Part 2

Delphi: Delft philosophy
on acoustic and elastic inversion

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II. A simple model study

The elastic processing scheme discussed in Part 1 (*TLE*, February 1990) is, in principle, suited to handle multicomponent seismic data that have been acquired over 3-D, inhomogeneous, anisotropic, subsurface geometries. The development of this scheme is the subject of current research in the Delphi consortium. To gain some insight in the performance of the first two steps, we conducted an experiment for simplified conditions.

Consider the horizontally layered elastic subsurface model in Figure 9. This model consists of three macro layers with different elastic parameters and a target zone below 1450 m. The target zone consists of a number of thin layers with different elastic parameters. The model is bounded by a free surface at $z = 0$ and by a homogeneous half space below the target zone. A synthetic multicomponent shot record is shown in Figure 10. Figure 10a shows the shot record for a vertical vibrator and vertical geophones. This type of data is often interpreted as *P-P* data. Note, however, that a significant converted event (indicated by an arrow) can be observed in this shot record. Similarly, Figure 10d shows the shot record for a horizontal vibrator and horizontal geophones. This type of data is often interpreted as *SV-SV* data. However, again a significant converted event (indicated by an arrow) can be observed.

Decomposition into *P* and *SV* wave responses (step 1a). The results of decomposition are shown in Figure 11. When we compare these data with the original multicomponent data (Figure 10), we see the quality improved significantly. For example, the converted events (indicated by arrows in Figure 10), vanished completely in the *P-P* and *SV-SV* responses (Figures 11a and 11d).

Elimination of surface related multiple reflections and conversions (step 1b). In the decomposed data set, significant surface-related multiples and conversions are present. Note, for instance, that the primary reflections from the target zone are blurred by a surface-related multiple of a shallower reflector. Applying full elastic multiple elimination, by making the surface reflectivity zero, all effects of the free surface (multiple reflections as well as conversions) are removed. The results are shown in Figure 12. Note the tremendous improvement compared with the original data.

Macro model estimation (step 2a). The macro model for *P*-wave propagation is estimated from the data in Figure 12a by a

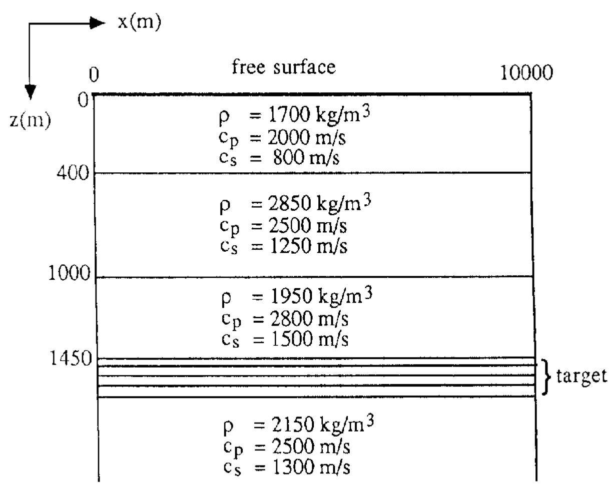


Figure 9. Horizontally layered elastic model, bounded by a free surface at $z = 0$.

