Logarithmic correlation of P-P and P-S seismic data

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ABSTRACT

A technique of correlating P-P and P-S seismic data in the logarithmic domain is developed. It has an advantage in deriving a squeezing factor from the data rather than the conventional trial-and-error approach. This technique is tested on the Blackfoot data with promising results.

INTRODUCTION

A more complete recording of the seismic experiment requires full vector (3-C) measurement of 3-C of the received waves. From these 3-C measurements, we can create independent converted-wave (P-S) images. Jointly interpreting P-P and P-S sections can significantly improve the description of the geological section and reservoir rocks. To facilitate this ultimate interpretation though, we need to make P-S data easily correlative to P-P data. To do this, we would like to have both sections in P-P time.

A traditional way of converting P-S data into P-P time is by a trial-and-error approach where a squeezing factor is estimated for P-S data such that the events in the P-S data line-up with that in P-P data. Sometimes, the visual judgement of the goodness of the match can be difficult due to the cycle nature of the seismic data.

In this paper, we propose a simple but robust approach to match both P-P and P-S data in the logarithmic time scale. The advantage of this approach is that the squeezing factor is derived from the data.

THEORY

Assume that the Vp/Vs ratios are constant throughout the seismic sections and are equal to γ, then the two-way vertical travel-times for P-P (T_{pp}) and P-S (T_{ps}) can be written as:

$$\frac{T_{ps}}{T_{pp}} = \frac{1+\gamma}{2} = k \quad (1)$$

where k is a constant.

Taking the logarithms on both sides of equation (1), we have

$$\log T_{ps} - \log T_{pp} = \log k \quad (2)$$

Equations (2) says that after logarithmic transformation, all events between both P-P and P-S sections are different by only a static shift (log k). This static shift can be estimated by optimizing the cross-correlation between two sections. Once this static shift is found, γ can be estimated.

This method can also apply in reverse time: That is, if an event at a later time is identified in both P-P and P-S sections, the method can be used to find γ or k above the event. To see that, let t_{pp} and t_{ps} be the times of the identified event in P-P and P-S sections respectively. From equation (1), we have

$$\begin{aligned} t_{ps} - T_{ps} &= kt_{pp} - kT_{pp} \\ &= k\,(t_{pp} - T_{pp}) \end{aligned} \qquad (3)$$

or

$$T_{ps} = kT_{pp} \qquad (4)$$

with

$$T_{ps} = t_{ps} - T_{ps} \qquad (5)$$

and

$$T_{pp} = t_{pp} - T_{pp} \qquad (6)$$

The method assumes a constant γ for the whole trace. Normally this assumption is violated for at least of two reasons. First, because of the difficulty of the refraction analysis for P-S data, both P-P and P-S may not be referenced to the same datum. Second, the Vp/Vs ratio at the near surface is significantly different from the Vp/Vs ratio at depth. However, once at depth, the Vp/Vs ratios are normally rather constant, at least in RMS terms. Therefore, the method is more applicable if γ is measured from an event on both P-P and P-S sections at a later time rather than the time zero. Unfortunately, this procedure implies that an event on P-P and P-S needs to be identified first.

BLACKFOOT EXAMPLE

In this section, the method is applied to a subset of a broad-band 3-C 2-D seismic experiment conducted at the Blackfoot Field in July 1995. Shown in Figure 1 is P-P DMO stack from station 2770 to 3510 on the left and P-S DMO stack from station 3520 to 4260 on the right. An event at 0.479s on P-P DMO stack is tied to an event at 0.864 s on P-S DMO stack. Both stacks are bulk shifted so that the both events are line-up at time zero as shown in Figure 2. A logarithmic transformation is applied to both stacks (Figure 3). A reasonable match (Figure 4) is found after P-P DMO stack is shifted by 0.4 (in logarithmic scale) downwards. The amount of shift (0.4) is translated into a reasonable γ =1.98. The P-S data in Figure 2 is then squeezed with the estimated γ to line-up with P-P data in P-P time. The result is shown in Figure 5 and the overall match is good.

