VSP interpretation from Joffre, Alberta

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ABSTRACT

The Joffre 3C-3D seismic survey was conducted to try to differentiate a dolomitized vuggy porosity Nisku reservoir from regions plugged by a later-stage anhydrite. Conventional P-wave images had not been successful. A suite of VSP data (near-offset, offset, and walkaway) including P-P and P-SV data has been processed. Compared with surface 3D P-SV seismic data of good quality, P-SV VSP data provide much higher resolution and better images of all horizons. It is evident that the lateral variation of the Nisku dolomite reservoir due to the anhydrite seal can be seen on the P-SV VSP map, and that this is not clear on surface 3-D P-P, P-SV (converted-wave) images, nor on the VSP P-P image.

INTRODUCTION

The dataset analyzed in this case study is the VSP survey from ESSO (Imperial Oil Resources) Joffre field, 11-22-39-26W4 well. The survey was part of a Consortium effort led by the Colorado School of Mines Reservoir Characterization Project on May 20 and 21, 1993. The VSP survey includes two parts: a suite of near-offset VSPs (including shear source and compressional source), and a suite of walkaway VSPs (compressional source). This case study is focused on the compressional-wave (P-wave) and converted shear-wave (P-SV wave) data, including measurements acquired at near offsets (P-wave), far offsets (P-wave and P-SV wave), and with a suite of walkaway compressional sources (P-wave and P-SV wave).

DATA ACQUISITION

Vertical vibrators were used as sources for the data under analysis here. The plan view of the survey is shown in Figure 1. The near-offset source was located to the east of the well with an offset of 21.4 m. A 3-component monitor geophone was located between the borehole and the near-offset compressional vibrator with an offset of 18.0 m at a depth of 30.0 m to aid source timing and coupling, and to monitor near-surface conditions. The offset P-wave source was located southwest of the VSP well with an offset of 883.4 m (V.P.5 in Figure 1a). The walkaway P-wave source locations are shown in Figure 1a denoted V.P. 1 through 6. The frequency of the source was 8–120 Hz with a 12-second sweep.

Receivers were positioned at two different intervals: at 5-m intervals from 2080 m to 2010 m depth, and at 15-m intervals from 2000 m to 635 m and from 360 m to 300 m. The data were recorded with Schlumberger's Maxis* recording system using

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Schlumberger's five-shuttle magnetically clamping ASI* tool (ASI - Array Seismic Imager: an array of five seismic shuttles, each containing three orthogonal geophones).

PROCESSING

Tool orientation was accomplished through processing of an offset compressional source southwest of the VSP well with an offset of 883.34 m (V.P.5 in Figure 1a). The polarization azimuth of the direct P wavefield was determined using hodogram analysis to determine the direction of maximum P-wave direct-arrival energy in a manner similar to that of DiSiena et al. (1984). The rotated three-component data are plotted in Figure 2 (vertical component), Figure 3 (radial component) and Figure 4 (transverse component).

The vertical channel of the zero-offset VSP is plotted in Figure 5. The corridor stack was generated by following normal zero-offset P-wave VSP processing flow. The result is plotted in Figure 6.

The offset VSP has been processed using a three-component processing flow. The flow is designed to extract the P-P and mode-converted P-SV reflections from the multicomponent dataset and further to create P-P and P-SV offset images. The data quality of the two components required for these images is quite good (Figures 2 and 3). The discontinuities along the first-break curve around the top levels are due to missing geophone levels in the recording geometry. Apparently, the data acquisition in the near surface from depth level 360 m to 665 m was incomplete due to the limitation of the operation time.

VSP wavefield separation was implemented by employing a parametric inversion technique developed by Leany and Esmersoy (1989) combining vertical and radial components. In the parametric inversion, the data are modeled as a superposition of P waves and SV waves. The local P and S velocities, angles of incidence, and waveforms are the model parameters. The model parameters are estimated by employing a least-squares match between the observed data and the model-generated data. This algorithm has been proven a robust way to separate wavefields and preserve accurate amplitudes. The output of this algorithm consists of the four separate wave-propagation modes: the downgoing P wavefield; the downgoing S wavefield; the upgoing P wavefield, and the upgoing S wavefield. The inverted upgoing P wavefield and upgoing S wavefield, with a 5-level window, are shown in Figures 7 and 8, respectively (trace equalization and deconvolution applied). Local parametric inversion requires uniform spacing between levels. The shorter the depth window, the higher the depth resolution at the expense of stability. There is an inherent tradeoff between resolution and stability.

The VSP NMO corrections for P-P and P-SV are implemented in a similar way to that described by Labonté (1990) and Stewart (1991) using a velocity determined from a sonic log (Figure 9 and Figure 10; left panels). As we can see, both P and P-SV upgoing wavefields have strong coherent energy with good quality.

The final step in the processing flow is to map the upgoing P and P-SV wavefields to the correct offset positions. The P-P and P-SV data are binned into 5.0-m bins centered every 5.0 m. This process is termed VSPCRP mapping for P-wave data and VSPCCP (common conversion point) mapping for P-SV data. The VSPCRP and

VSPCCP maps are shown in Figures 9 and 10 (right panels) in which both are plotted in P-wave time.

INTEGRATED INTERPRETATION

The Joffre Nisku reservoir is a special type of stratigraphic trap. It is characterized by a diagenetic updip trap of anhydrite. The pool is defined by a halo of dolomitized vuggy porosity that has not been plugged by the later-stage anhydrite diagenetic event. The late-stage anhydrite event also filled in some of the primary porosity of earlier dolomitization, resulting in reservoir heterogeneity. Conventional P-wave seismic has not been successful in contrasting the dolomite reservoir from the anhydrite because of their similar acoustic impedances.

A surface 3C-3D seismic survey was carried out in the summer of 1993 as part of a Consortium effort led by the Colorado School of Mines Reservoir Characterization Project. The interpretation of P-P and P-S (converted shear-wave) data is discussed by Larson and Stewart (1994). A stress-field orientation has been detected (anisotropy). The fast shear wave is polarized in the southeast direction (135° clockwise from north), and the slow shear is polarized in the southwest direction (225° clockwise from north), that is, the same directions as for the offset VSP. However, the use of shear waves to find Nisku porosity is still not very encouraging. VSP has been demonstrated often to provide good, and high-resolution, P-P and P-SV images (Geis et al., 1990). We are interested in extracting some information from the VSP data to help delineate dolomite porosity.

Figure 11 shows the formation tops at Joffre. Synthetic seismograms with normal and reversed polarities are plotted together with a sonic log from the survey well. A composite plot (**L** plot) of P-wave VSP data is shown in Figure 9. All the formation tops can be quickly determined on VSP data as VSP yields the most reliable time-depth correlation. The plot shows that the offset VSP, the zero-offset corridor stack, the synthetic from the sonic log, and the surface 3-D seismic tie to each other quite well. However, the Nisku porosity still cannot be delineated using the P-P VSP image.

Figure 10 shows a composite plot (**L** plot) of the P-SV (converted-wave) VSP data and a comparison with the surface-seismic slow shear wave (S2). The VSP P-SV data are plotted in P-wave time. The surface S-wave data are plotted at two-thirds of the scale of the P-SV VSP data. As we can see, the Nisku converted reflection (marked event below 1.2 s) is changed from one single peak to two small low-amplitude peaks at an offset around 120 m from the VSP well. We believe that this is due to a porosity change.

