. If γ_{rms} is too high, the event curves upwards as the distance from the shot to the analyzed surface location increases. If γ_{rms} is too low, the event curves downwards (see Figure 2). Furthermore the event shifts to the shots away from the analyzed surface location as the dip of the event increases.
8) repeat 3-7 for other selected surface locations.

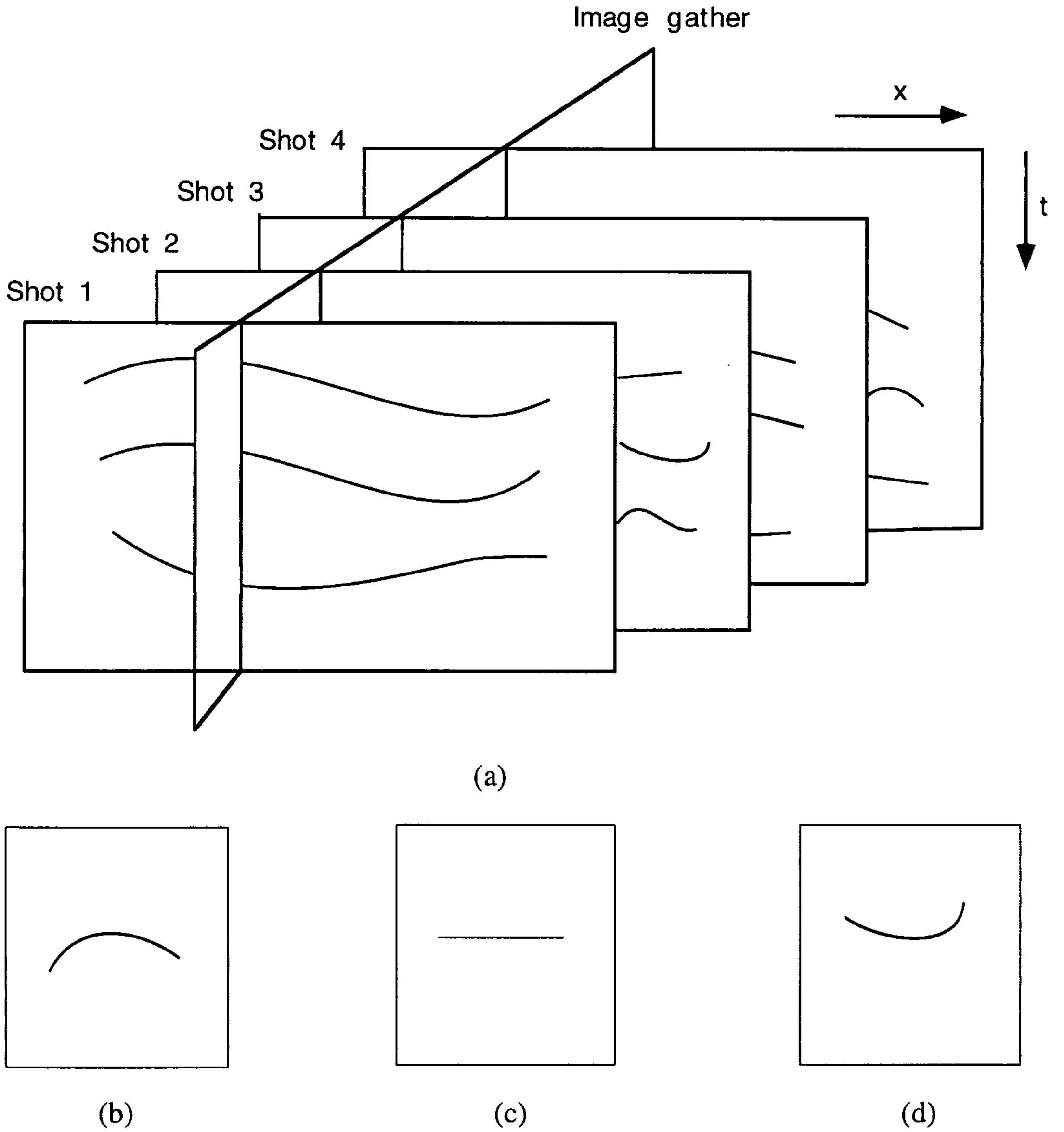

FIG. 2. Schematic diagram for an image gather. (a) Collecting an image gather at a surface location from migrated shot records. (b) when γ_{rms} is too low the event curves downwards. (c) when γ_{rms} is correct the event becomes flat. (c) when γ_{rms} is too high the event curves upwards.

Synthetic example

A set of 2-D prestack gathers is created using a finite-difference elastic modelling package. The model shown in Figure 3 consists of a syncline, a dipping layer and an anticline. A uniform explosive point source is simulated at each shot location and both vertical and radial components are recorded at the receiver stations. Each split spread record has 59 receivers, and with 50 meters group spacing. The maximum offset is 1450 meters. Shots are at every station. Typical shot records are shown in Figure 4 and 5. Figure 6 is a section of zero offset traces (100 %) of vertical component. Figure 7 is a section of near offset traces (100 % at 150 meters) of radial component. Semblance velocity analysis of vertical component is used to pick P-P stacking velocity at 7 equal-spacing locations. One of the velocity spectra is shown in Figure 8. The velocity functions for all 7 locations are shown in table 1. These velocity functions are then linear interpolated and are used to stack the vertical component data set. Figure 9 is the result of a P-P stacked section. The linear interpolated stacking velocity field is then used as a RMS velocity field for P waves to migrate the shots with different γ_{rms}. Figures 10 to 12 are image gathers at the station 1803. Figure 10 shows the trial γ_{rms} is too low for all three events. Figure 12 shows the trial γ_{rms} is too high for all three events. Figure 11 shows the correct γ_{rms} with exception of slightly higher for the second event. A constant γ_{rms} of 1.95 is chosen to migrate all the shots and stacked the common surface location image gather to produce the final time-migrated P-S stacked. Figure 13 shows an example for migrate shot at station 1974, and Figure 14. shows the final migrated stacked section.