FUTURE WORK

Although this method is developed based on a constant γ, the method can be repeatedly applied to different time windows, to obtain variant γ. For example, in Figure 5, the mis-match starts appearing at 1 second. This implies that γ starts changing significantly from the earlier time. We could have repeated the method starting from 1 second and obtained a different γ. In addition, we could have a suite of bulk time shifts prior to the transformation and scan these for a maximum correlation in the logarithmic domain.

CONCLUSIONS

A technique of correlating P-P and P-S seismic data in the logarithmic domain is presented. This technique has an advantage in deriving a Vp/Vs ratio from the data rather than the conventional method of trial-and-error technique. Although, in the Blackfoot example, we used an average γ in a time window, we are developing a technique that can be repeatedly applied in multiple windows to obtain a time-variant γ.

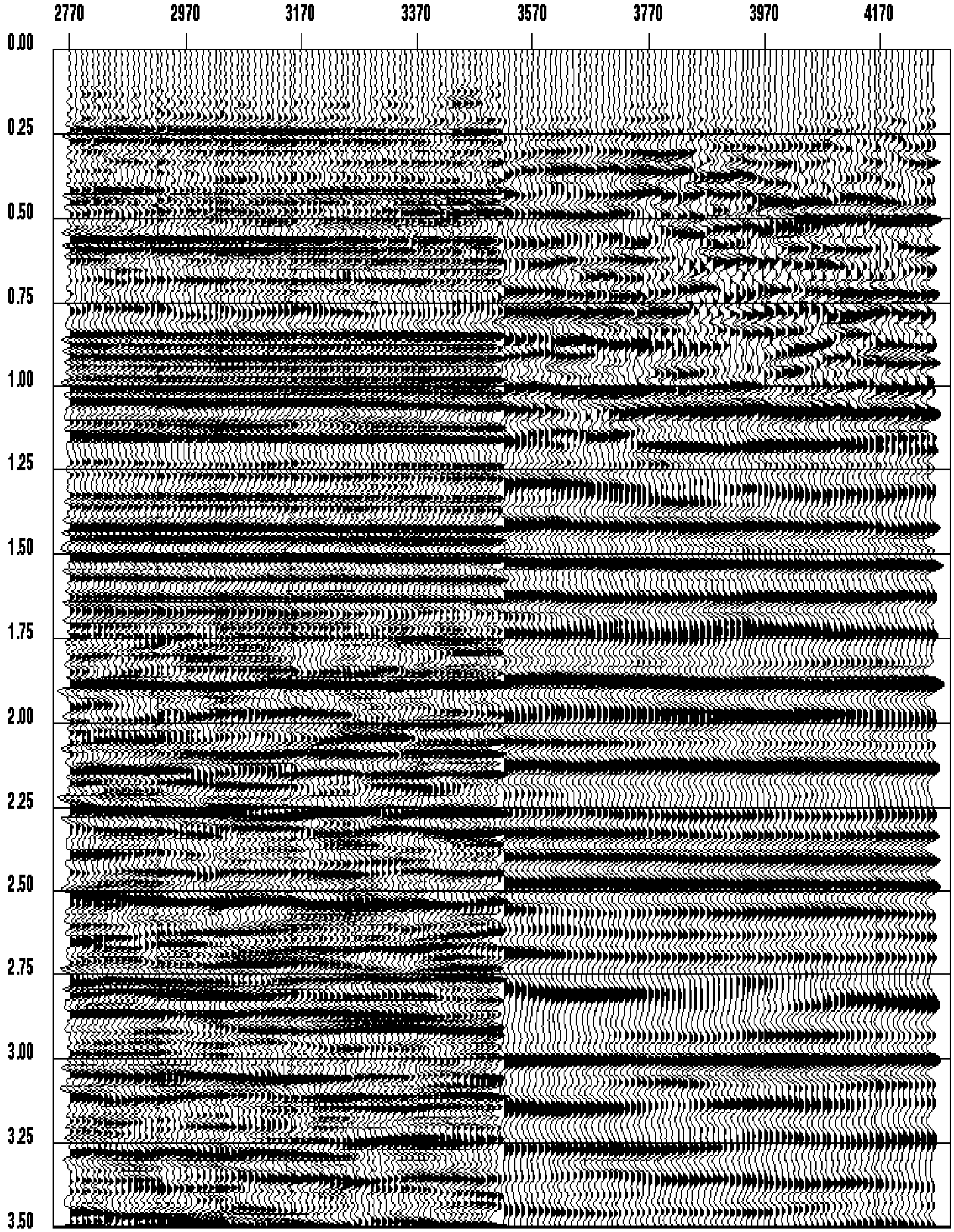

Fig. 1. P-P DMO and P-S DMO Stacks. The first half of record is P-P DMO stack from stations 2770 to 3510, the second half of record is P-S DMO stack from stations 3520 to 4260.

