Computing shear-wave statics with the help of seismic tomography

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ABSTRACT

The purpose of statics for seismic data is to remove the disturbing effects of the near-surface low-velocity layer (LVL) on the continuity of deep seismic reflections. The traveltimes of waves at the bottom of the LVL can often be obtained by picking first breaks on shot records. Since the LVL often has irregular velocities and thicknesses both vertically and laterally, we develop a vertically and laterally inhomogeneous velocity and thickness model with the help of refraction traveltimes, from which the statics can be obtained. Then we describe a method for computing accurate statics from first breaks according to the model. It is based on a linearizing principle for first break traveltimes and leads to the algorithm that is widely and successfully applied within the framework of seismic tomography. In this method, the differences between observed traveltimes on field records and those computed by ray tracing from an initial model of the LVL are minimized in the least-squares sense by iterative techniques to obtain accurate statics. The accuracy of the method lies in dividing the LVL into small finite blocks, each having particular values of the P and S velocities and of thickness, first obtaining accurate velocities and thicknesses for these blocks, then obtaining accurate statics by the method. The potential importance of this refraction-tomography statics method is shown through an application of the method to the vertical- and radial-component data (P-P and P-SV) from the Line EUE001, Slave Lake, northern Alberta.

INTRODUCTION

Many methods had been described in the seismic literature for computing refraction statics from first breaks. Most of these are based on special shallow refraction statics survey measurements (e.g. Hampson and Russell, 1984). Together with well-established programs for calculating residual static corrections, they are routinely applied in the seismic processing of land data. Besides, many more advanced and more useful statics methods had been developed, including refraction tomography (de Amorim et al., 1987; Boadu, 1988) and delay-time analysis (Lawton, 1989) and the contrast of two methods (Schafer, 1989).

As is well known, first breaks are the most useful arrivals on shot records for determining the characteristics of the near-surface LVL. They can often be easily identified by hand and, in most cases, even automatically picked. Besides, we know that the presence of the LVL anomalies can cause serious problems in the processing of seismic data, especially in the processing of shear-wave seismic data (including converted shear-wave) for the shear-wave velocity in the LVL is one half or less than that of compressional waves in the same medium. The purpose of this paper is to develop a method of using P-wave, converted-wave (P or SV) and SV-wave refraction traveltimes to determine the structure of the LVL to obtain accurate refraction statics on the basis of the above-mentioned refraction tomography, finally obtaining a best stacked section. The method is suitable for any kind of head wave and any portion of the LVL.

FUNDAMENTALS

The technique of seismic refraction tomography involves dividing the LVL into many small layers both laterally and vertically. In fact, each small layer is a block that has a constant velocity and thickness (de Amorim et al., 1987; Boadu, 1988; Schafer, 1989). But all the above methods have their limitations, including those associated with head-wave type (PPP, PPS, PSP, PSS, SPP, SPS, SSP, and SSS) and the number of low-velocity layers. In view of the above-mentioned facts, we try to develop a new method of seismic refraction tomography. All different kinds of refraction tomography statics can be obtained using the method, no matter how many low-velocity layers there are and what kind of head wave the refraction is. First, an initial guess of the velocity and thickness for each small refractor (block) is obtained from the inverse slope and intercept time of the refraction (Gardner, 1939), then the accurate velocity and thickness for each refractor is determined by minimizing the differences between observed traveltimes on field records and calculated traveltimes from the model by ray tracing using the least-squares norm. In general, to avoid wasting unnecessary computer time, the algorithm continues iteratively until the error is below a specified limit (Hampson and Russell, 1984). In addition, when the algorithm is run, both velocity and thickness are varied at the same time, rather than just one of them at a time (de Amorim et al., 1987; Boadu, 1988; Schafer, 1989).

THE ALGORITHM

The process of specific realization for the algorithm is as follows.

Firstly, we need to acquire the multicomponent seismic data with good refraction traveltimes which can easily be picked by hand. So long as the propagation of the waves accords with Snell's law, a refraction arrival can be one of the following kinds of refractions (PPP, PPS, PSP, PSS, SPP, SPS, SSP, and SSS).

Secondly, we need to develop an initial model which consists of small finite blocks with equal lateral extent. According to the inverse slope and intercept time of the refraction waves, an initial guess of the velocity and thickness of each refractor can in turn be obtained.

Thirdly, by minimizing the differences between the observed traveltimes on field data and the calculated traveltimes from the model by ray tracing, an accurate velocity and thickness for each refractor for the LVL can be obtained. In my program, to avoid wasting unnecessary computer time, the program continues iteratively until the error energy between observed and calculated traveltimes is less than 0.001 s, or the change in the parameter (h or v) c is less than 0.01%, or the twentieth (or the fifteenth) iteration is reached.

Fourthly, accurate refraction tomography statics are obtained by using the accurate velocity and thickness for each refractor for the LVL.

Fifthly, final stacked sections are obtained by applying some necessary processing to the seismic data with or without refraction tomography statics or with other refraction statics applied.

Finally, the results of these stacked sections are compared with each other.

AN EXAMPLE

An example of the application of this method for static correction is carried out on PSS (or P-SSS) and PPP refraction waves from the radial (Figures 1, 2b, and 3b) and the vertical (Figures 2a and 3a) components of a three-component P-source seismic data set: Slave Lake Line EUE001. These data are processed by using the necessary conventional and special processing. The final products were the stacked sections with hand statics (Figure 4b), with refraction-tomography statics (Figure 4c), with a commercial refraction statics (Figure 4d) applied for the vertical (P-P) component data, a common-source-point stacked section (Figure 5a) and a common-receiver-point stacked section (Figure 5b) for the radial (P-SV) component data (Schafer, 1989), and the stacked sections with hand statics (Figure 6b), with refraction-tomography statics (Figures 6c and 6d), with a commercial refraction statics (Figure 6e) applied for the radial (P-SV) component data. The problem of converted-wave (P-SV) or shear-wave (P-SSS) statics becomes obvious by inspection of the above-mentioned relative stacked sections (Figures 5a and 5b). These large static shifts lead to poor quality of the brute stack (Figure 6a) and difficulty in finding a good statics solution. Even after several attempts at picking these static shifts by hand, a good quality stacked section could not be obtained (Schafer, 1989; Figure 6b). But the stacked section with refraction-tomography statics applied (Figures 6c and 6d) are satisfactory. It is worth mentioning that the stacked section with the commercial statics applied (Figure 6e) is quite poor in quality. The possible reason is that it is difficulty to pick automatically the correct first refraction breaks from the radial (P-SV) component data due to an irregular refraction wave resulting from the LVL, thus resulting in mispicking and applying incorrect statics to the seismic data. Therefore, the present method could be useful for picking first breaks from seismic records with low signal-to-noise ratio and in the case of a complex near-surface LVL due to the fact that picks are made manually, not automatically.