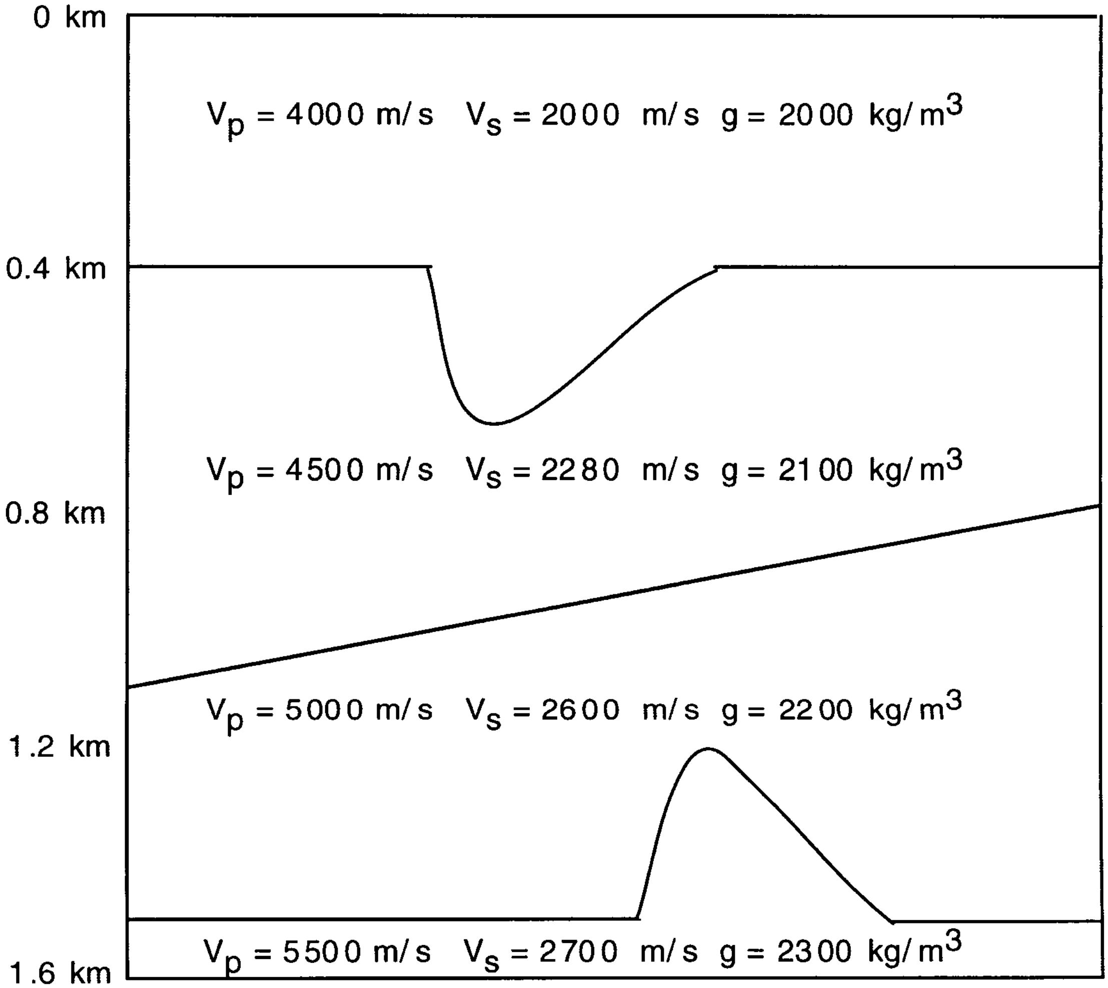

FIG. 3. An earth model for the synthetic data set.