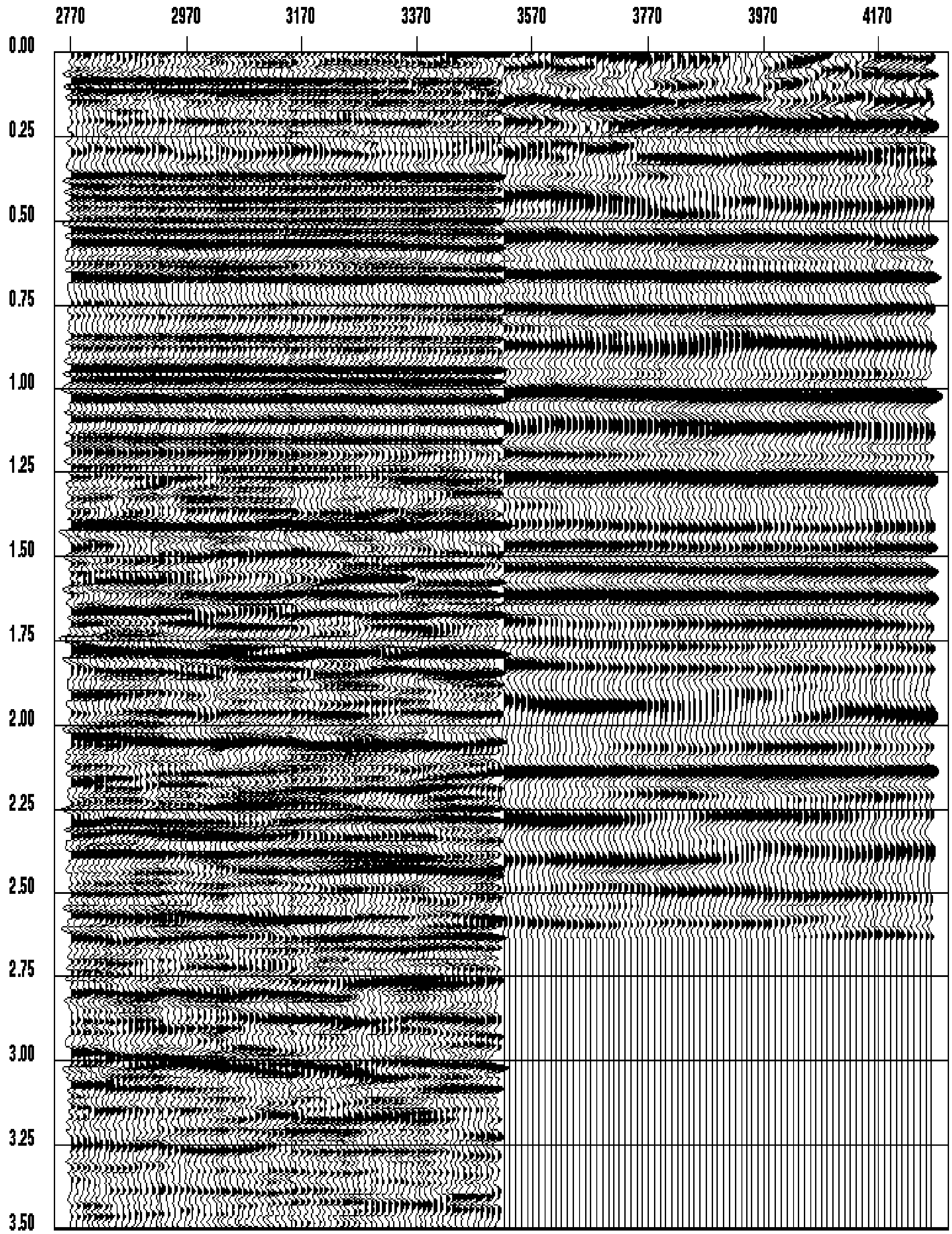

Fig. 2. Input to the log-method. The first half of record is P-P DMO stack shifted by 0.479 seconds upwards, and the second half is P-S DMO stack shifted by 0.864 seconds upwards, so that the event on both stacks are line-up at zero second.