In general, the reason that converted waves or shear waves have large static shifts is that their velocities are very low in the LVL. They usually travel at about one half the velocity of P waves (or less) in the same LVL. The static effect for these two kinds of waves is anticipated to be about twice as great as it is for P waves (Schafer, 1989; Lawton, 1989; Boadu, 1988). However, the difference is usually not so simple for converted waves (P-SV) or perhaps shear waves are affected more complexly and very differently than P waves by irregular near-surface conditions. For example, P waves are greatly affected by the water table, but shear waves seem to ignore the water table (Lawton, 1989; Houston et al., 1989) and are more affected by another layer at depth, perhaps a layer of unconsolidated sediments overlying more consolidated sediments (Lawton, 1989). So shear waves (or converted waves) and P waves often have different refraction boundaries at depth. Therefore, refraction statics of shear waves or converted waves (P-SV) can be several times as great as for P waves. (Converted waves originate as compressional waves from a regular P-wave source and are converted to shear waves upon reflection or refraction from the boundary at depth.) In this example, the thickness of the P-wave LVL is about 20 m. Its static correction is about 30 ms. But the converted-wave or shear-wave LVL is about 120 m thick. Their static corrections are about 280 and 450 ms, respectively. Therefore, very great differences between P and SV static shifts often result due to their different LVL thicknesses and velocities.

In the example, P-wave refractions (PPP) are clearly seen as first breaks on the vertical component of the three-component P-source seismic data from Slave Lake EUE001 (Figures 2a and 3a). Due to their strong amplitudes, their first-break traveltimes can easily be determined. Two converted-wave refractions and shear-wave refractions have been seen on the radial component of the above-mentioned data (Figures 1, 2b, 3b). They are delayed with respect to the P refractions and have a similar and a different moveout velocity. Thus they are interpreted to be due to PPS, PSS, and P-SSS head waves, respectively. Similarly, due to their strong amplitudes, their propagation traveltimes can easily be observed and picked. The PSS and P-SSS traveltimes extend from 0.7-0.8 s at the near offset to 2.8-2.9 s at the far offset, whereas the PPP and PPS traveltimes extend

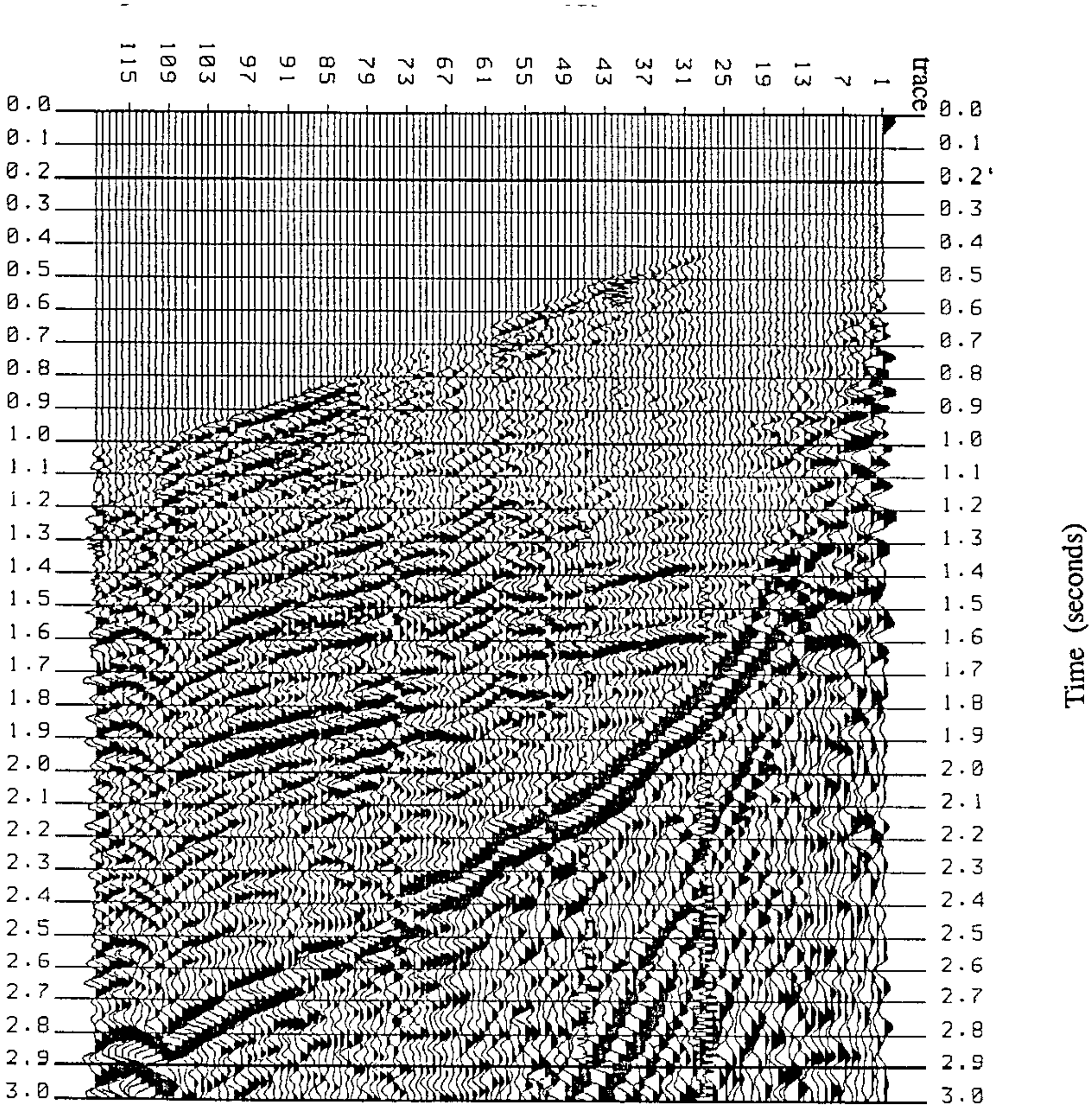

Fig. 1: Sample shot record from the radial component (P-SV) from Line EUE001, Slave Lake, northern Alberta.