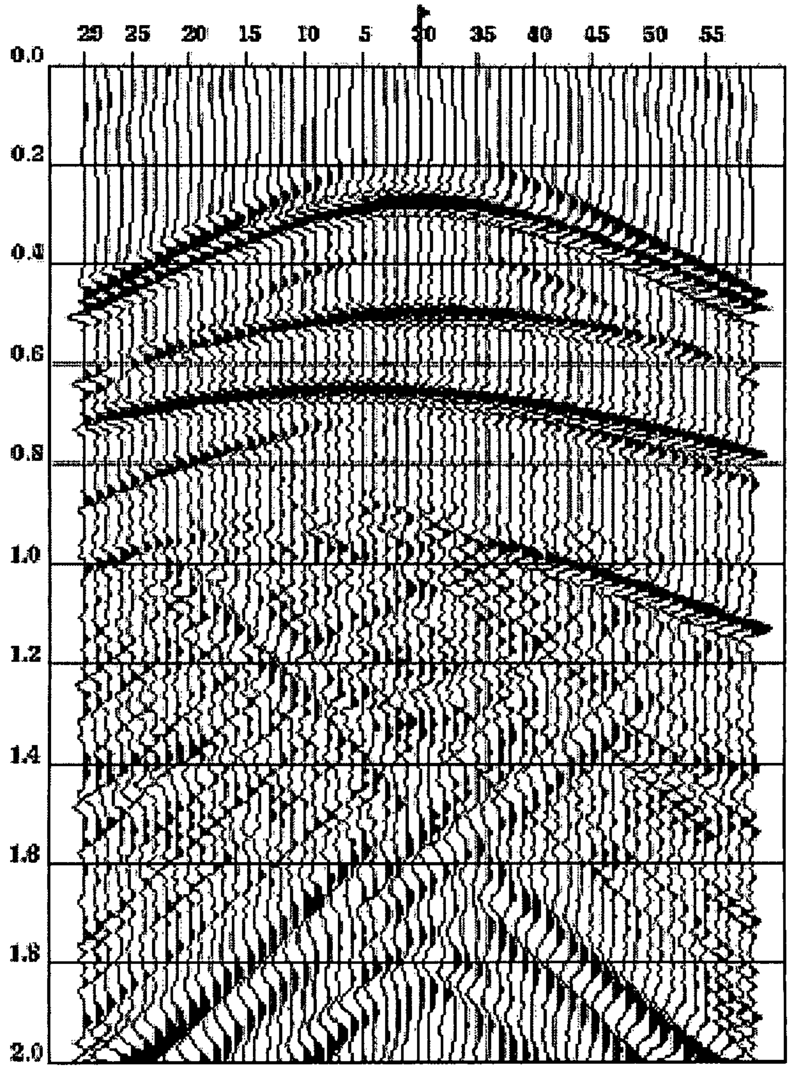

FIG. 4. A vertical component of the synthetic shot record at station 1974.

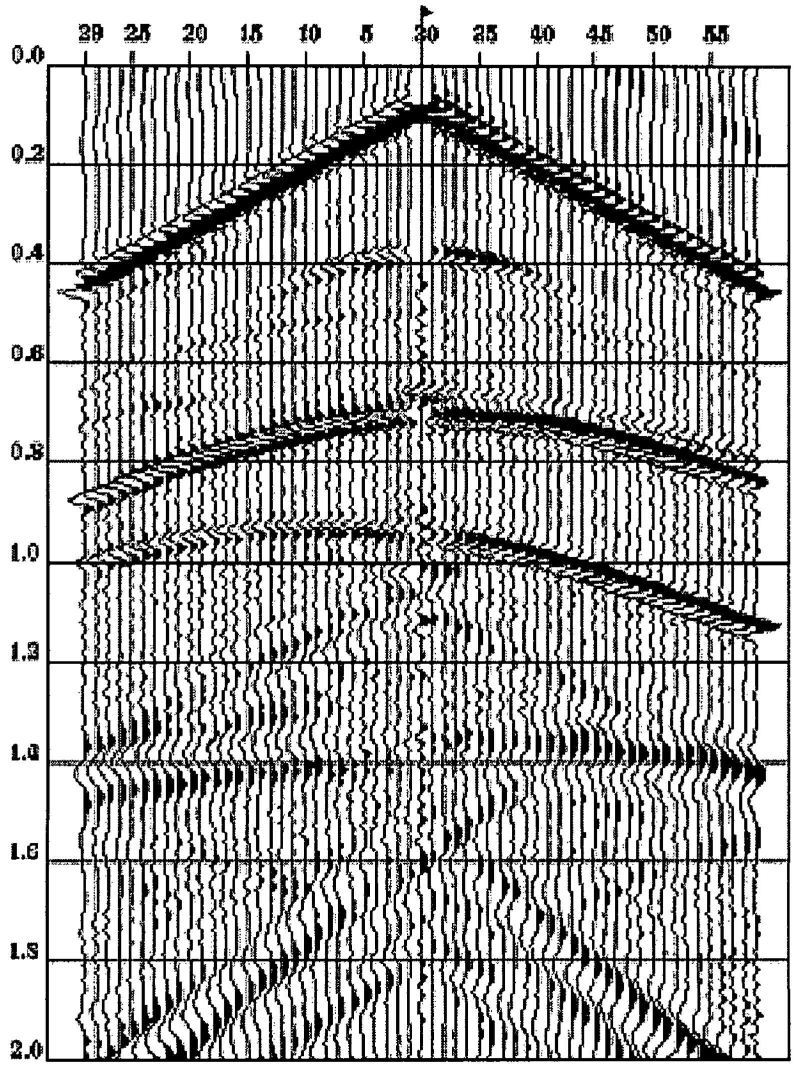

FIG. 5. A radial component of the synthetic shot record at station 1974.