CONCLUSIONS

This study has shown that the VSP P-SV can provide excellent images for all formations in the Joffre area through careful processing. The integrated interpretation of P-P and P-SV combined with surface multicomponent 3-D seismic, indicates the VSP P-SV can be advantageous in contrasting the image of lateral amplitude variation of the Nisku dolomite reservoir from that of the diagenetic anhydrite seal. Overall, the highfrequency shear-wave VSP indicates differentiation of the dolomite reservoir from anhydrite plugging.

FUTURE WORK

Careful processing of the walkaway VSP dataset is being undertaken (Figures 12 and 13). We hope that the walkaway P-SV image will confirm the offset VSP P-SV image of the reservoir termination. P-P and P-SV modeling of a dolomite reservoir and of dolomite with an anhydrite seal is also being implemented.

ACKNOWLEDGMENTS

The authors would like to thank the sponsors of the CREWES Project for their support. We appreciate the help of Michael J. Jones, with Schlumberger of Canada, in the P-P and P-SV wavefield separation, in which a robust least-square inversion algorithm for offset VSP and walkaway VSP was applied. We also had constructive discussions with Glenn A. Larson in the interpretation.

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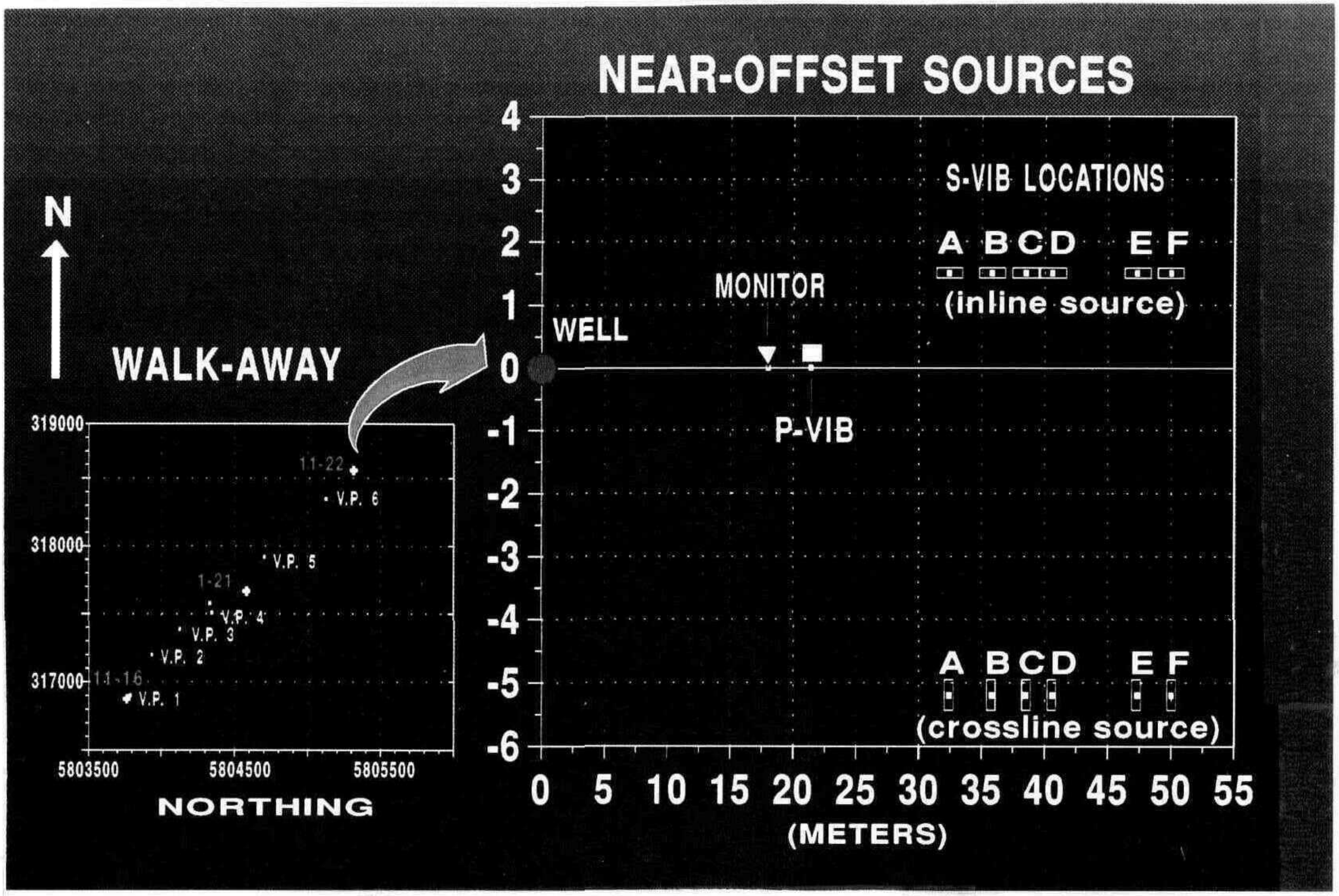

FIG. 1. Survey geometry layout of Joffre VSP walkaway; P-source locations are denoted by V.P.1 through 6; the near-offset P-source is located east of the VSP well denoted P-VIB. V.P.5 was used for the offset image through the whole well.