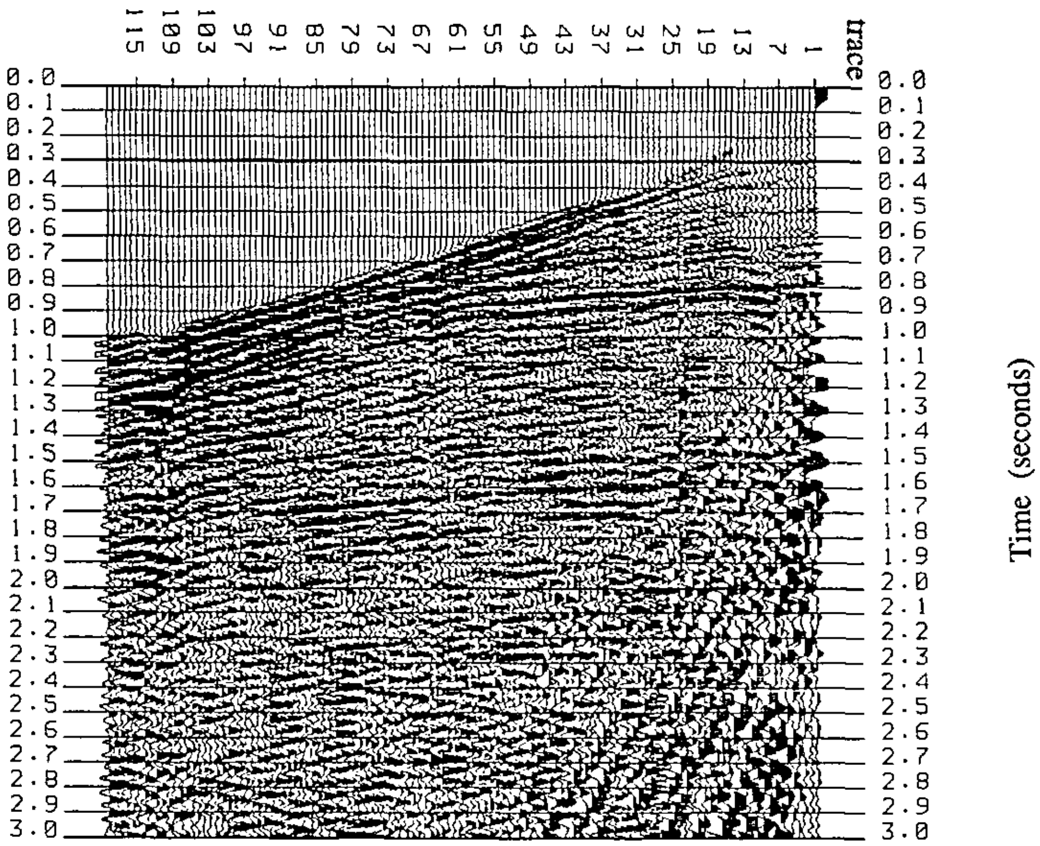

Fig. 2a: End-on shot record from the vertical (P-P) component data from Line EUE001, Slave Lake, northern Alberta.

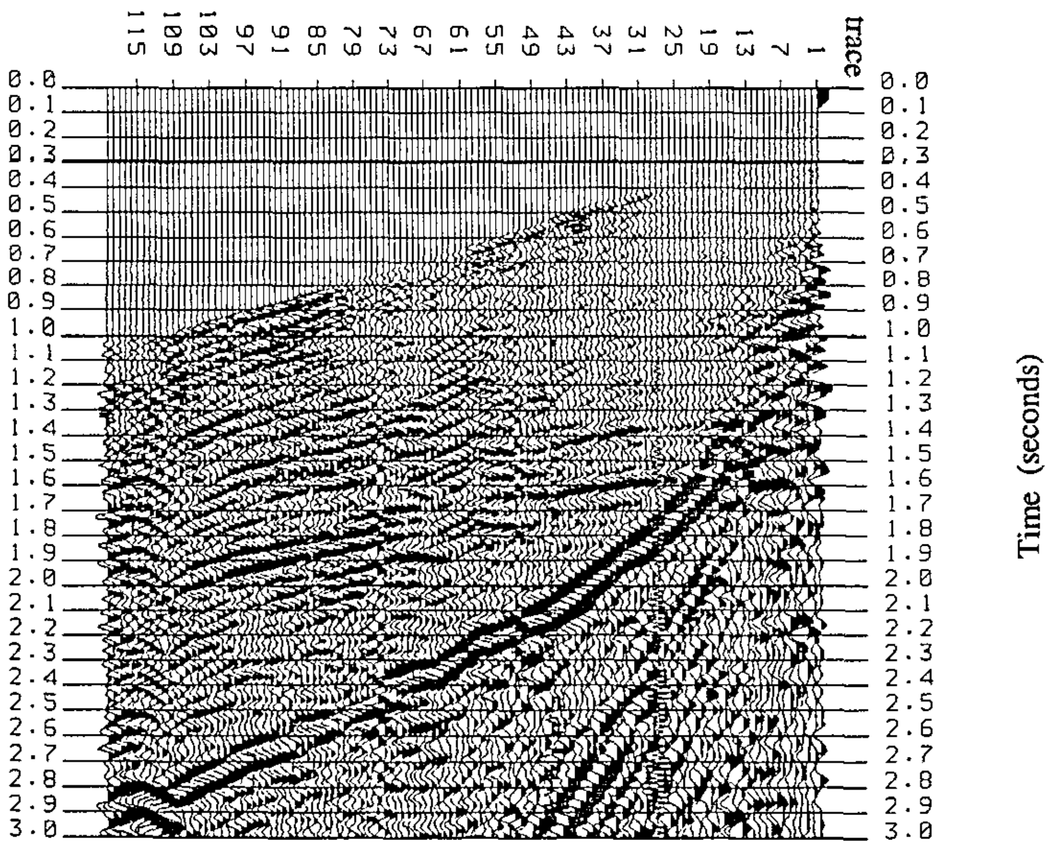

Fig. 2b: End-on shot record from the radial (P-SV) component data from Line EUE001, Slave Lake, northern Alberta.

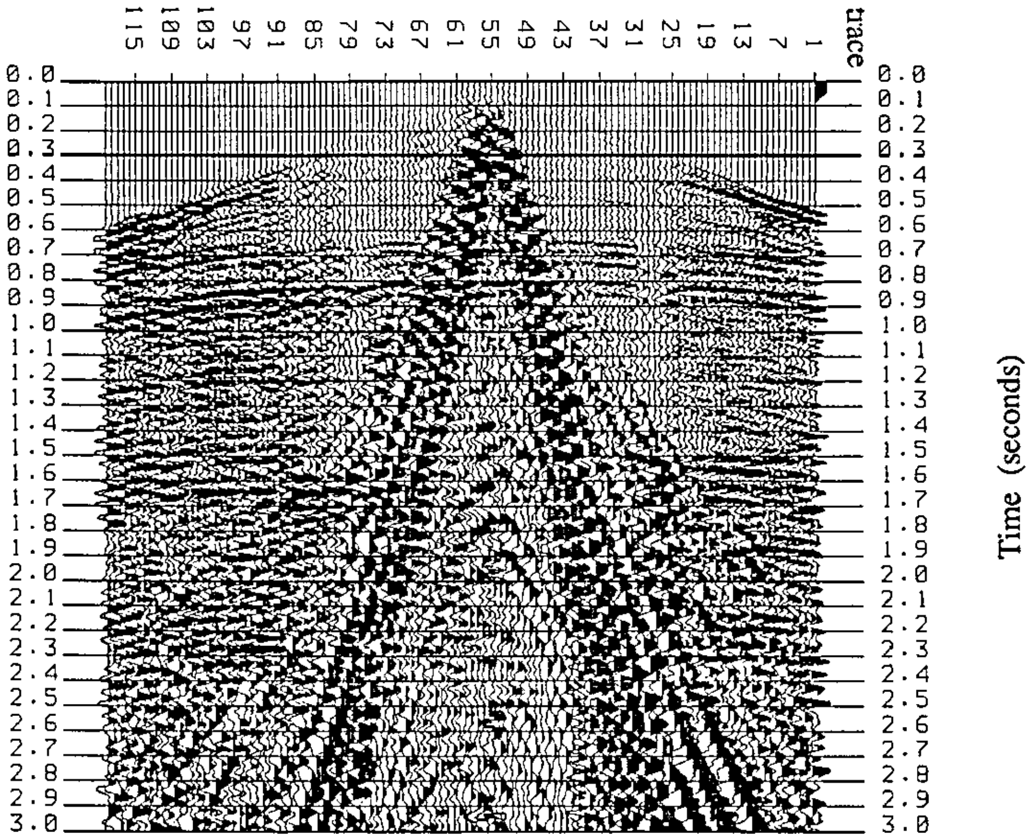

Fig. 3a: Split-spread shot record from the vertical (P-P) component data from Line EUE001, Slave Lake, northern Alberta.