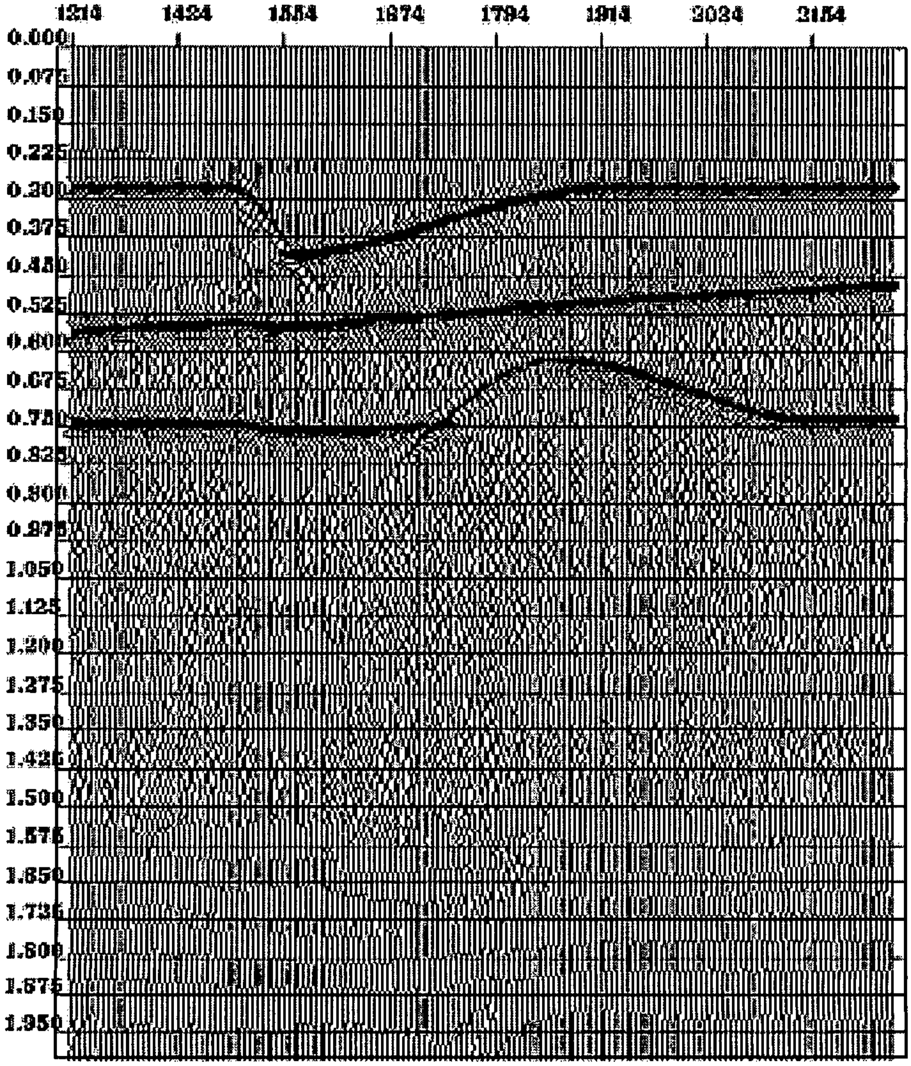

FIG. 6. A section of zero offset trace (100 %) of vertical component

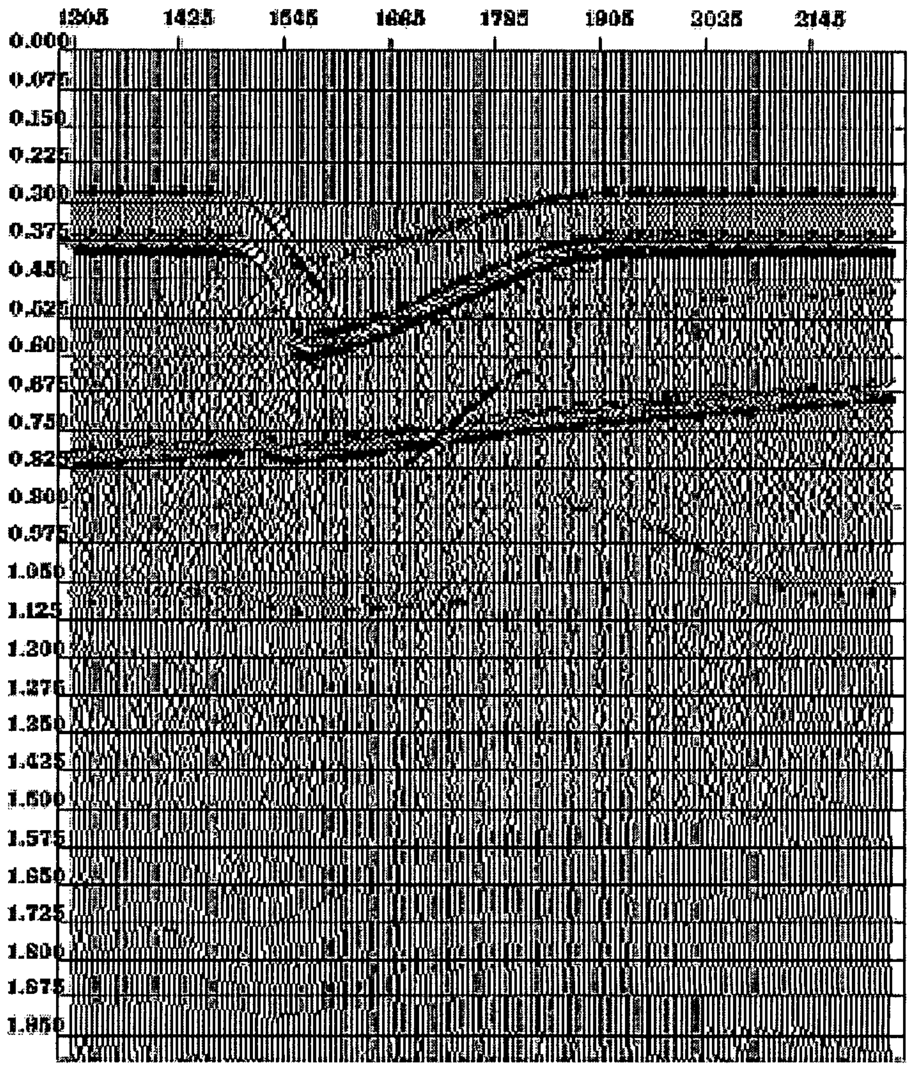

FIG. 7. A section of near offset traces @ 150 m (100 %) of radial component.