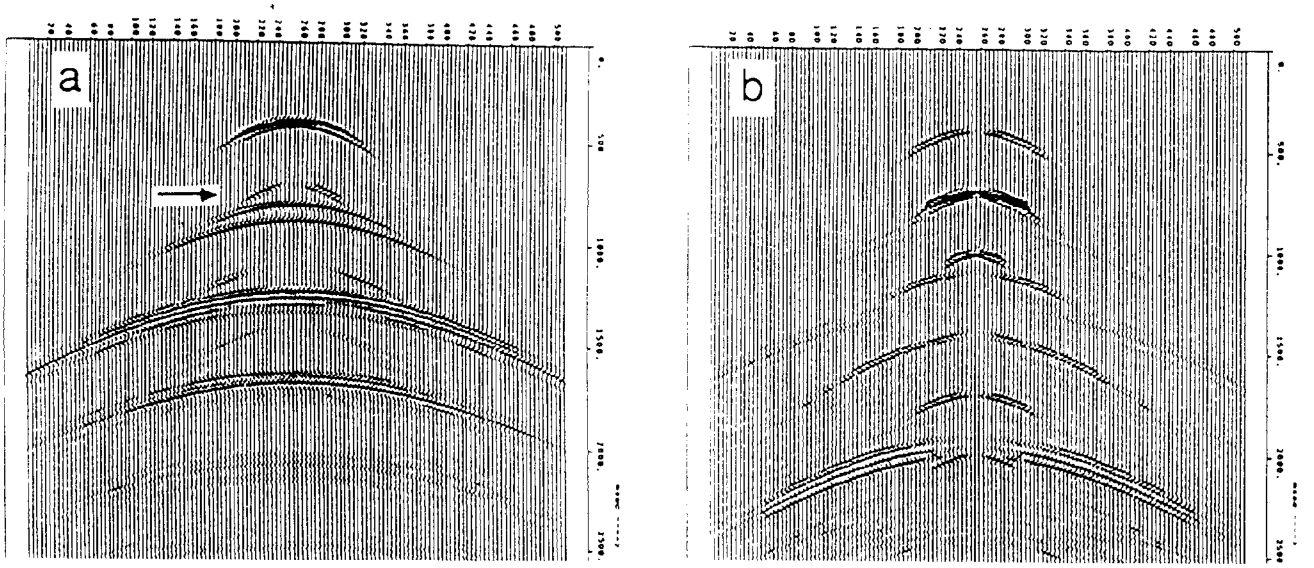


Figure 10. Multicomponent shot record, generated for the model in Figure 9: (a) pseudo *P-P* data, (b) pseudo *SV-P* data, (c) pseudo *P-SV*

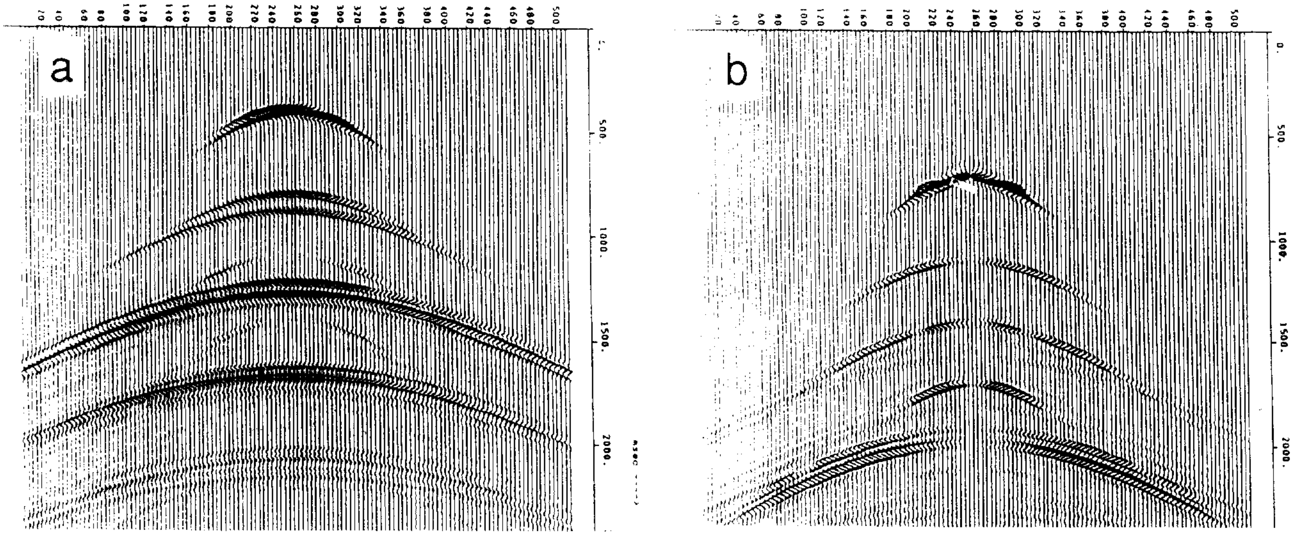


Figure 11. Results after applying decomposition: (a) true *P-P* data, (b) true *SV-P* data, (c) true *P-SV* data, (d) true *SV-SV* data.