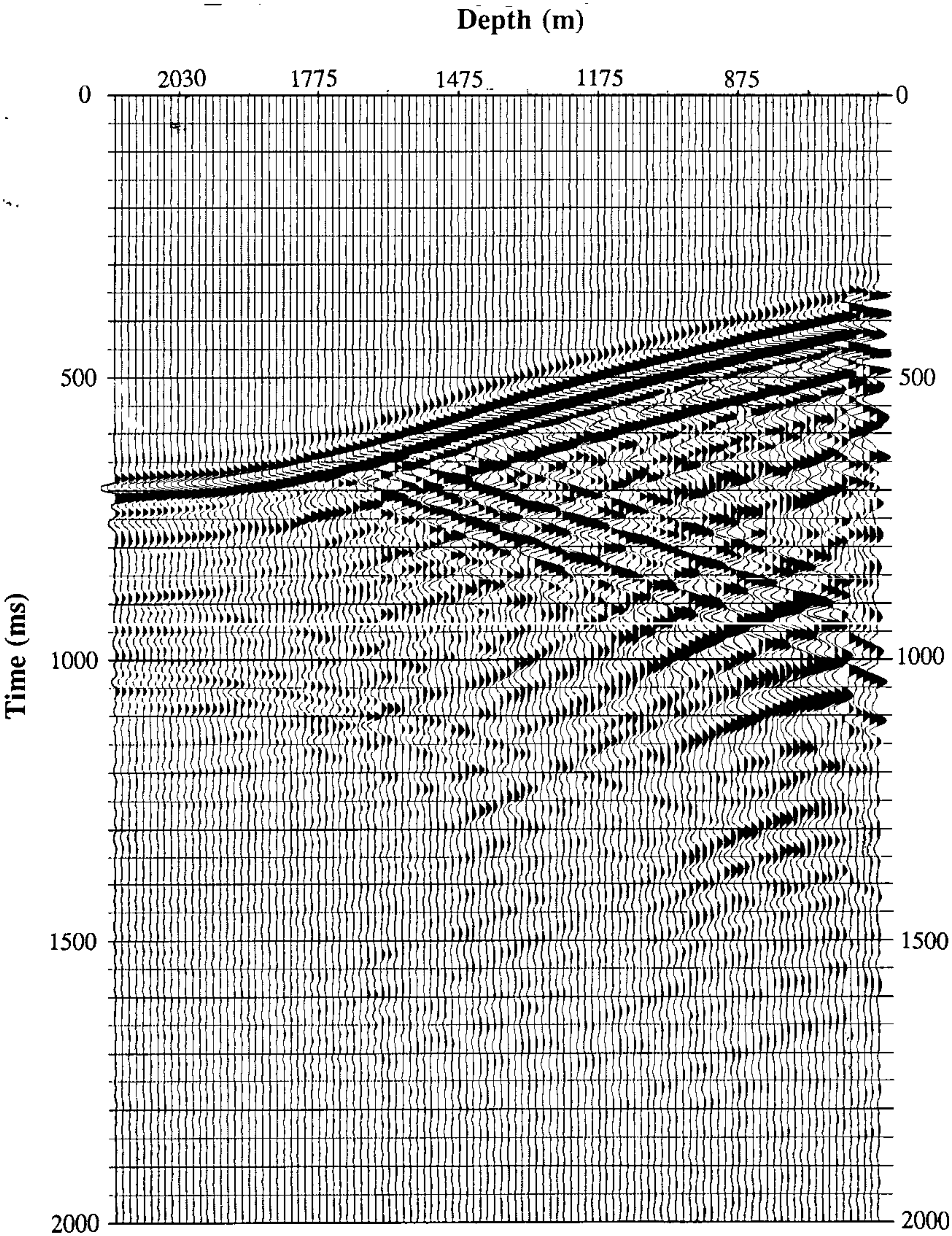

FIG. 2. Vertical component of the offset VSP.

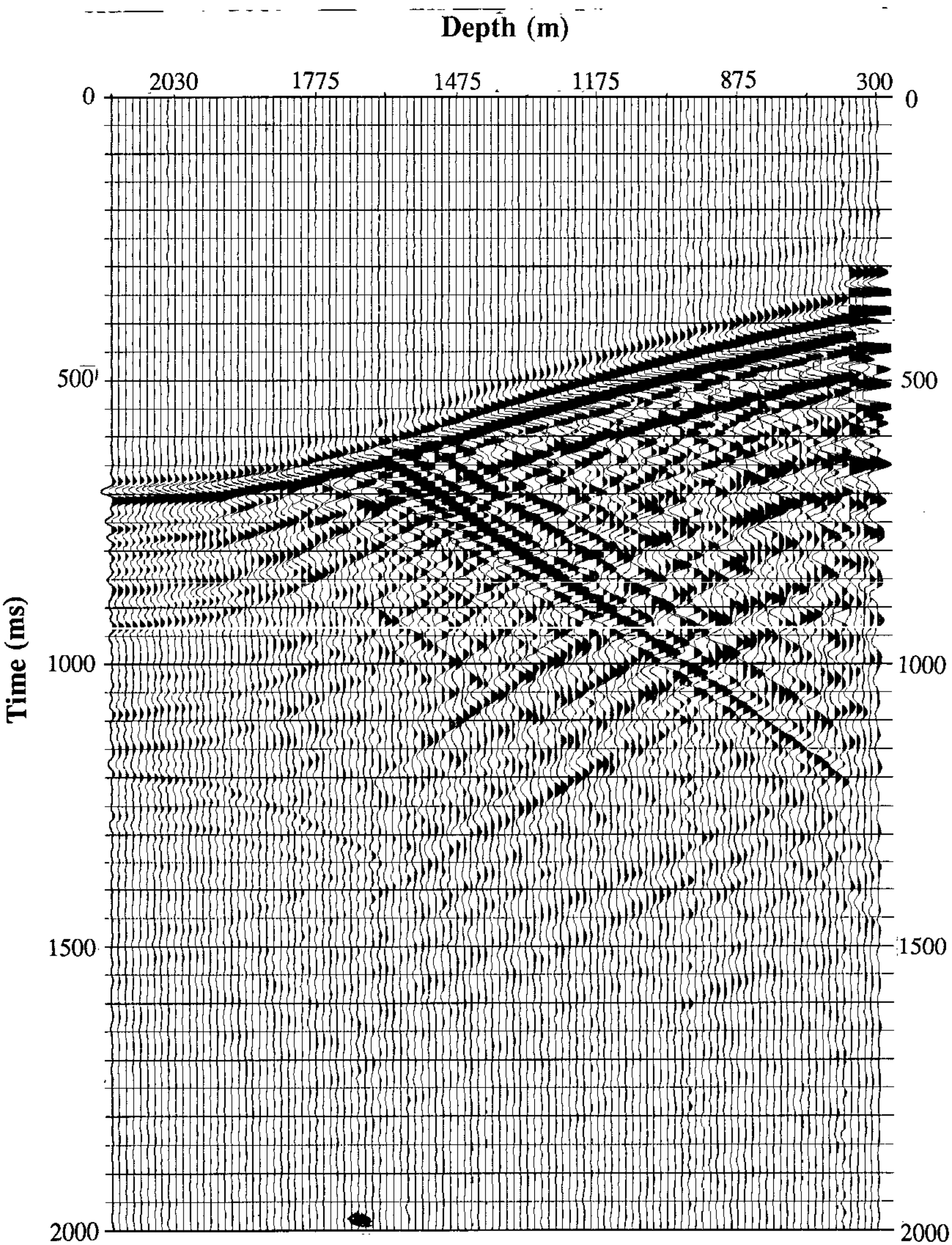

FIG. 3. Radial component of the offset VSP.