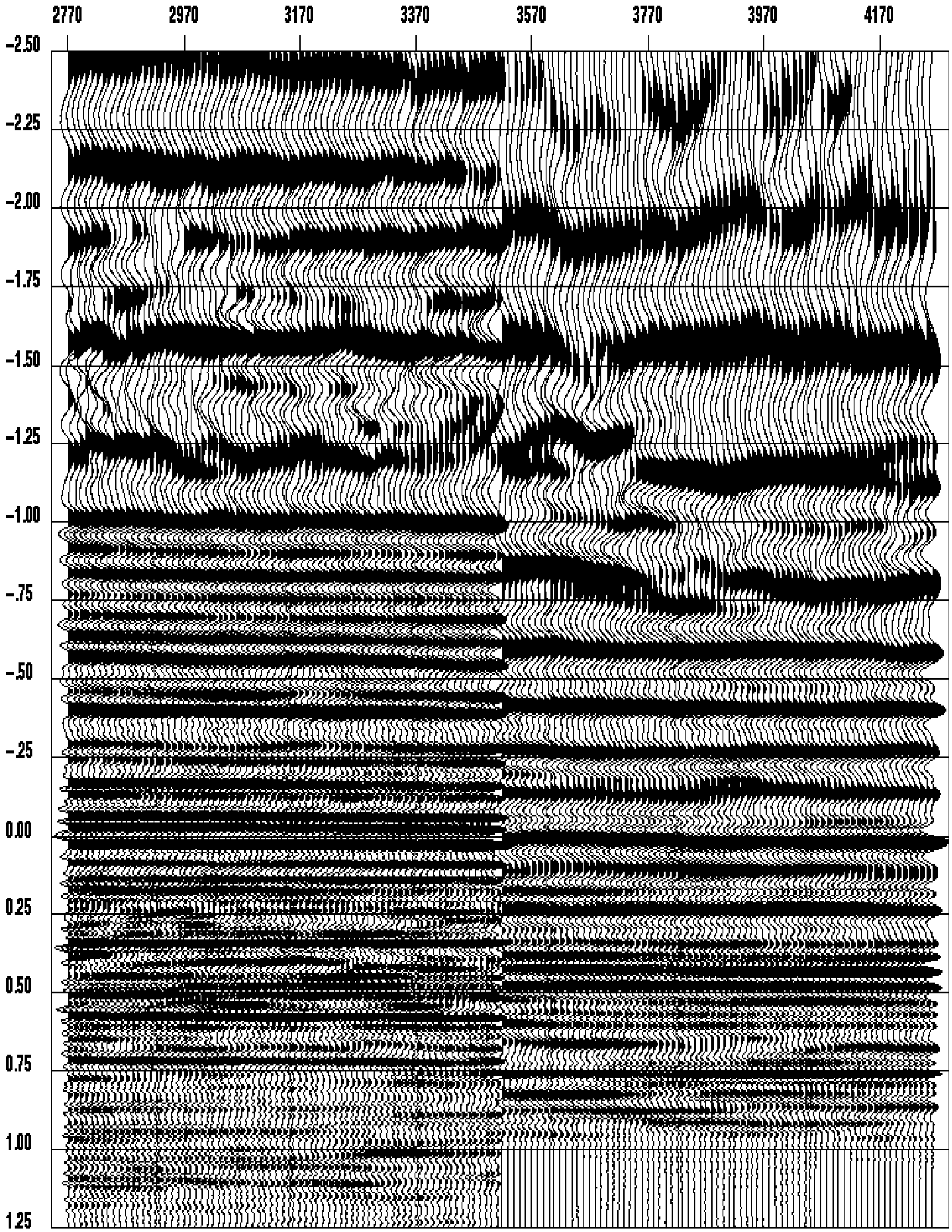

Fig. 3. Log-domain version of Figure 2.