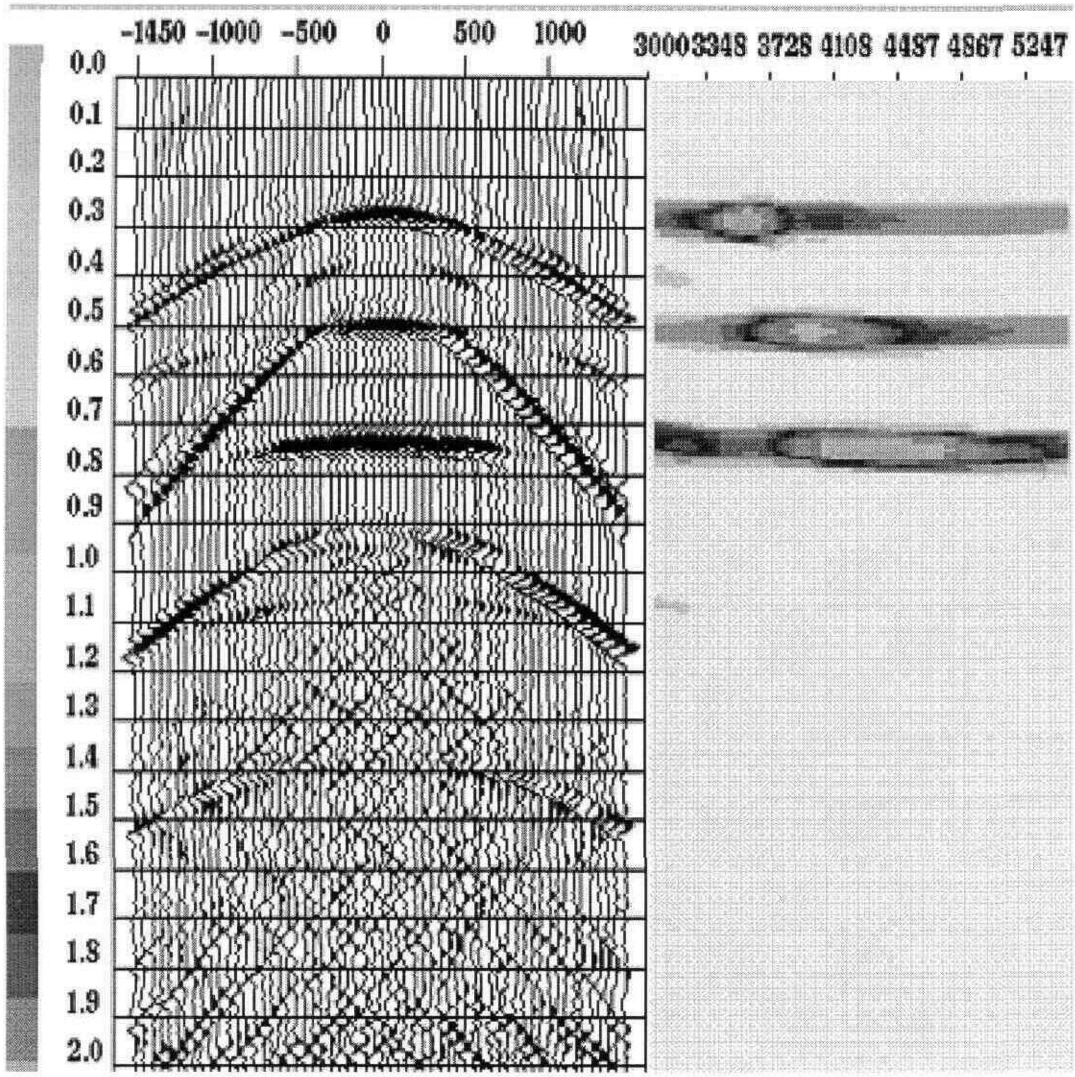

FIG. 8. P-P waves velocity semblance at CMP 1728.

station	time (s)	stacking vel (m/s)
1332	0.296000	3569.62
	0.560000	4006.33
	0.752000	4253.16
1464		
	0.280000	3537.97
	0.552000	4063.29
	0.752000	4354.43
1596		
	0.288000	3537.97
	0.536000	4018.99
	0.632000	4170.89
1728		
	0.280000	3531.65
	0.520000	3968.35
	0.672000	4240.51
1860		
	0.280000	3531.65
	0.512000	3968.35
	0.736000	4386.08
1992		
	0.280000	3569.62
	0.496000	3981.01
	0.736000	4272.15
2124		
	0.280000	3506.33
	0.480000	3968.35
	0.736000	4392.41

Table 1. Stacking velocity pairs for the synthetic data.