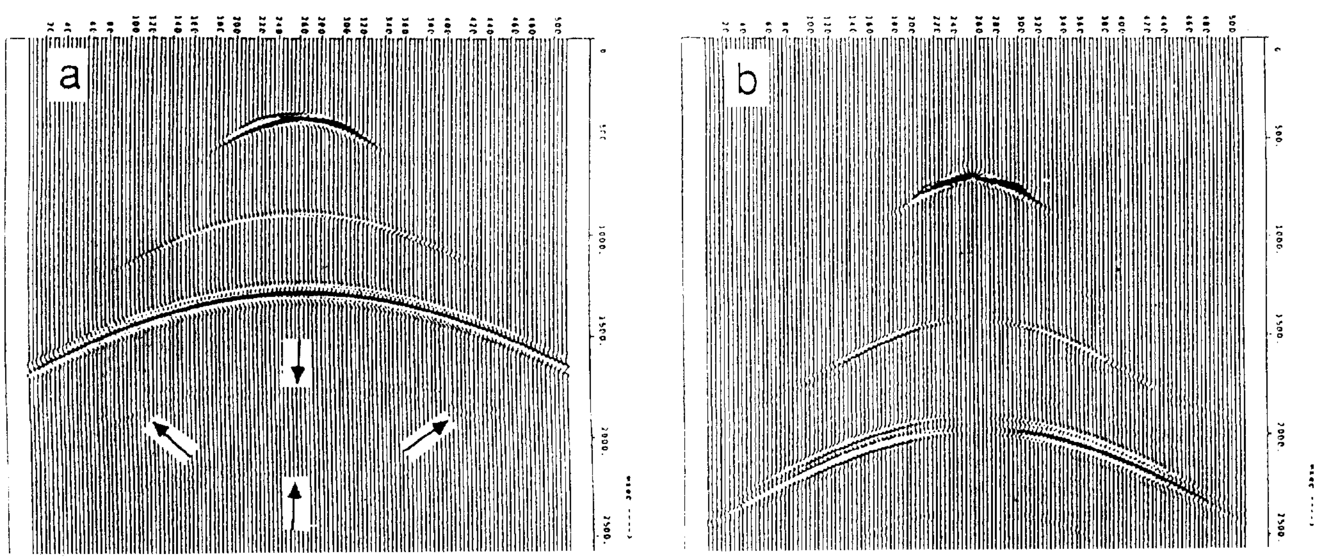
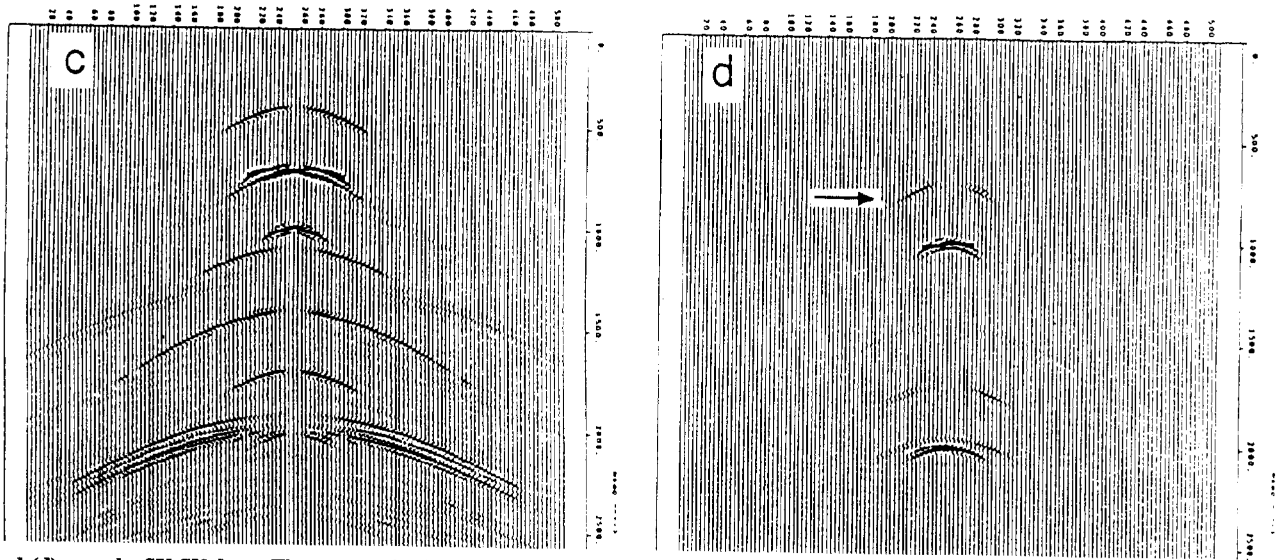