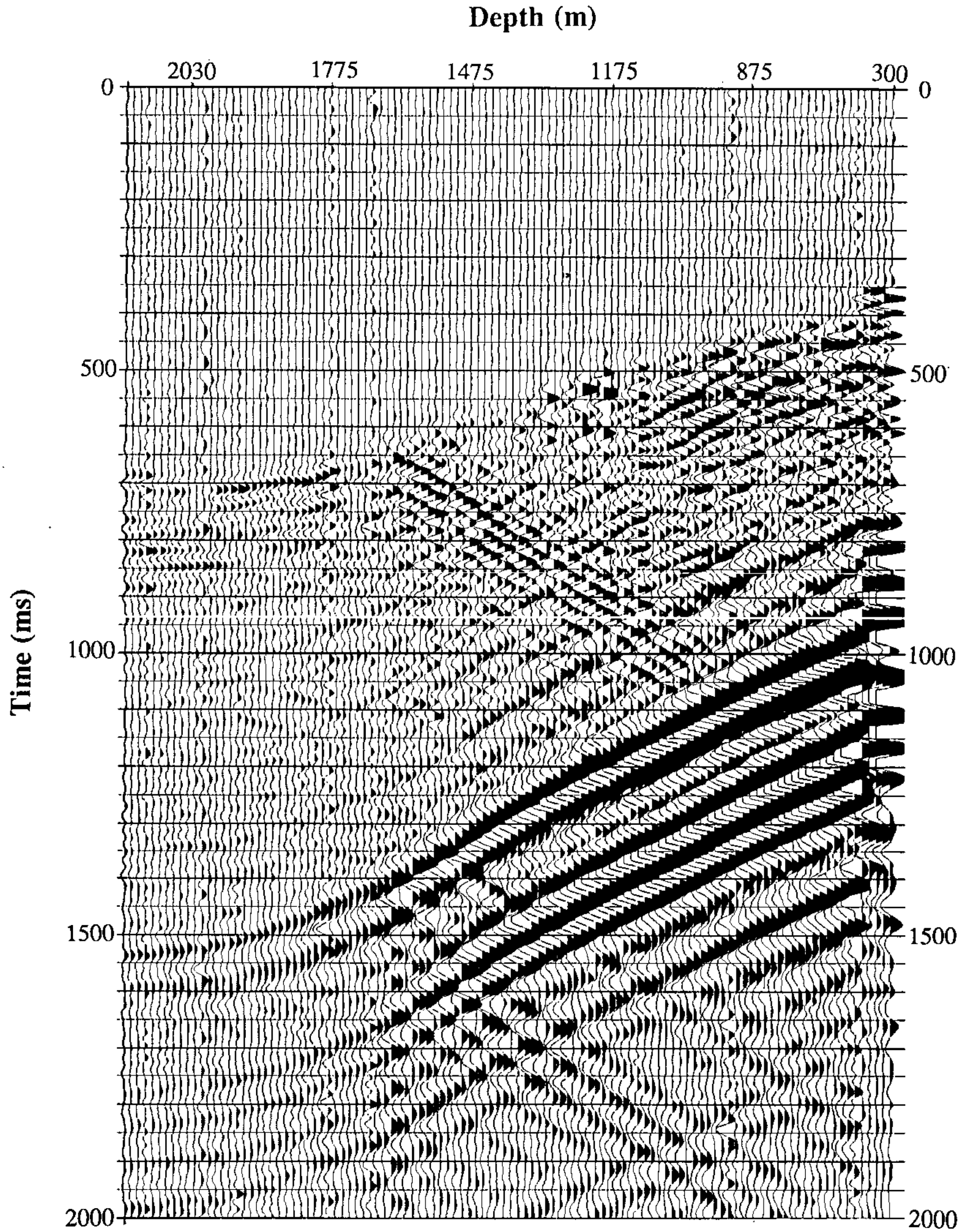

FIG. 4. Transverse component of the offset VSP, showing some split upgoing converted shear energy from the coal-bed.

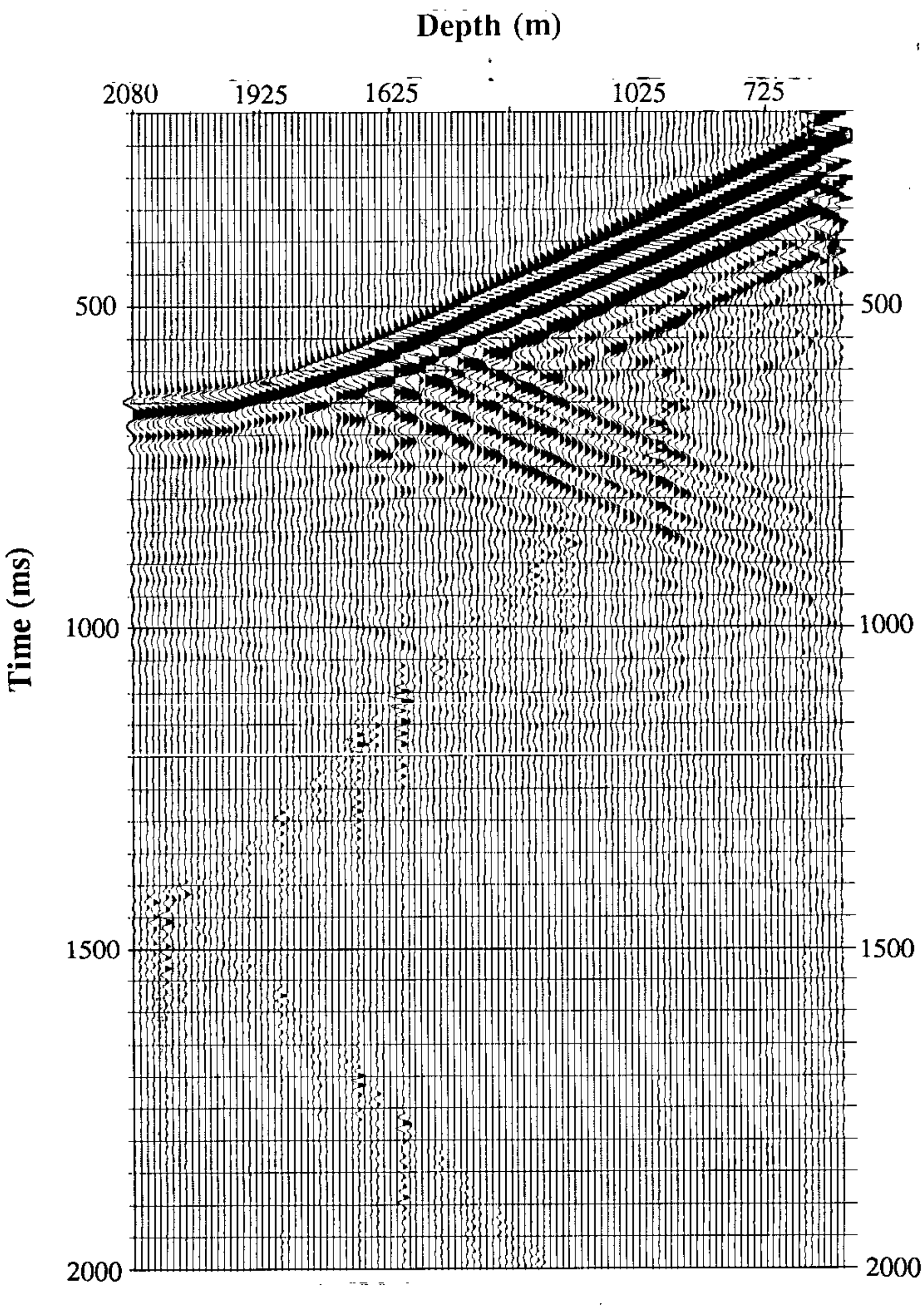

FIG. 5. Vertical channel of the raw data of the near-offset VSP.