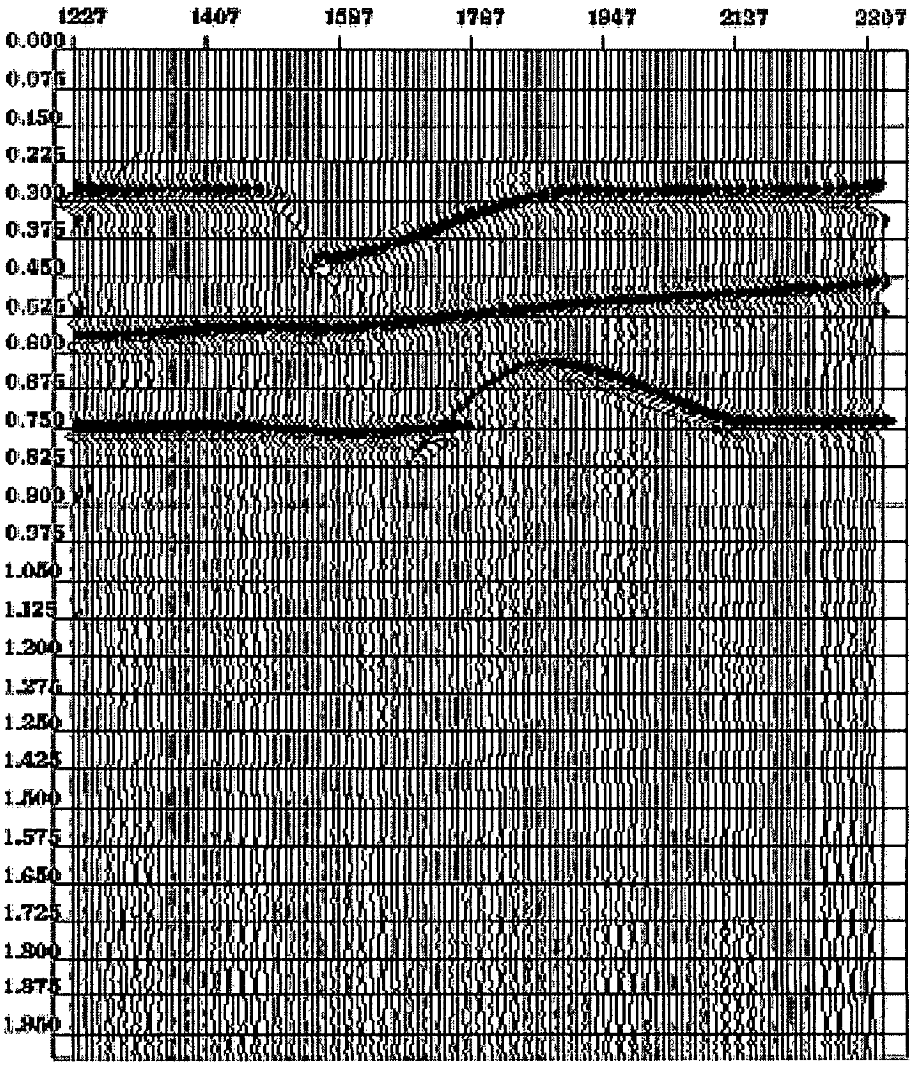

FIG. 9. A stack section for P-P waves.

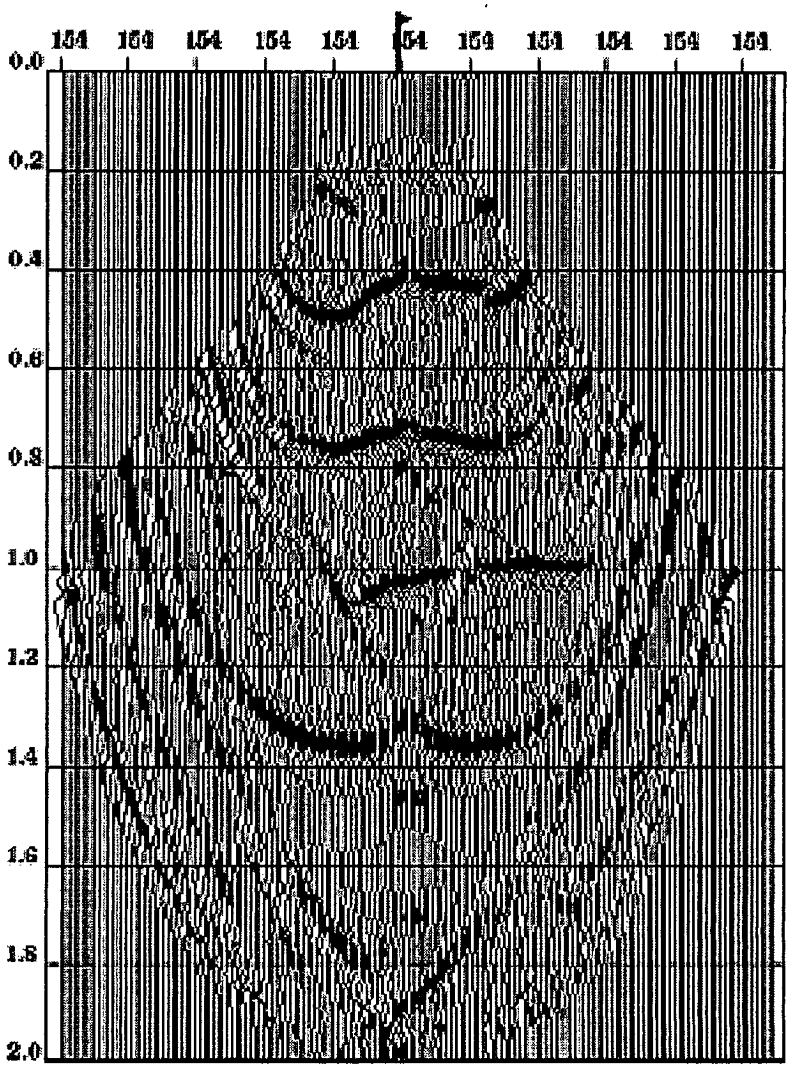

FIG. 10 An image gather at station 1803 with too low $\gamma_{rms} = 1.55$. All 3 events appear curving upwards.