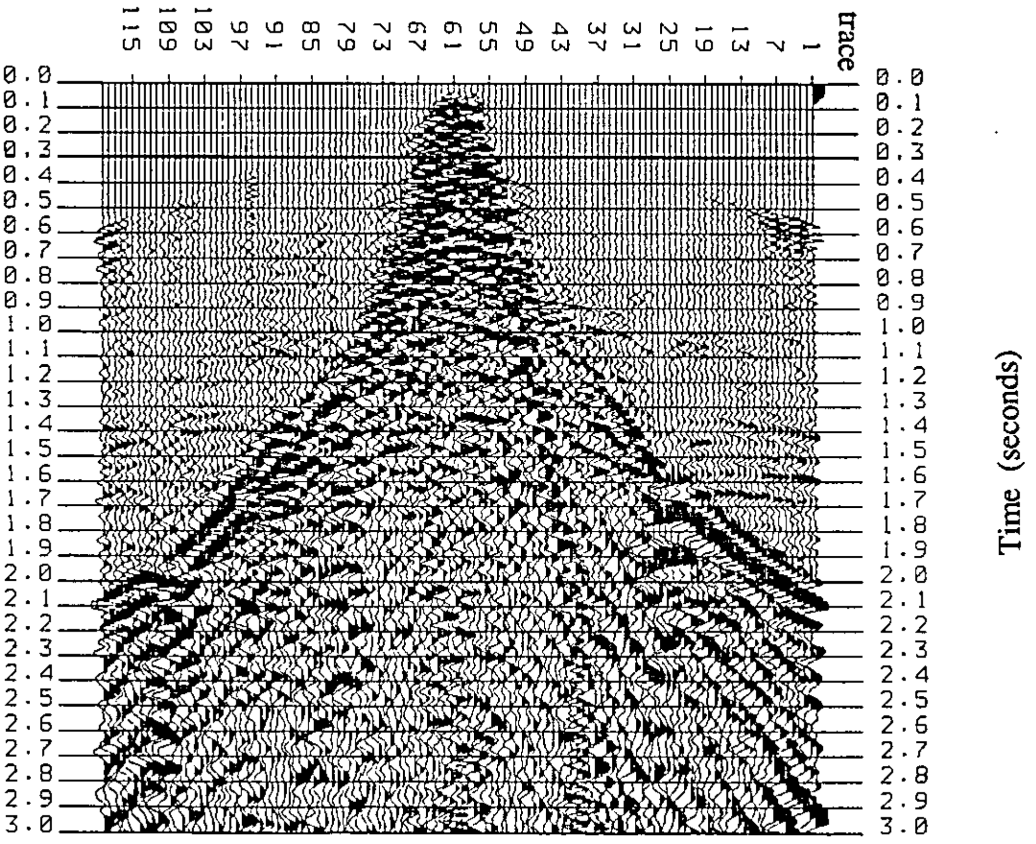

Fig. 3b: Split-spread shot record from the radial (P-SV) component data from Line EUE001, Slave Lake, northern Alberta.

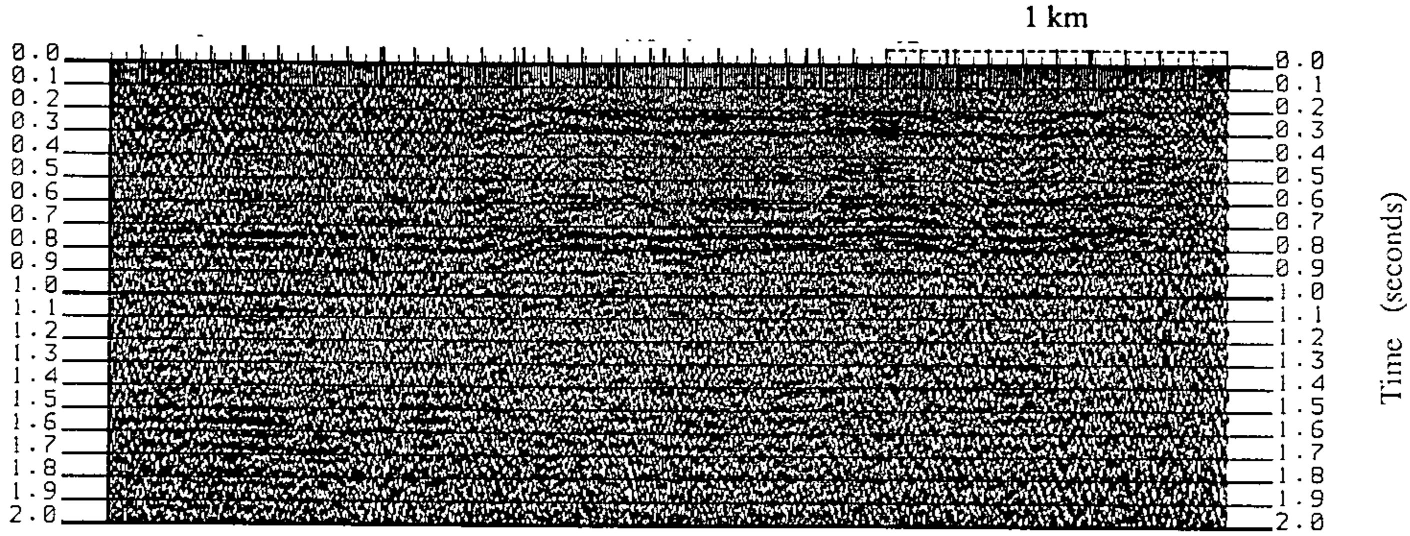

Fig. 4a: The brute stack of the vertical (P-P) component data from Line EUE001, Slave Lake, northern Alberta.