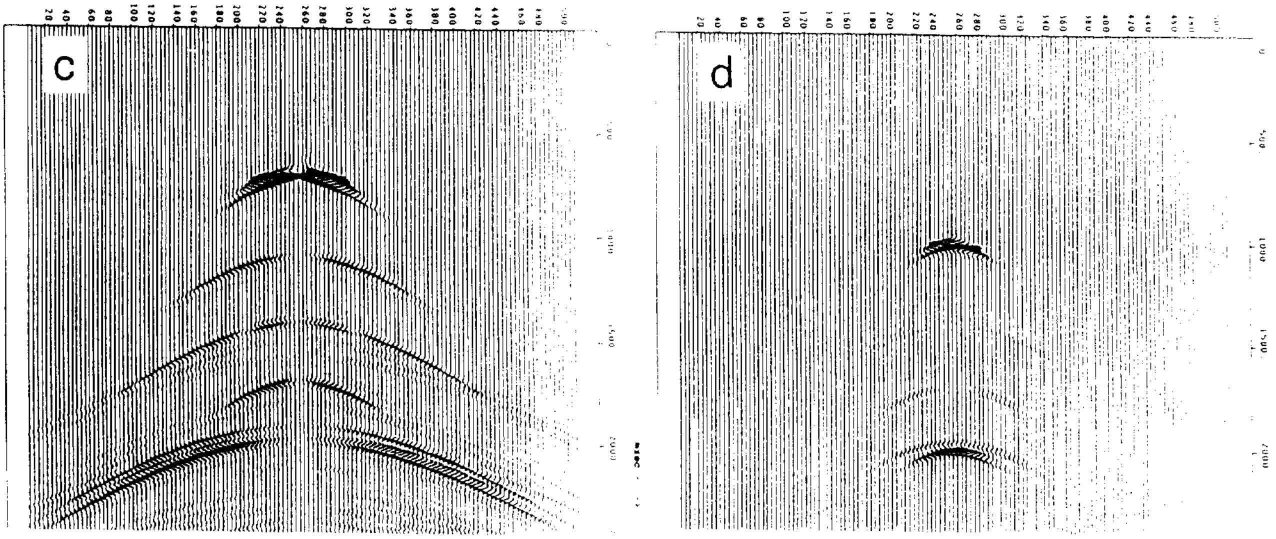
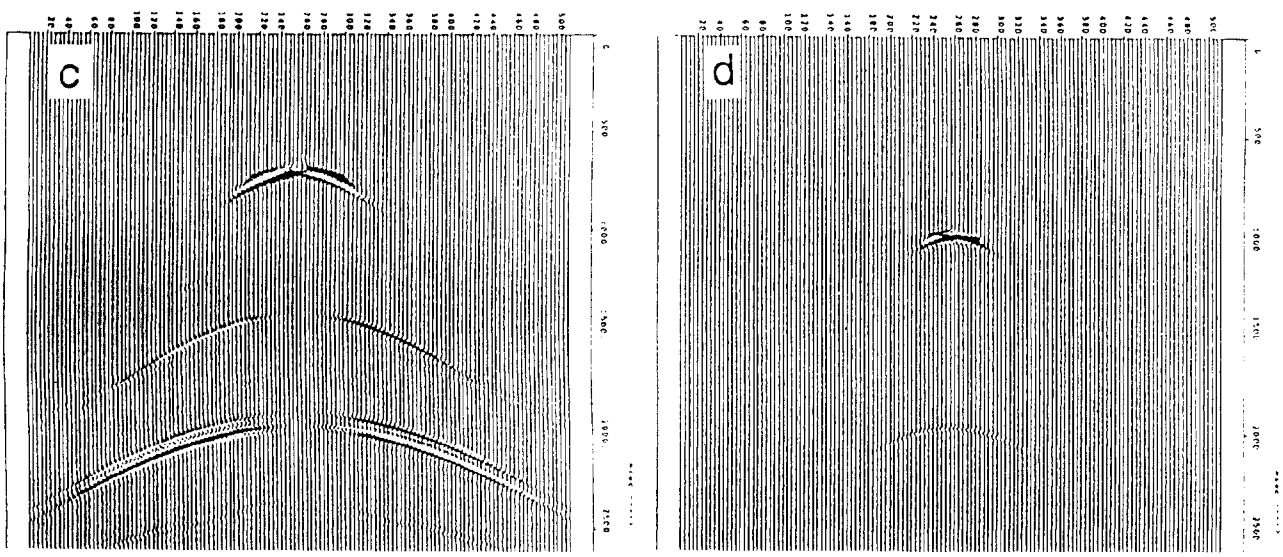