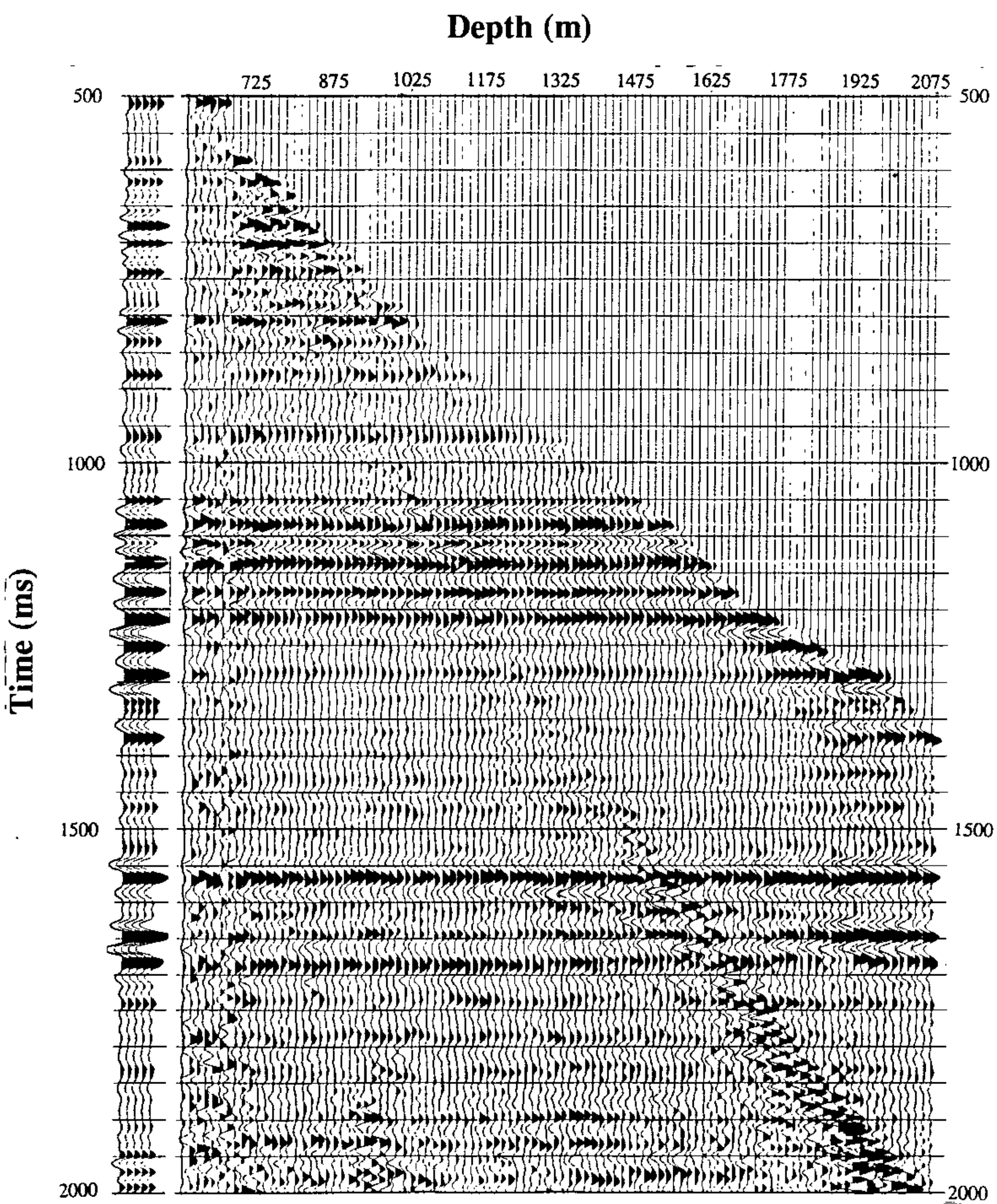

FIG. 6. The corridor stack (left) and flattened upgoing wavefield (right) of the near-offset VSP.

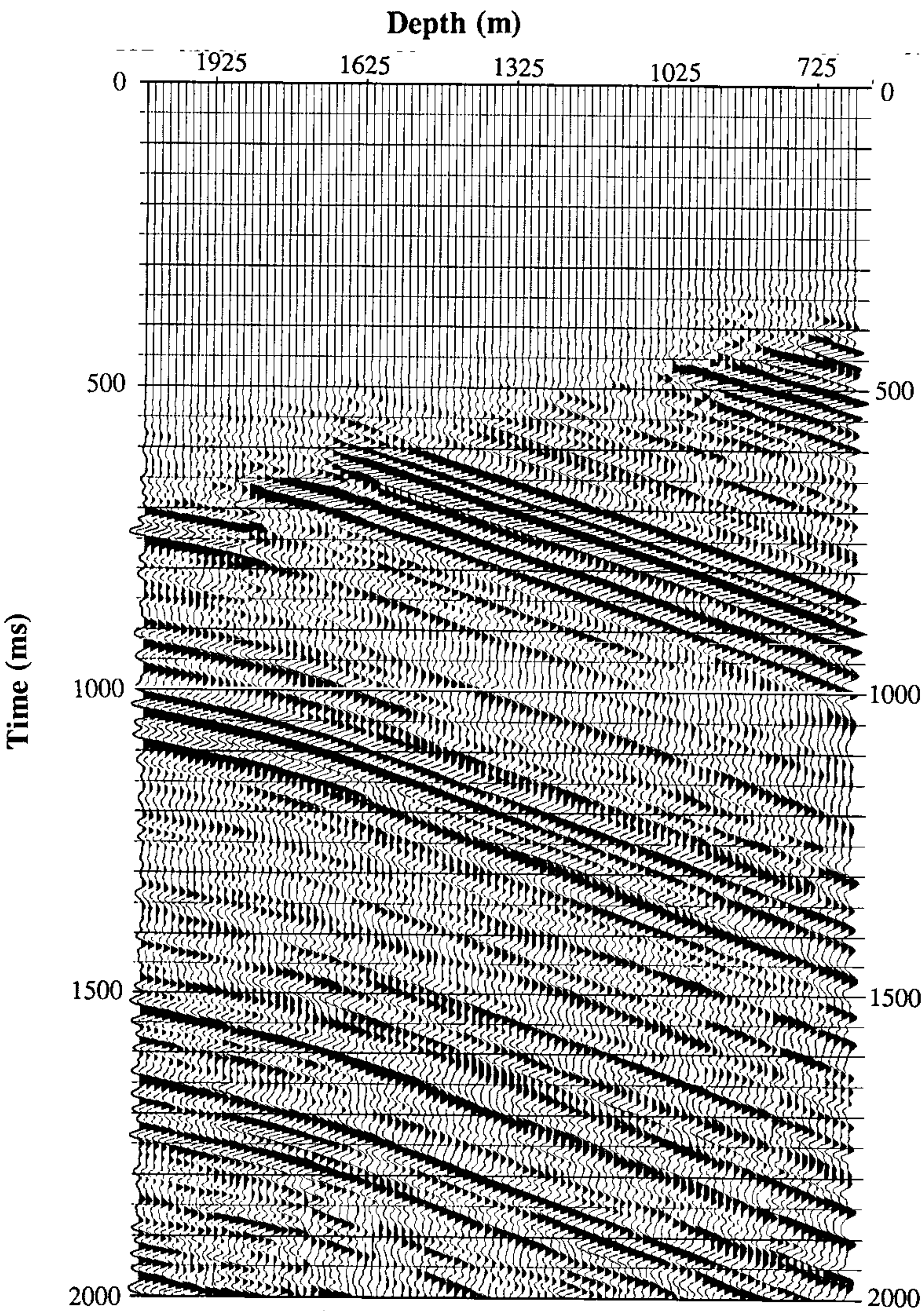

FIG. 7 Deconvolved upgoing P-wave after wavefield separation.