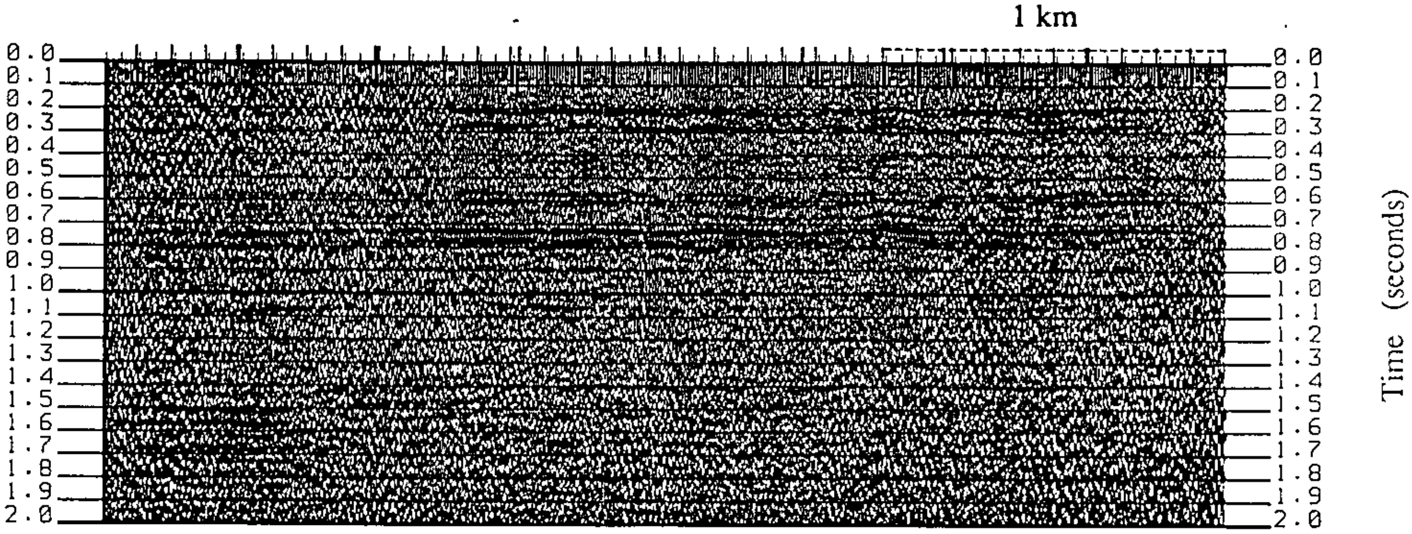

Fig. 4b: The vertical (P-P) component stacked section with hand statics applied.

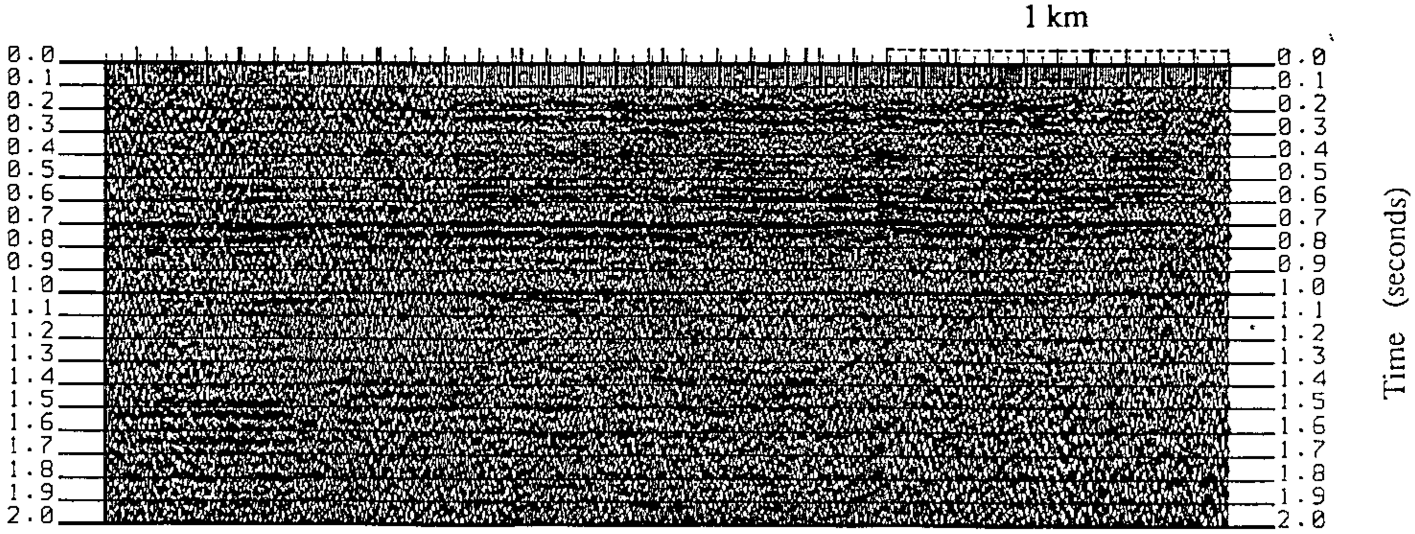

Fig. 4c: The vertical (P-P) component stacked section with refraction tomography statics applied.

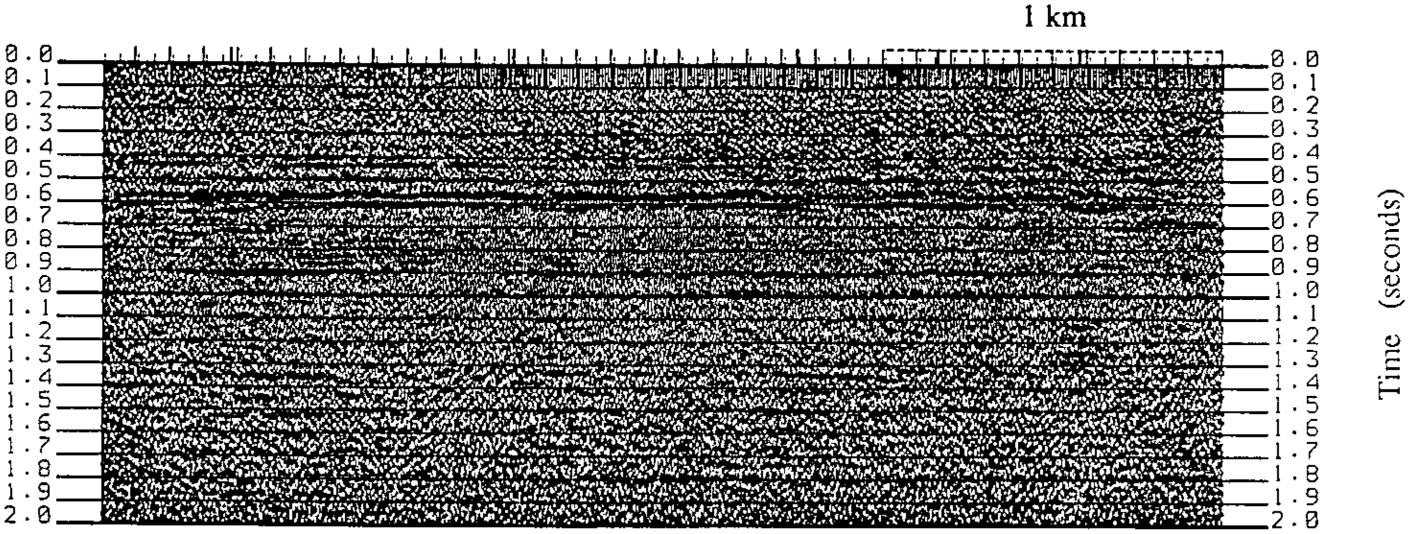

Fig. 4d: The vertical (P-P) component stacked section with commercial refraction statics applied.