Figure 12. Results after applying multiple elimination: (a) multiple free *P-P* data, (b) multiple free *SV-P* data, (c) multiple free *P-SV*



data, and (d) pseudo *SV-SV* data. The arrows indicate converted events.





data, (d) multiple free *SV-SV* data. Arrows indicate minor artifacts related to internal multiple reflections and conversions.

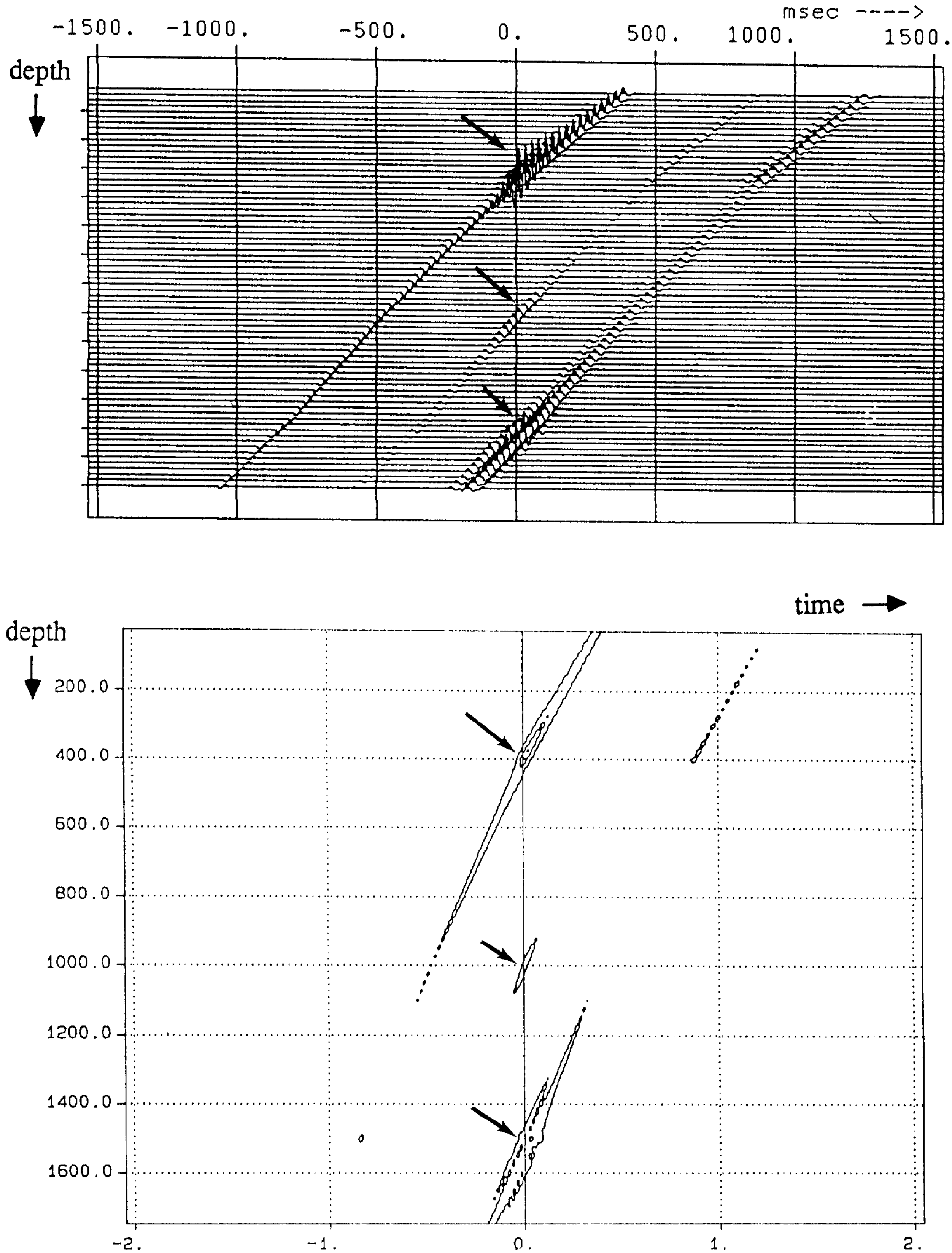


Figure 13. Focus panel for *P*-wave velocity analysis. All foci occur at $t = 0$, meaning that the correct *P*-wave macro model has been found.