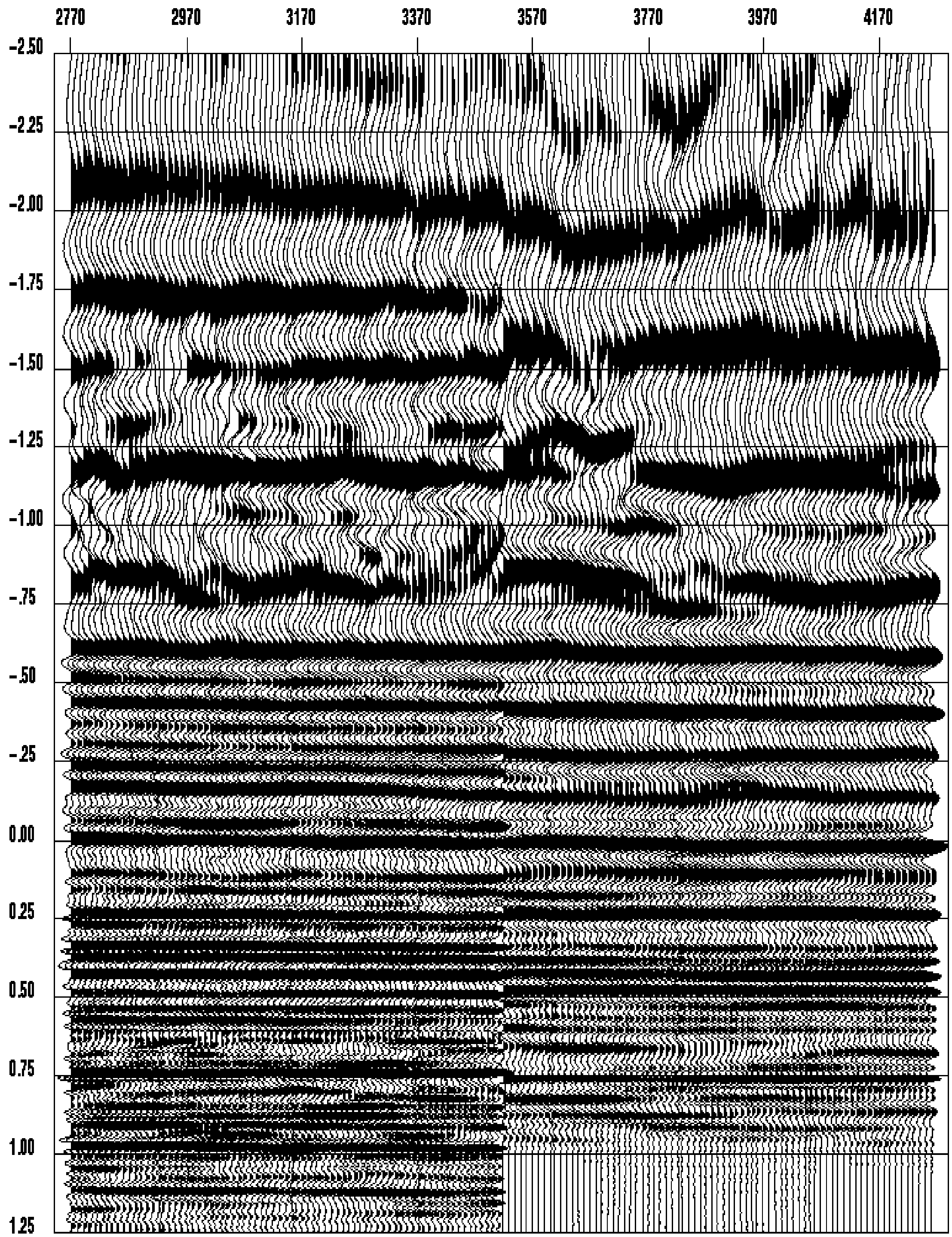

Fig. 4. Events are matched reasonably well in the log-domain after P-P DMO stack (the first half of record) are shifted by 0.4 downwards.