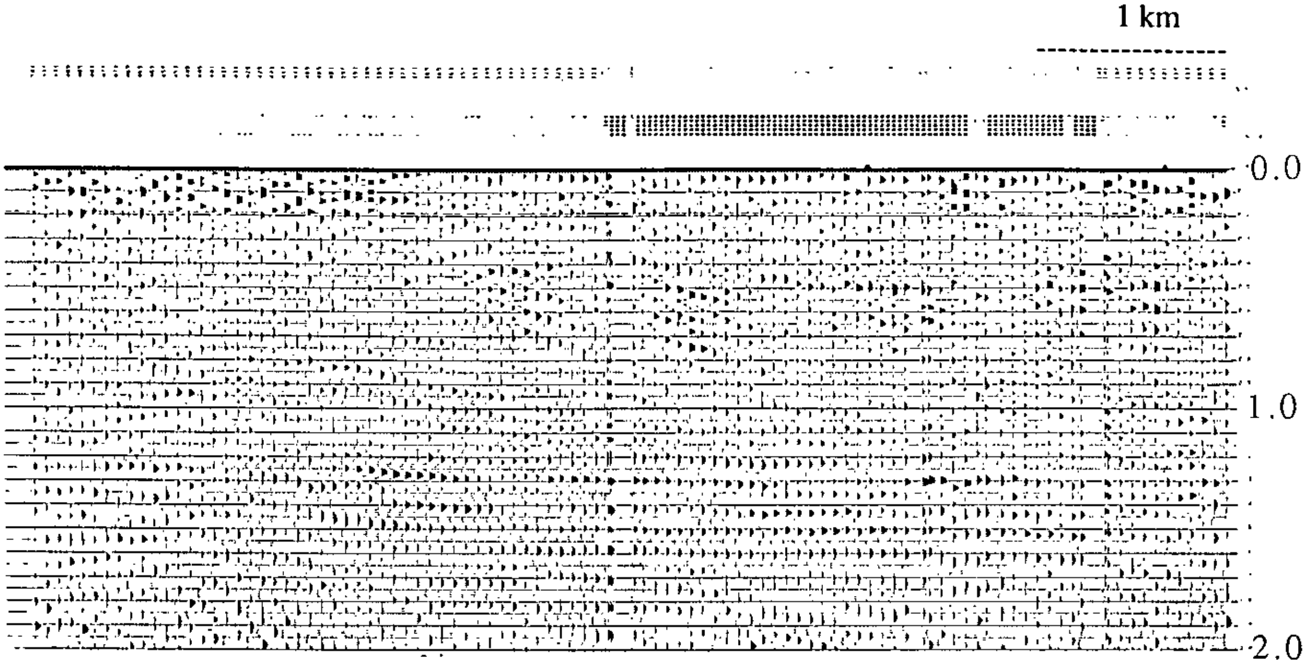

Fig. 5a: Common-sourcepoint stack section for the radial (P-SV) component data from Line EUE001, Slave Lake, northern Alberta.

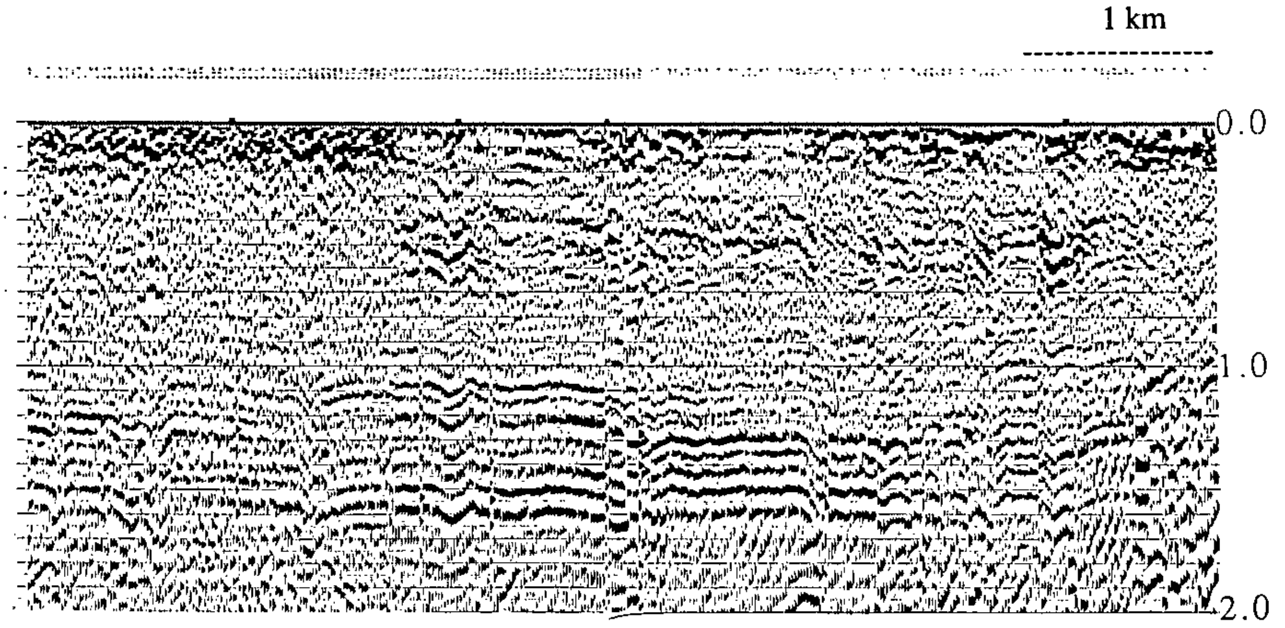

Fig. 5b: Common-receiver stack section for the radial (P-SV) component data.