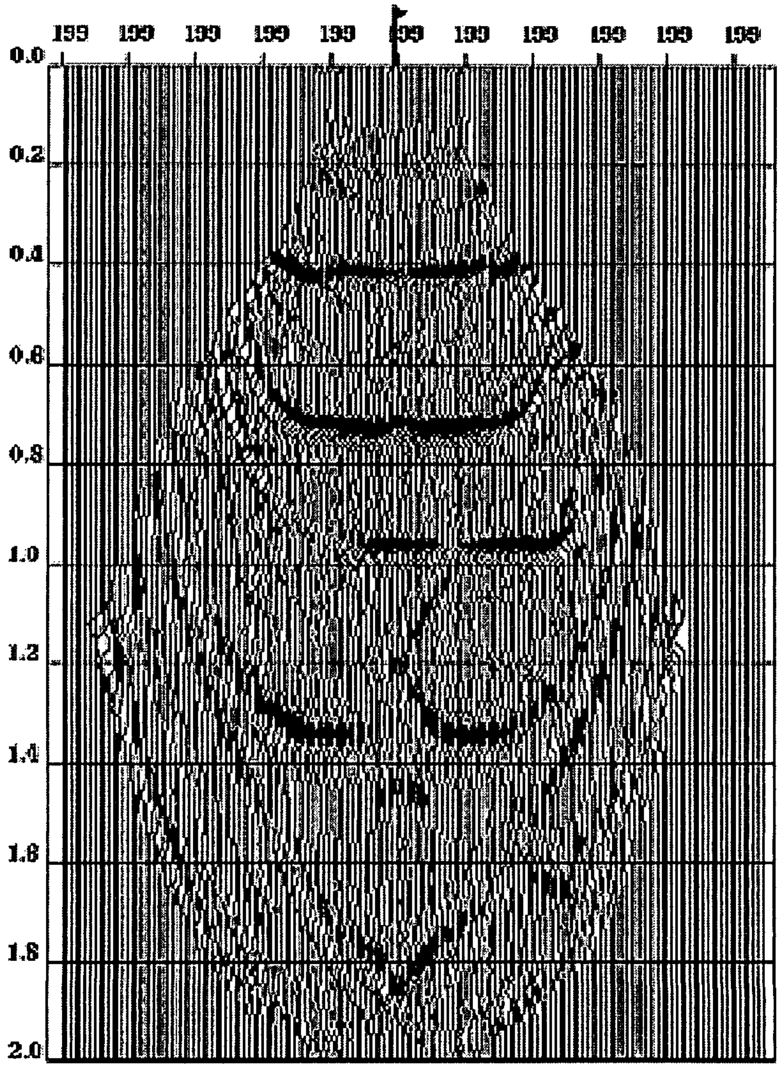

FIG. 11 An image gather at station 1803 with $\gamma_{rms} = 2.00$. The first and the third events become flat. The second event still appears slightly curving upwards.

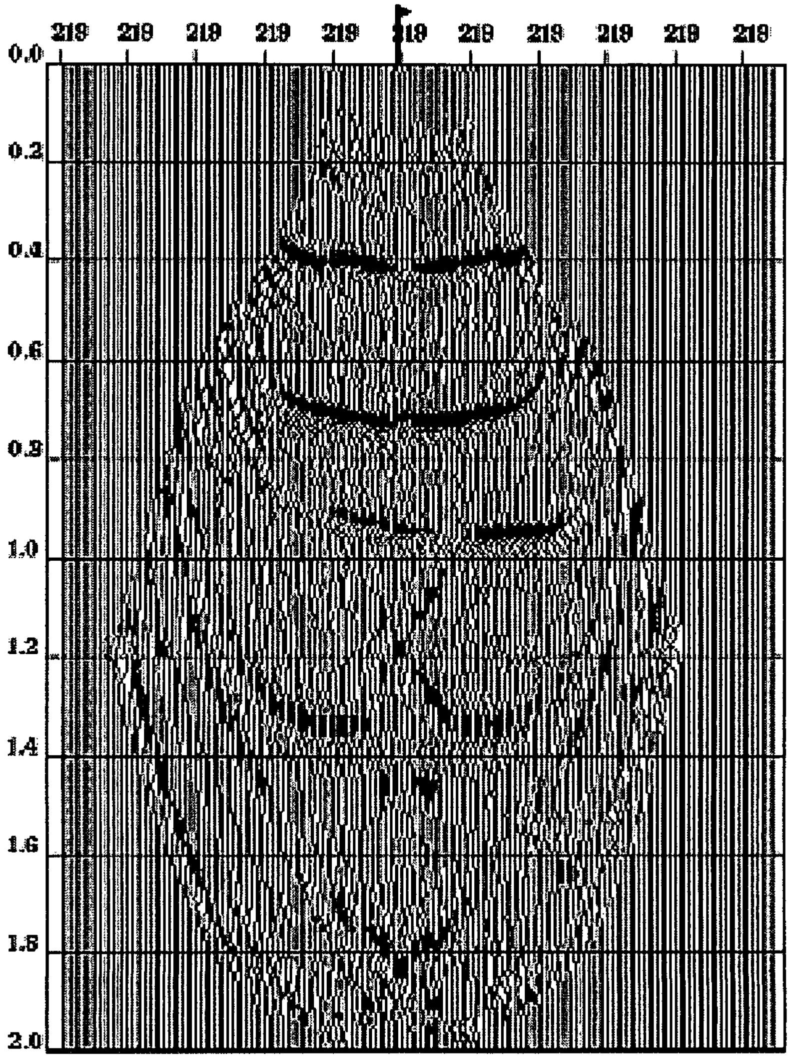

FIG. 12 An image gather at station 1803 with too high γ_{rms} = 2.20. All 3 events appear curving upwards.