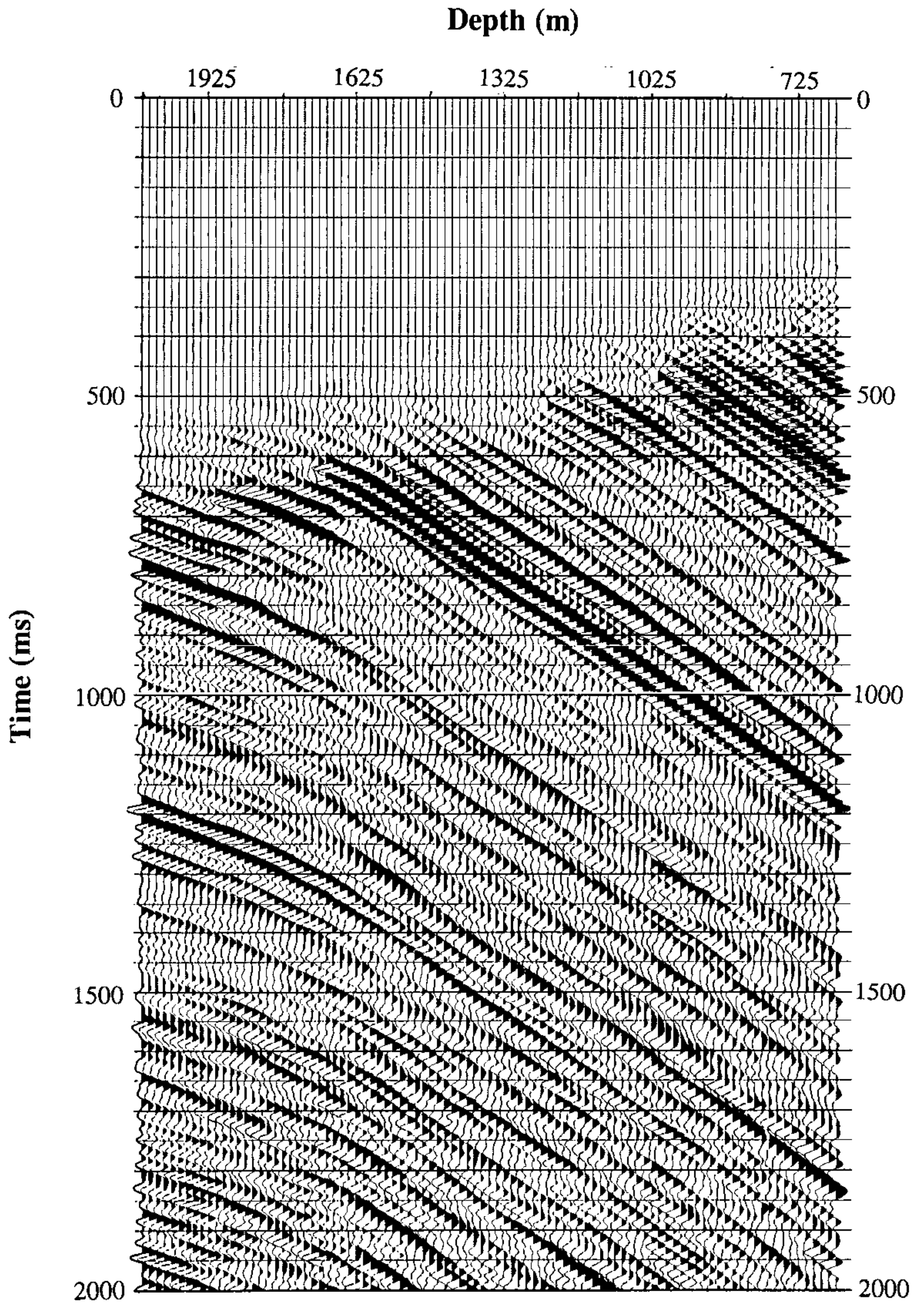

FIG. 8 Deconvolved upgoing P-SV wave after wavefield separation.

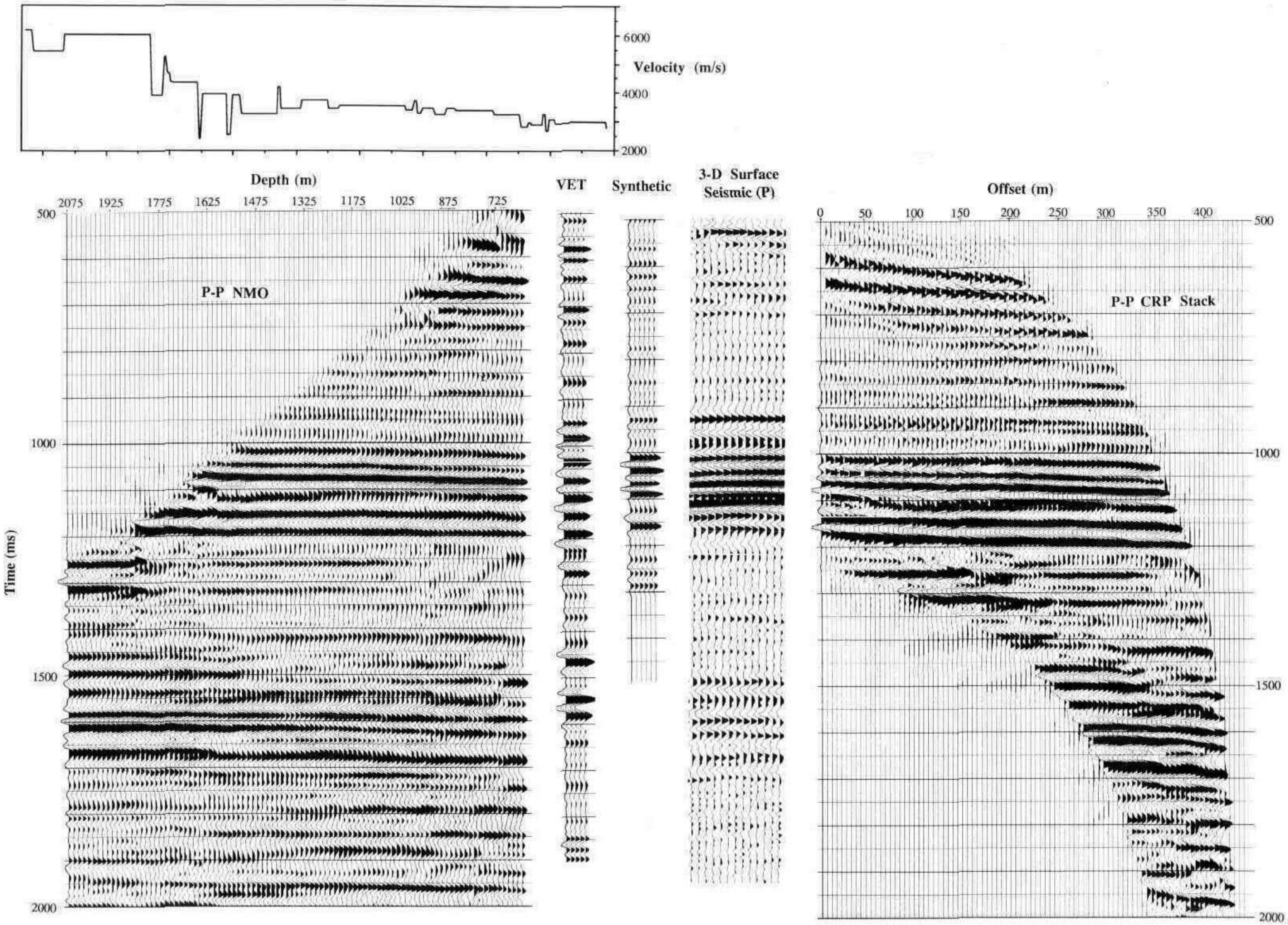

FIG. 9. P-wave interpretation of VSP from Joffre compared with surface 3-D P-P image. VET stands for VSP extracted traces from the near-offset P-wave source.