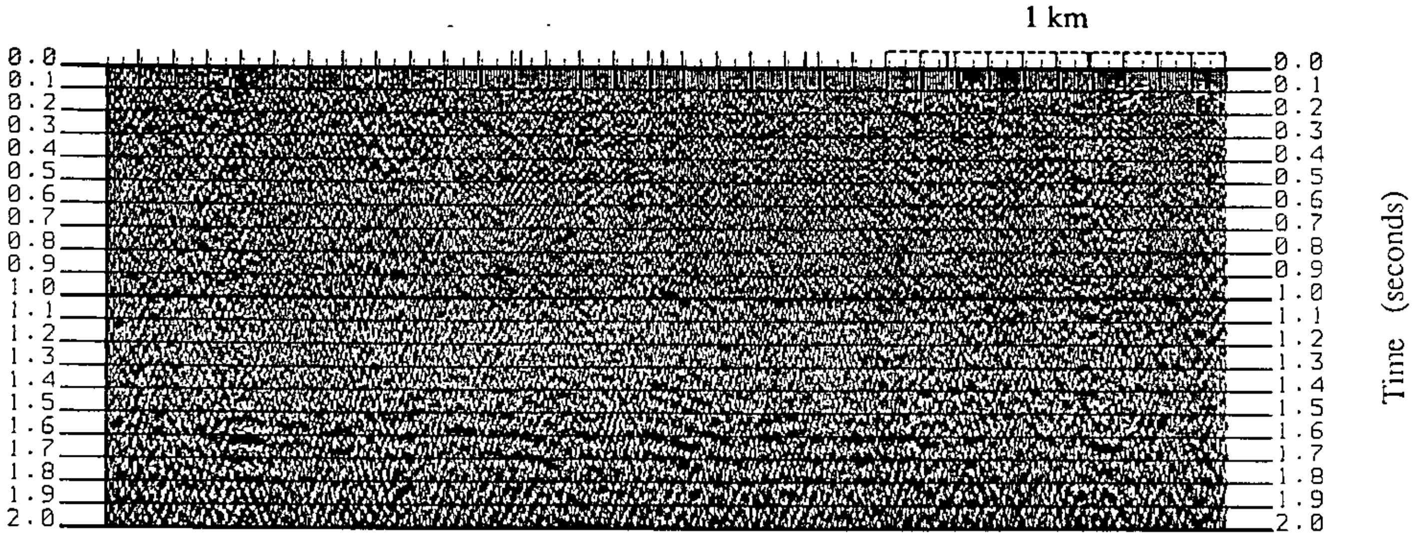

Fig. 6a: The brute stack of the radial (P-SV) component data from Line EUE001, Slave Lake, northern Alberta.

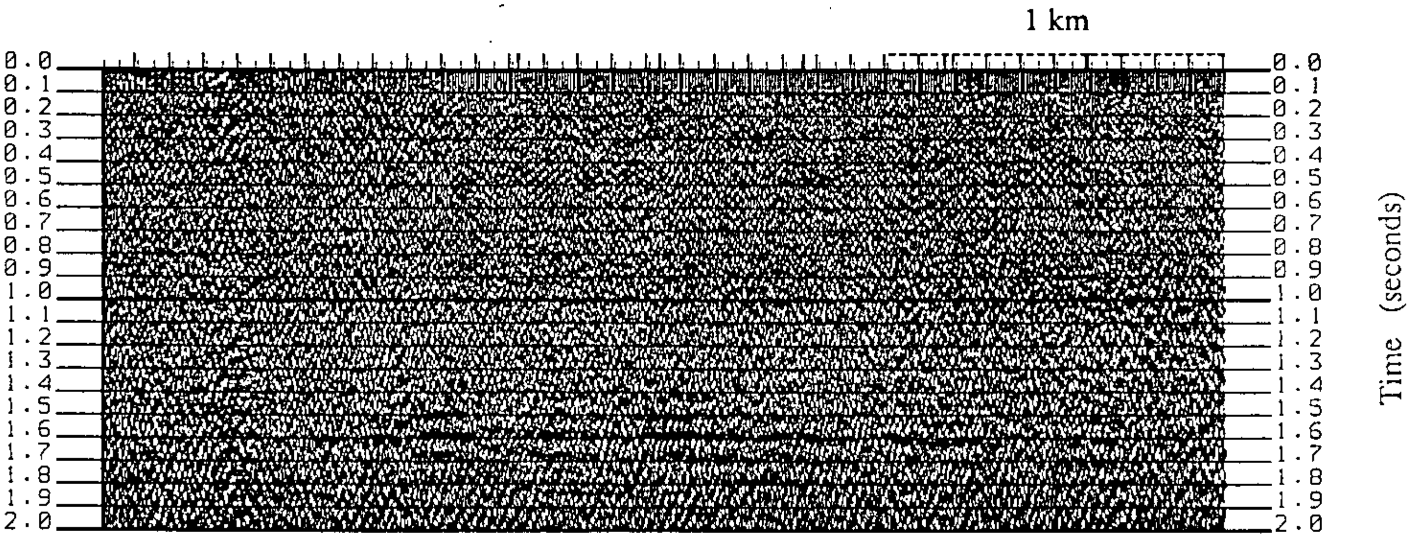

Fig. 6b: The radial (P-SV) component stacked section with hand statics applied.

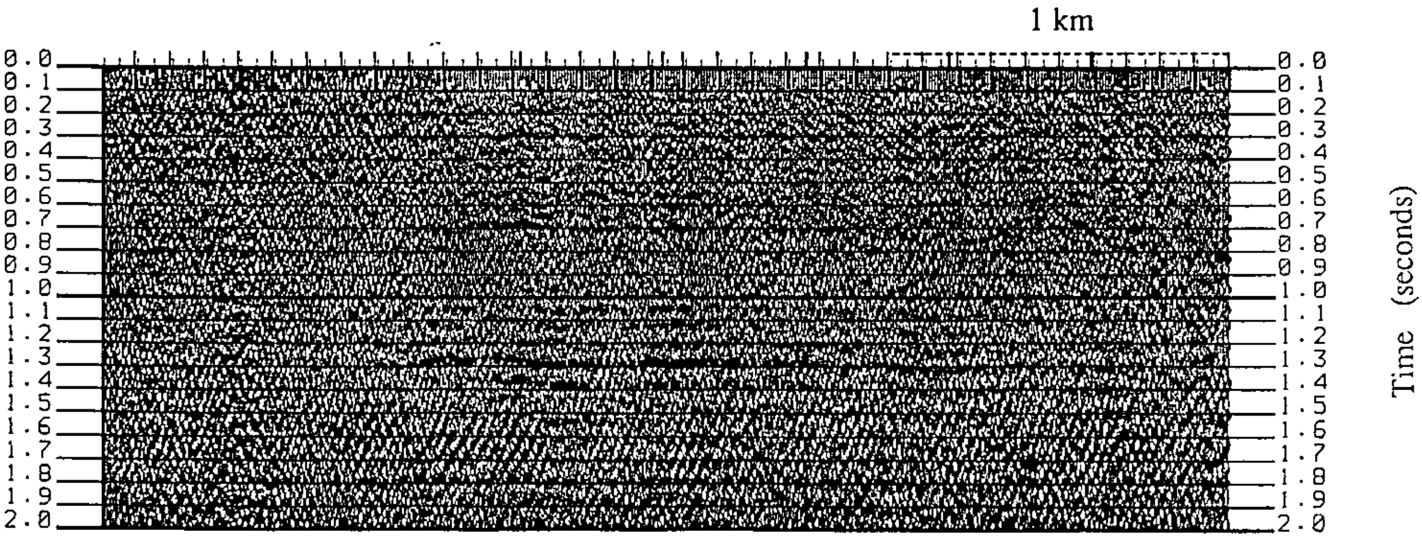

Fig. 6c: The radial (P-SV) component stacked section with refraction tomography statics applied.