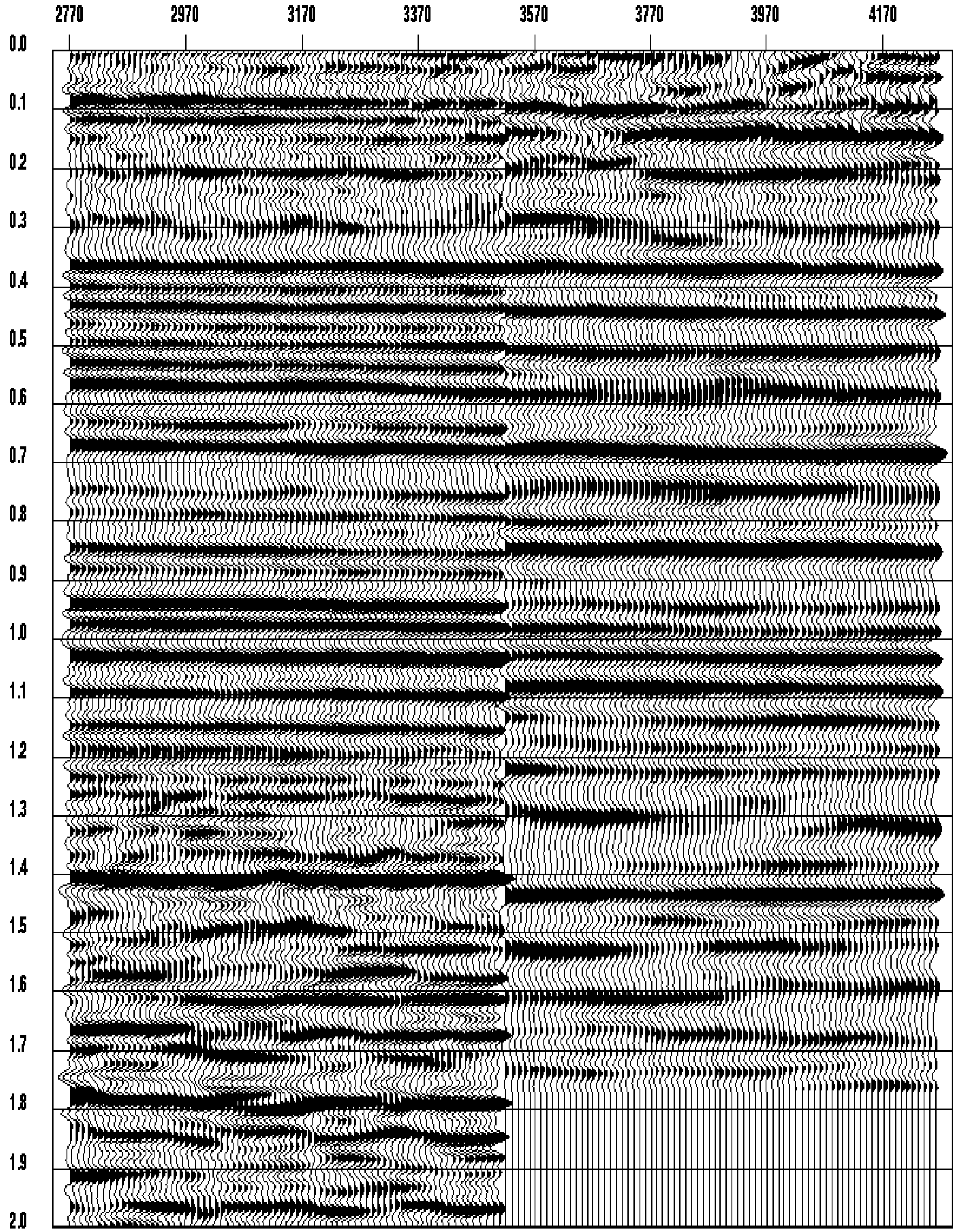

Fig. 5. P-P and P-S match in P-P time. The P-S data on the right has been squeezed with γ_{ps} =1.98 to match P-P data on the left.