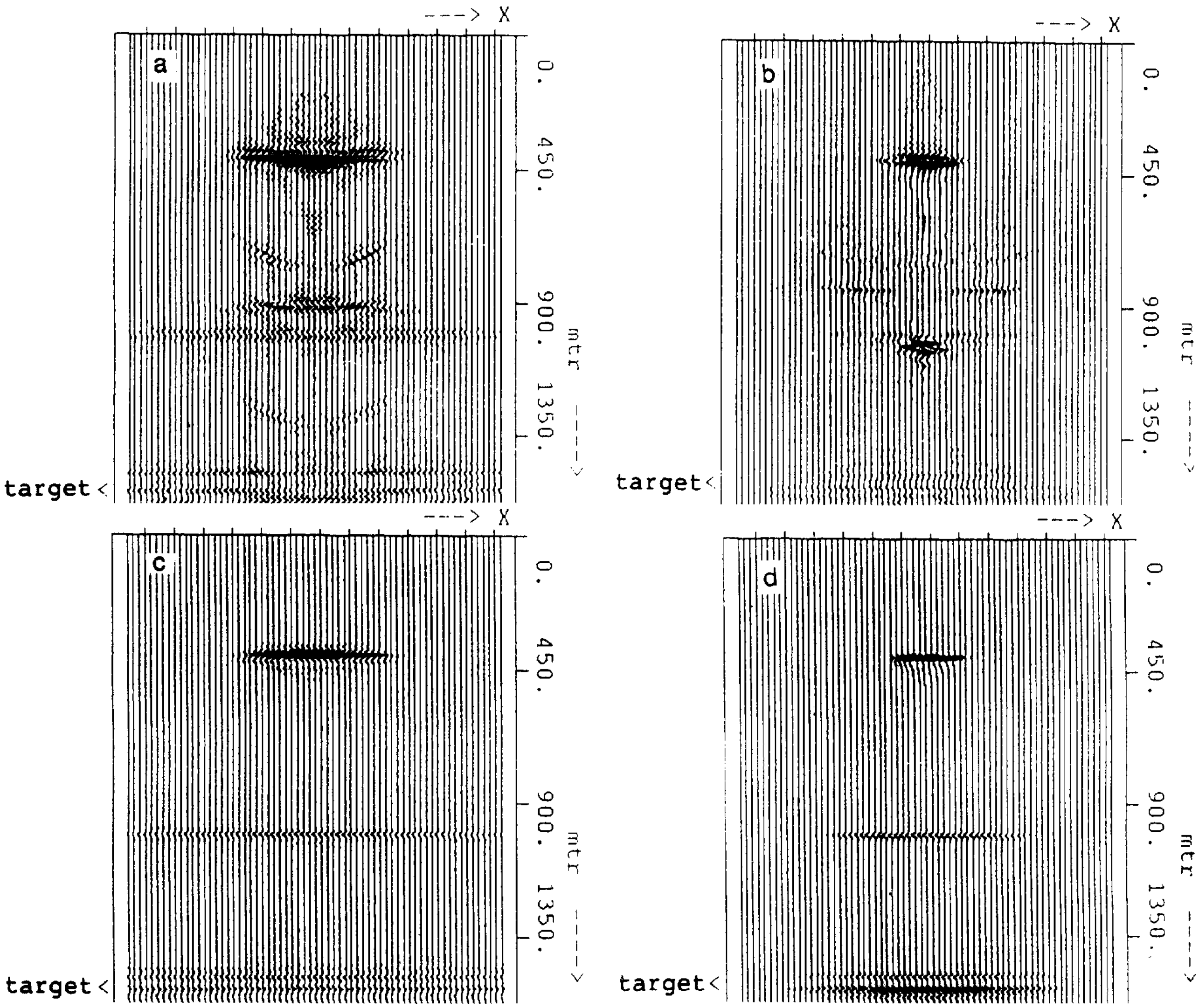


Figure 14. Results of single shot record migration: (a) migrated pseudo *P-P* data, (b) migrated pseudo *SV-SV* data, (c) migrated true *P-P* data, and (d) migrated true *SV-SV* data. Note that in (c) and (d) the target zone is very well resolved.

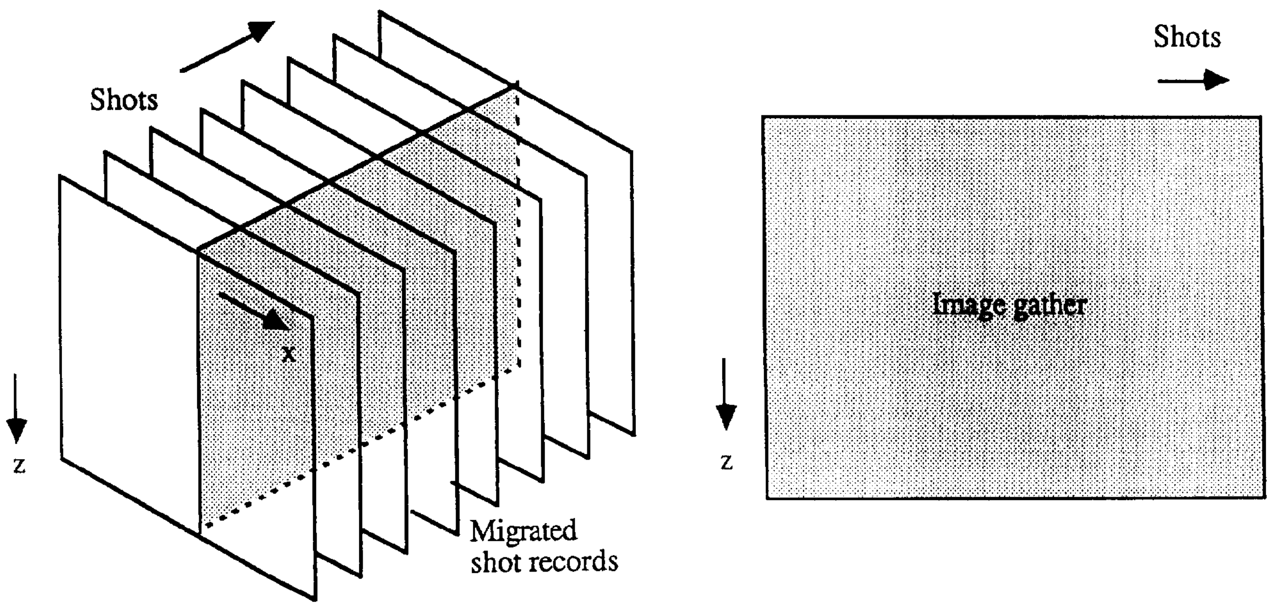


Figure 15. The migrated shot records in a 2-D seismic line together form a 3-D data volume. A cross-section for constant x forms an image gather.