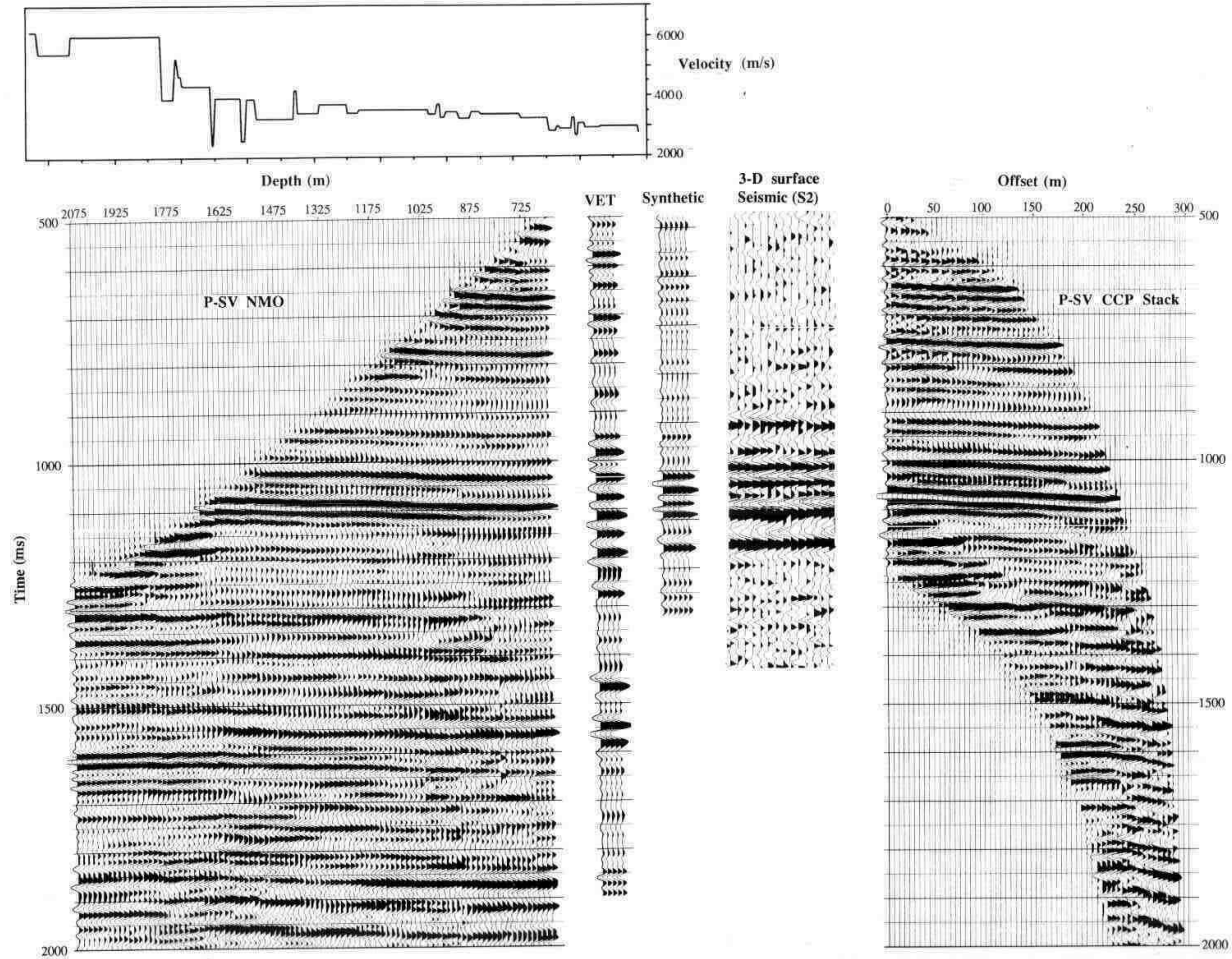

FIG. 10. P-SV wave interpretation of VSP from Joffre compared with surface 3-D converted-wave data (slow shear S2). VET stands for VSP extracted traces from the near-offset P-wave source.

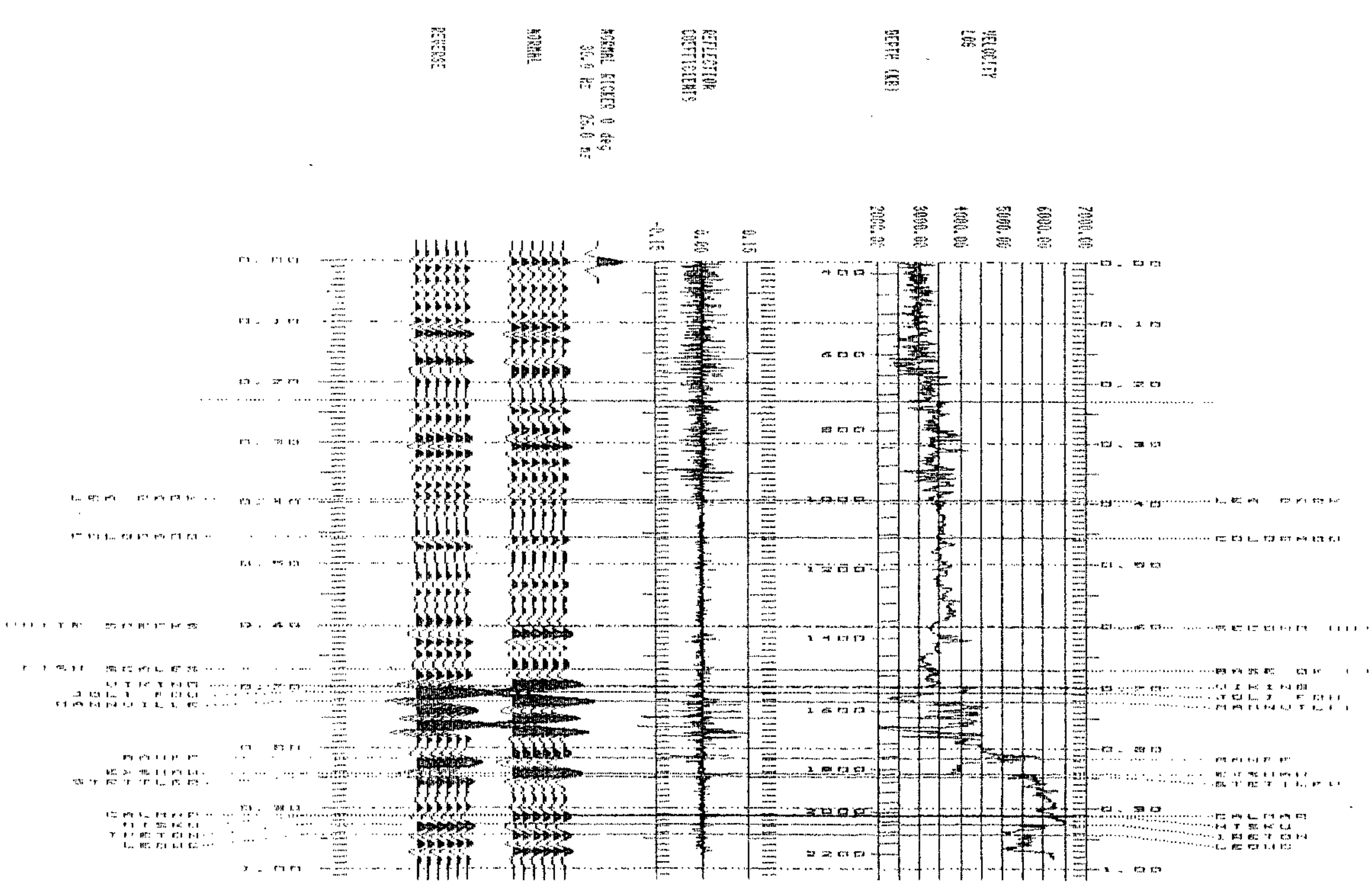

FIG. 11. Synthetic seismogram from sonic log, showing formation tops.