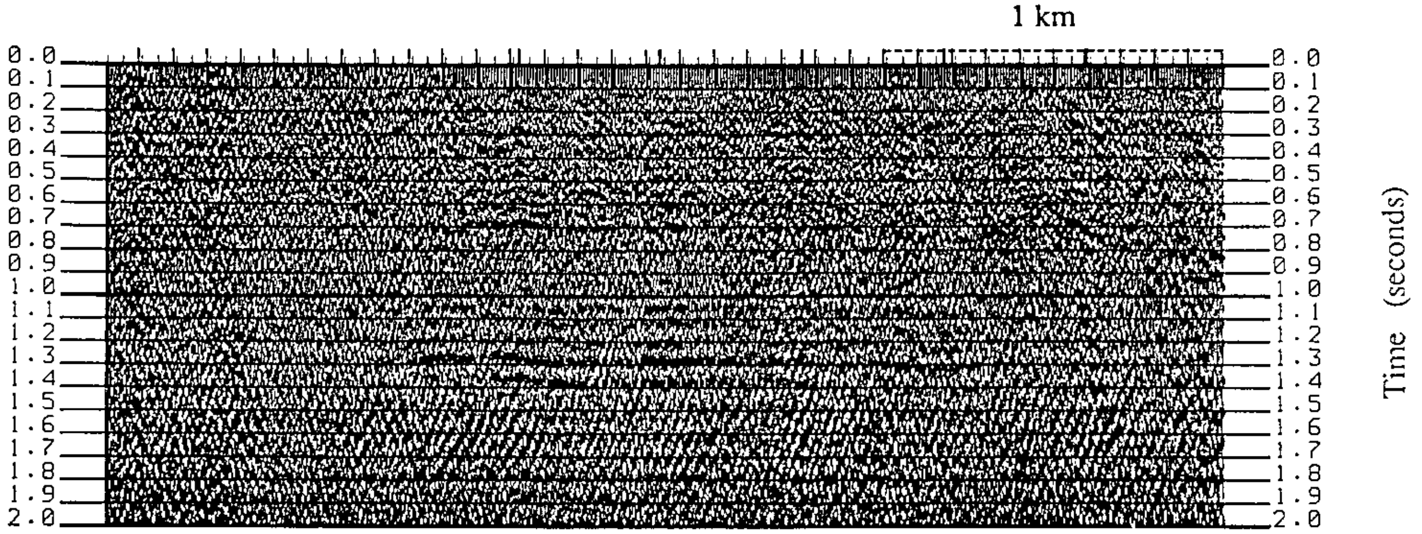

Fig. 6d: The radial (P-SSS) component stacked section with refraction tomography statics applied.

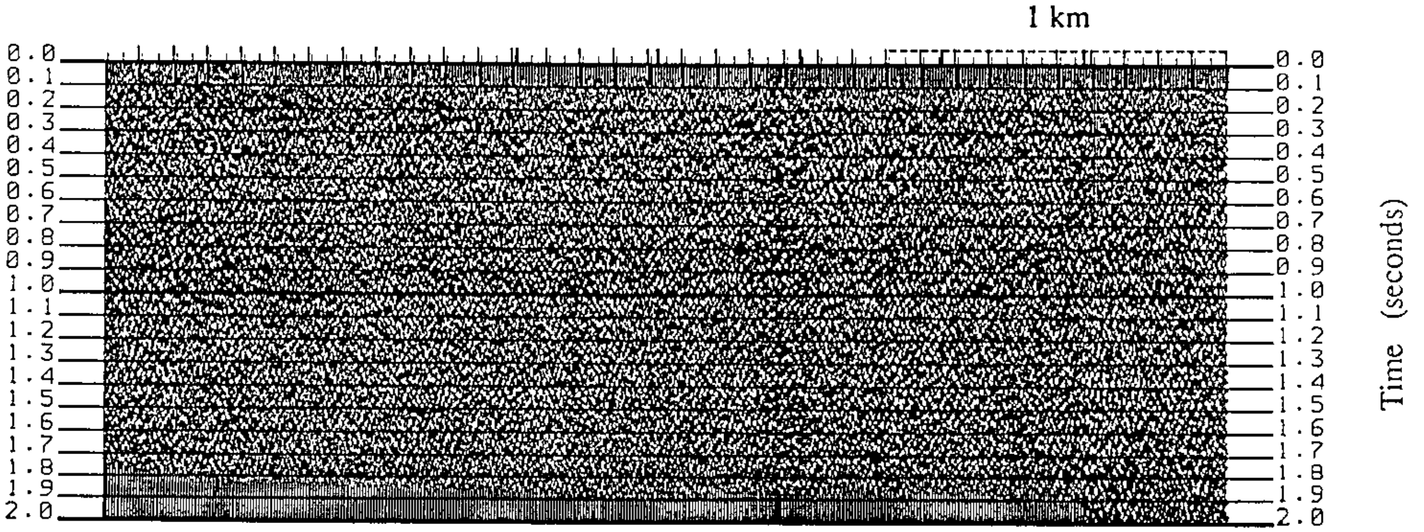

Fig. 6e: The radial (P-SV) component stacked section with commercial refraction statics applied.

from 0.1-0.12 s to 1.05-1.08 s. This means it is possible for PSS and P-SSS to have a lower LVL velocity and deeper refraction boundary with respect to PPP and PPS.

CONCLUSIONS

The converted-wave refraction (or shear-wave) tomography statics technique is extended to making S-wave static corrections not only down to the P-wave refractor depth but down to the depth of the S-wave refractor. This is the full S-wave refraction (including both short- and long-wavelength components). We have seen that the S-wave refraction statics are totally different from the P-wave refraction statics within the area covered by the whole EUE001 Line due to different LVL velocities and refraction boundaries for both wave types. Obviously, converted-wave (PSS) or S-wave statics can be a considerable problem and applying the refraction-tomography statics technique in the seismic data processing can effectively and successfully solve the statics problem, thus increasing the quality of the converted-wave or shear-wave stacked section.

This method could be useful when picking first breaks from seismic records with low signal-to-noise ratio and in the case of a complex near-surface LVL due to the manual, rather than automatic picking.

Another advantage of this method is that it is suitable for several layers and all kinds of head waves including PPP, PPS, PSP, PSS, SPP, SPS, SSP, and SSS, according to Snell's law.

FUTURE WORK

In this method, we assume that each refractor is a flat horizontal layer. To reflect the real structure of subsurface media, there exists the possibility of extension to include more complex models, for instance including curvature in the refractors.

Besides this, the algorithm does not form a standard computer program, for example, a seismic module. It is realized and run on the computer by using a FORTRAN program. Therefore the algorithm, at present, wastes computer time in contrast with other, commercial, statics programs. It is believed that improvements in the program speed could also be made in the future.

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