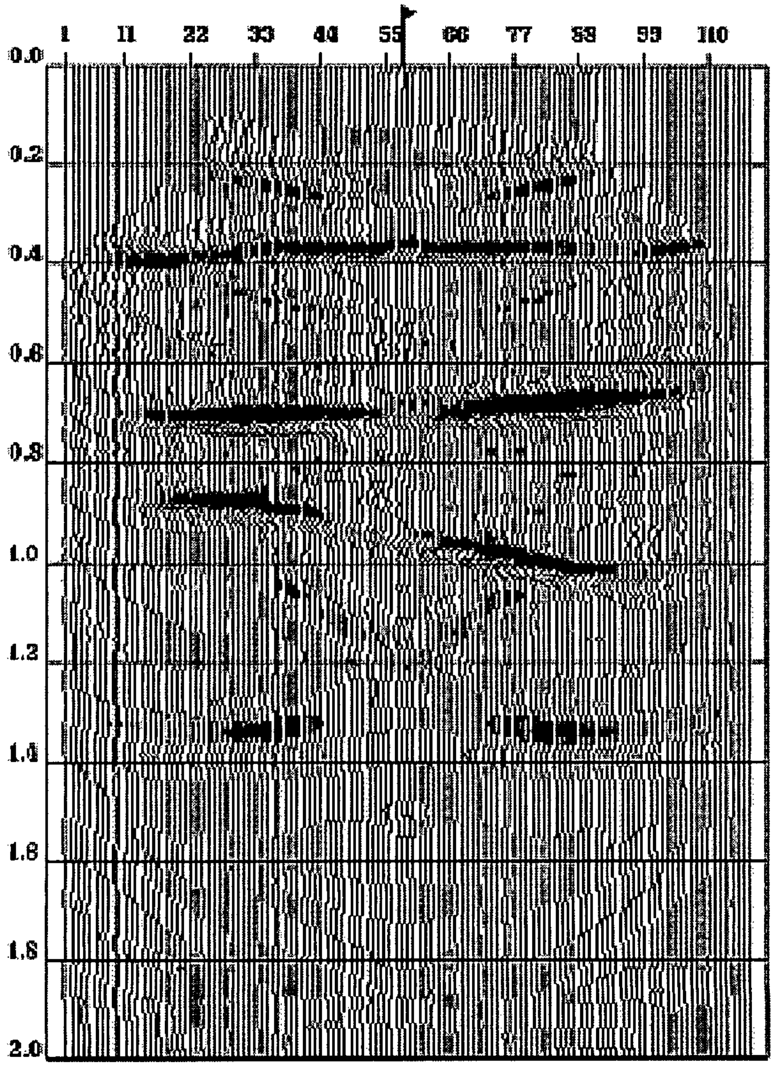

FIG. 13 A migrated P-S shot record at station 1974, with constant γ_{rms} = 1.95.

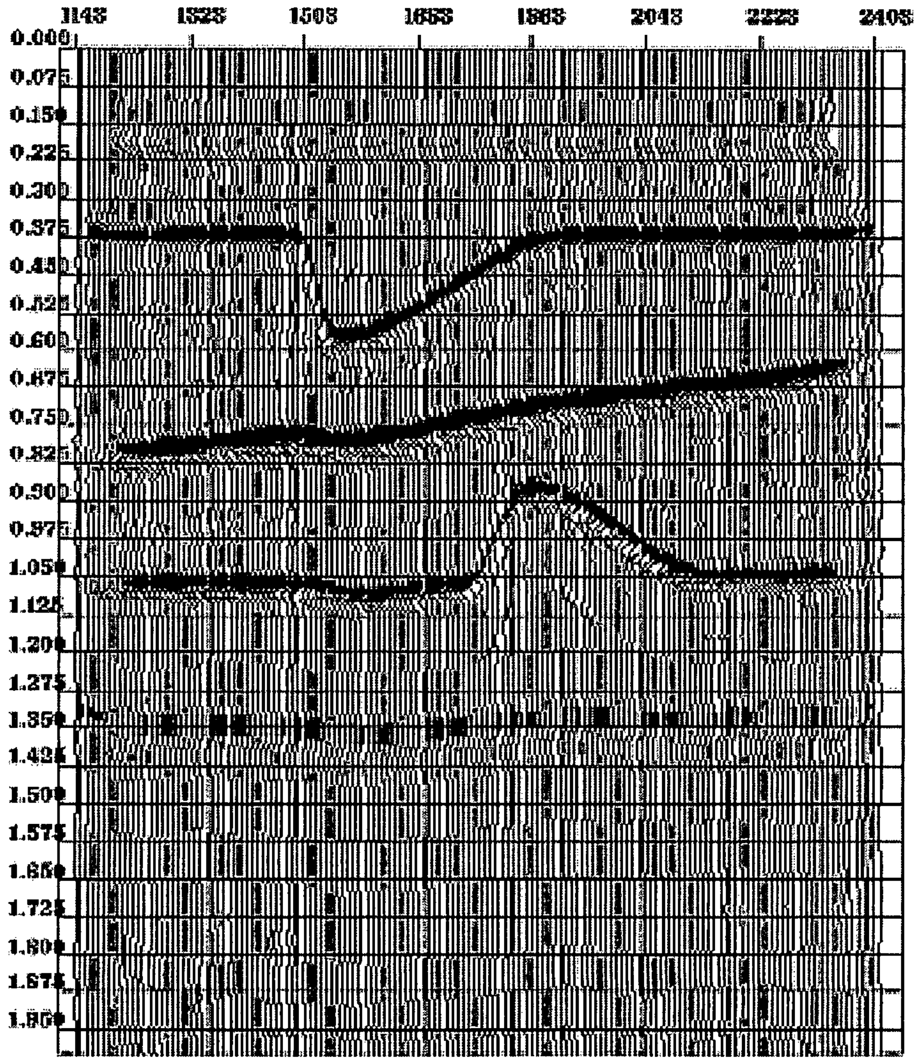

FIG 14. A final P-S migrated stacked record.

Conclusion

In this paper MVA technique for P-S converted data is demonstrated and is shown to be successful in a synthetic data set. With prestack time migration, a symmetrical raypath is not assumed, and hence restrictions involved in CCP stacking can be avoided. The method outlined here is also applicable to S-P converted waves.

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