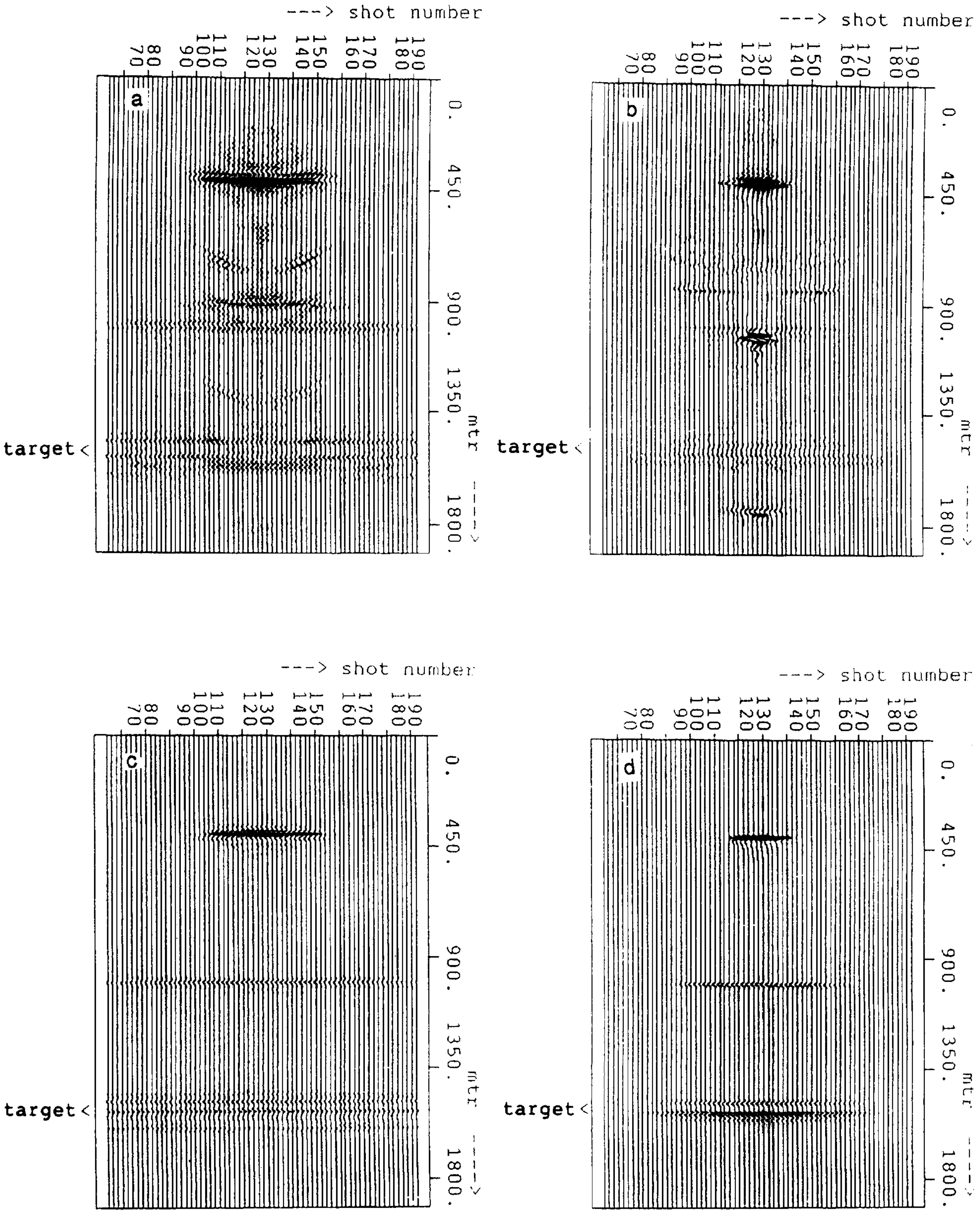


Figure 16. Image gathers at $x = 0$, selected from the shot record migration results of many shots in a seismic line: (a) pseudo *P-P* image gather, (b) pseudo *SV-SV* image gather, (c) true *P-P* image gather, and (d) true *SV-SV* image gather. Note than in (c) and (d) all events are perfectly aligned.