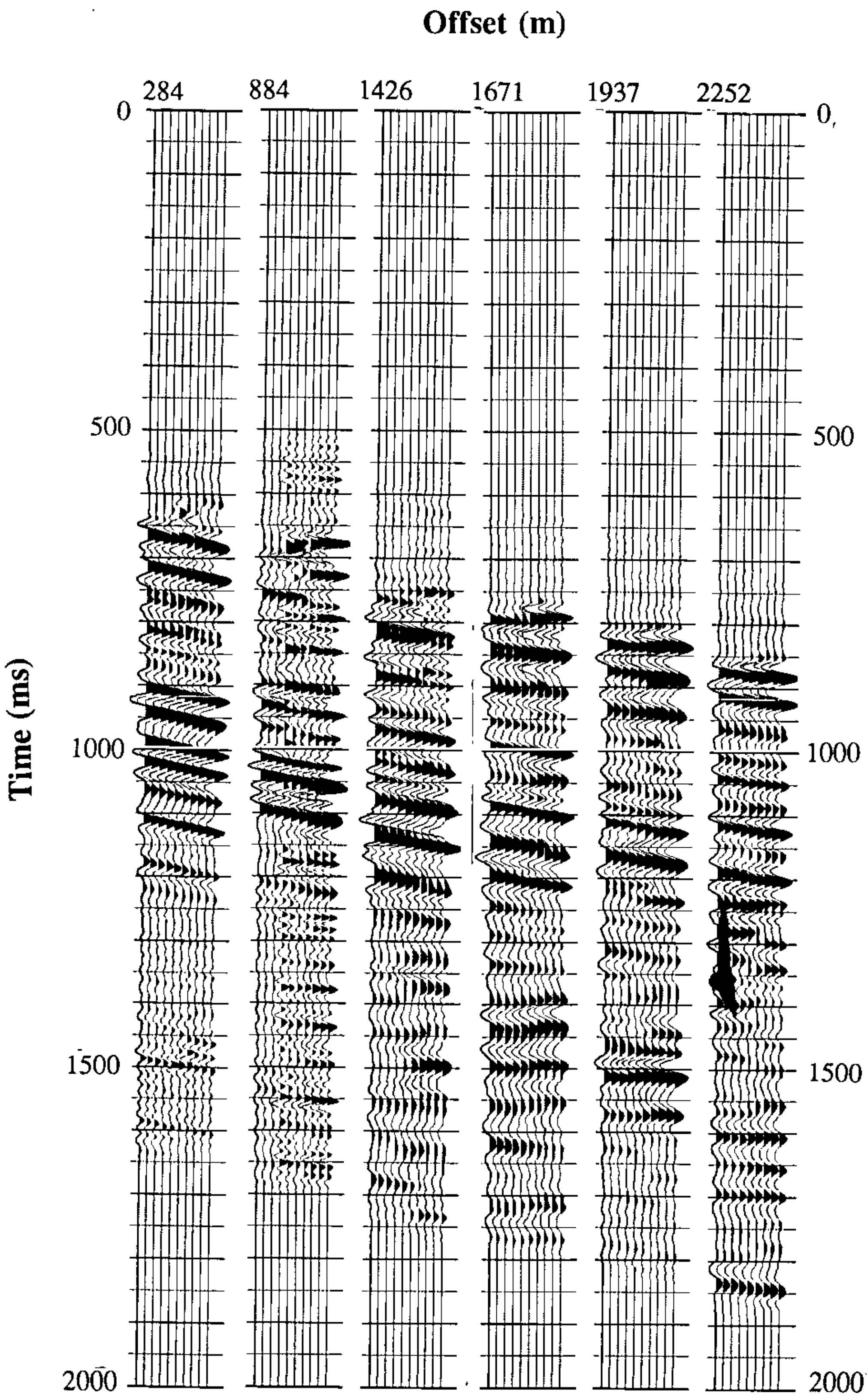

FIG. 12. Upgoing P-P wavefield from six walkaway sources.

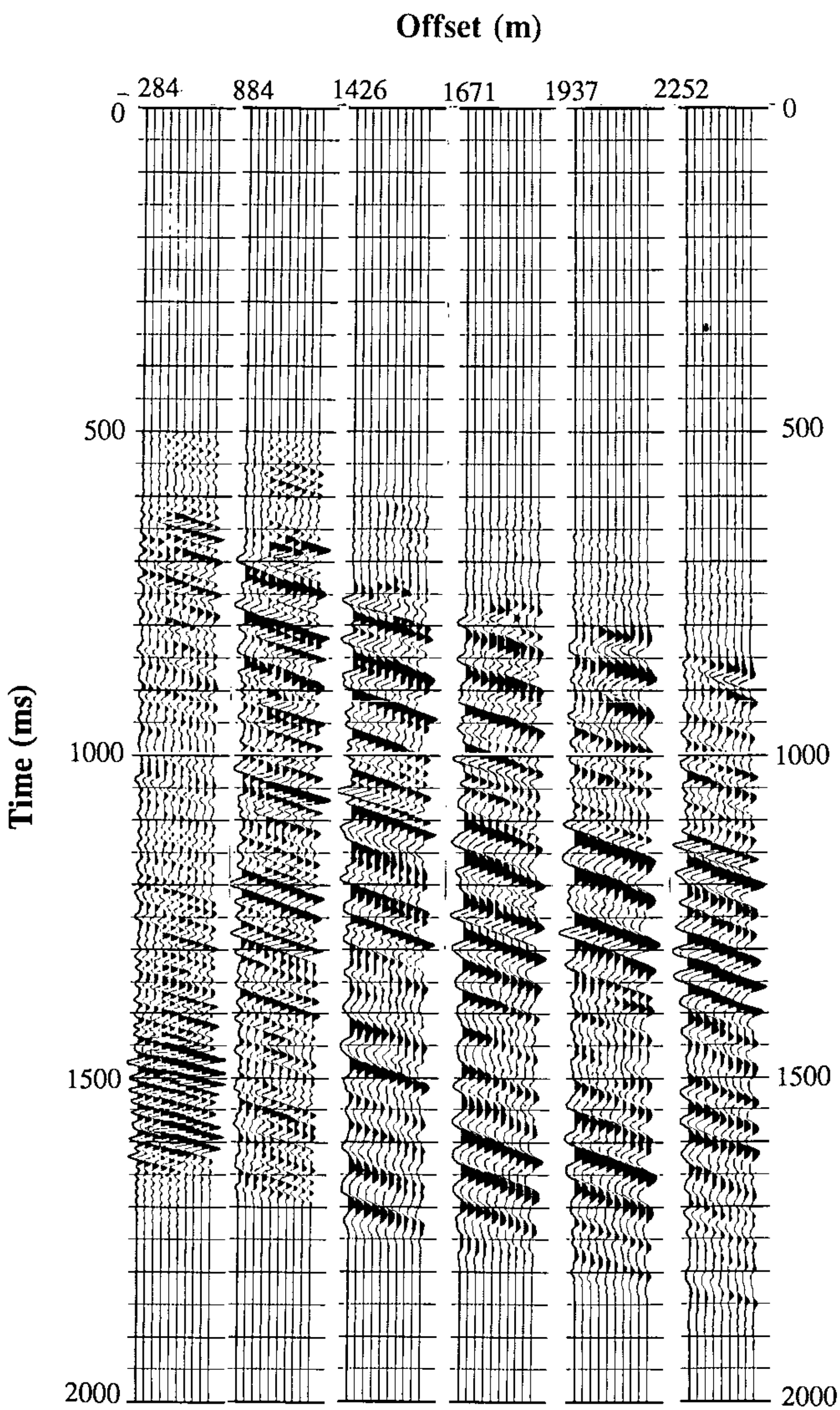

FIG. 13. Upgoing P-SV wavefield from 6 walkaway sources.