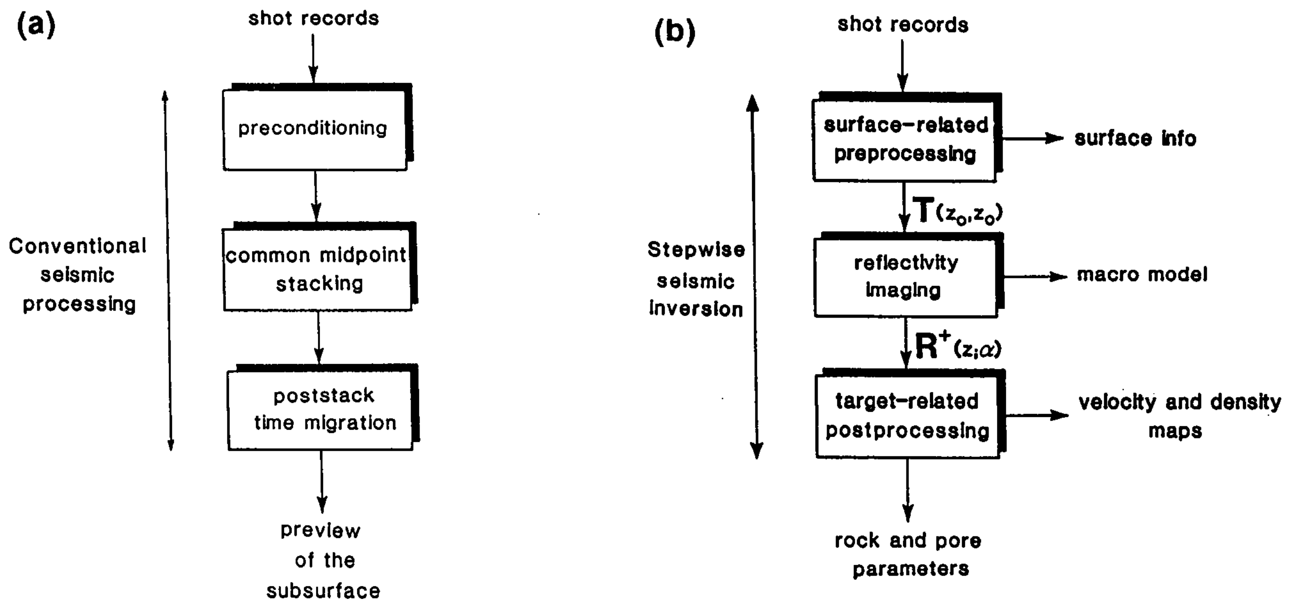


Figure 17. (a) Seismic processing of the '70s in terms of preconditioning, stacking and time migration. (b) Seismic processing of the '90s in terms of surface-related preprocessing, reflectivity imaging, and target-related postprocessing.

coherency analysis on the CDP gathers ("focusing analysis"). The final focus panel is shown in Figure 13. Similarly, the macro model for *S*-wave propagation is estimated from the data in Figure 12d. The result is only a few percent in error compared with the model shown in Figure 9.

Elastic prestack migration (step 2b). To show the importance of the preprocessing procedure (decomposition and multiple elimination), we applied the migration process to the original "pseudo *P-P*" and "pseudo *SV-SV*" data (Figures 10a and 10d) and to the multiple and conversion-free "true *P-P*" and "true *SV-SV*" data (Figures 12a and 12d). Figures 14a-d each shows one migrated shot record. Figures 14a and 14b represent the migrated pseudo *P-P* and pseudo *SV-SV* data, respectively; Figures 14c and 14d represent the migrated true *P-P* and true *SV-SV* data, respectively.

The effect of the preprocessing is obvious: The results in Figures 14c and 14d are far superior to 14a and 14b. In particular, the target zone (z = 1450 m) is very well resolved in Figures 14c and 14d. When we migrate all shot records in a seismic line, then so-called image gathers (fixed x, variable shot coordinate) can be selected from the migrated shot records. The principle is illustrated in Figure 15. Figure 16 shows image gathers related to the pseudo *P-P* data (Figure 10a), the pseudo *SV-SV* data (10d), the true *P-P* data (12a), and the true *SV-SV* data (12d). Again, the effect of the preprocessing is obvious. In Figures 16c and 16d all events are perfectly aligned. This confirms that the correct *P*- and *S*-wave macro models were estimated in step 2a. Note that the image gathers in Figures 16c and 16d contain directly the information on the angle-dependent *P-P* and *SV-SV* reflectivity. They are used as input for the last inversion step.

Summary. Conventional seismic processing is a time-domain method in which input/output consist of time traces and processing is largely based on time series techniques. Therefore, conventional seismic processing gives an economic preview (Figure 17a) of the subsurface.

When a more accurate image is required, a depth-oriented technique must be implemented. Our expectation is that this will consist of three different layers of software. The first will generate a homogeneous nonreflecting earth surface. In the second, the subsurface is penetrated by downward extrapolation (i.e., elimination of the propagation effects) which will result in a depth image of the subsurface in terms of reflectivity. In the third, the angle-dependent reflectivity for areas of special interest will be further used in the calculation of velocity and density logs and/or maps which again can be used for the estimation of rock and pore parameters (Figure 17b).

If multicomponent data are involved, preprocessing should start with decomposition into one-way *P* and *S* waves. A far-reaching consequence of this approach is that elastic processing can then be carried out by applying the aforementioned scalar processing software twice. LE

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