Estimation of *Macro* P and S velocity models.

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SUMMARY

In this paper a macro model estimation technique is presented based on non–recursive wave field extrapolation. By shot record redatuming, using an initial macro model, true Common Depth Point (CDP-)gathers are generated at grid points along one or more lateral positions (such as potential boreholes). By analyzing the coherency properties of the CDP data at each grid point it is possible to determine the errors in the macro model. At each lateral position the interval *velocities* of the macro *layers* are estimated as well as the positions of the macro *boundaries*. To obtain the complete model, the macro interval velocities are interpolated within each layer and the macro boundaries are fitted in by tracking the macro time horizons and, next, applying ray migration using the derived macro interval velocities.

INTRODUCTION

An interesting and important analysis of a velocity log is given by a subdivision in trend and detail. The trend gives information on the depth dependent compaction properties of the subsurface. The detail gives information on the rock and pore properties of the individual geologic layers. Using trend information, the subsurface may be subdivided in so-called macro layers, where each macro layer can be seen as a package of geologically related layers with the same compaction property. The distinction between trend and detail, or macro layering and fine layering, plays an important role in migration and inversion.

Since prestack wave field extrapolation is highly sensitive to the accuracy of the macro model this process itself is used in the estimation: Through prestack redatuming of shot records it is possible to obtain *true* Common Depth Point gathers that have to contain an 'aligned' event at zero time if the macro model is correct and the depth point is located on a reflector. So, by alignment analysis of *CDP-gathers* it is possible to tell whether the macro model is correct and, if not, how it has to be updated. One particular version of alignment analysis is given by the well-known focussing analysis (Jeannot et al., 1986); this process investigates the amplitude distribution after *stacking* the CDP-gathers. In addition to CDP-gathers, the shot record approach allows to generate *Image gathers* as well; they can serve as an additional quality indicator for the macro model. An Image gather contains the migrated

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result at one lateral position, *before* stacking over the shots, but *after* the imaging principle has been applied at all depth levels of interest. All events in an image gather should be horizontally aligned if the correct macro model is used, even if the macro model is structurally complex.

THE METHOD

Figure 1 (after Berkhout and Wapenaar, 1990) shows the complete stepwise inversion sequence for the determination of the rock and pore parameters from (multi-component) surface seismic measurements as proposed by the DELPHI consortium project at the Delft University. This target oriented approach consists of three basic steps: Estimation and elimination of the (near) surface effects (A), estimation and elimination of the propagation effects due to the overburden (B) and, finally, the determination of the rock and pore parameters in the target from angle dependent information (C). One of the reasons for this subdivision in a number of well-defined steps is the possibility to make use of additional information in each step (maximum external control).

In the first step the multi-component data are decomposed into PP, SS PS and SP data followed by elimination of the strong surface related multiples. In this paper the attention is focussed on the second step of the DELPHI inversion scheme, i.e. the subsequent estimation and removal of the propagation effects due to the overburden between the surface and the target. Because the data have been decomposed the P and S macro models, that define the propagation parameters of P and S waves, can be estimated separately from the PP data and the SS data respectively.

In the DELPHI inversion project, macro velocities are estimated by alignment analysis on *CDP-gathers* (before imaging) or by alignment analysis on *Image gathers* (after imaging). For economic reasons the macro *velocities* are estimated on a sparse set of lateral positions (just as with conventional velocity analysis), followed by an interpolation process within each macro layer. Next, the macro *boundaries* are depth converted using the estimated macro velocities. The macro boundaries combined with the macro velocities define the macro velocity model, which forms the basis for depth migration and inversion.

First we will explain how the extrapolated data is used to estimate the macro interval velocities as well as a sparse set of updated macro boundary locations. Secondly, to obtain the complete model a dense set of macro boundary coordinates is derived. In the examples shown here, the results for the estimation of the P wave macro model are shown only. The estimation of the S wave macro model yields comparable results.

Estimation of the interval velocities

Figures 2 and 3 show some shot records before and after surface related preprocessing, respectively (step A in the DELPHI-scheme). The velocity analysis is done at a sparse set of lateral positions. Therefore, with an initial macro model (figure 4) CDP–gathers are generated by wave field extrapolation to depth points lying on a vertical line below the lateral position of interest. Since, in general, the macro interval velocity doesn't change too much laterally within a layer, the lateral positions can be chosen rather sparse. The wave field extrapolation is done by shot record redatuming as described by Kinneging et al. (1989). Normally redatuming is thought of as to bring the acquisition level down from the surface to a level in the subsurface called the new datum. For our purpose we just define the new datum to be vertical! To investigate the alignment the CDP-gathers may be stacked. This so-called Common Depth Point stacking should not be confused with conventional CMP-stacking. An aligned event in a CDP-gather yields a high amplitude in the stacked trace (focussing of energy). By stacking the CDP-gathers of all related grid points a focus panel is obtained for this vertical datum (Figure 4b). Macro model errors are expressed in the extrapolation operators and, as a consequence, in the extrapolated data. So, by inspecting the extrapolated data it can be determined whether the macro model contains errors. It can be shown that a focus in the focus panel at $t > 0$ indicates too high a velocity in the model. Similarly, a focus at $t < 0$ indicates too low a velocity in the model. It is possible to tell from the errors in the data how the macro model will have to be updated. For each major reflection a focus coordinate pair (z_f,t_f) is picked from the focus panel. Application of recursive updating equations (Cox et al.,1988) yields a set of updated interval velocities and a set of interface depths at this particular lateral position. The procedure is repeated for each lateral position.

Interface delineation by tracking ZO-data and subsequent ray migration

Once the interval velocities are estimated the major interfaces have to be determined to build the updated macro model. From the velocity analysis already a sparse set of (x,z)–coordinates is available for each interface. By calculating splines through those coordinates the interfaces are only roughly determined; fast lateral boundary changes such as faults are missed. Especially in the presence of pinch–outs this method breaks down, since the exact location of the pinch–out can not be accurately derived from the sparsely sampled coordinates. A fast and accurate method to obtain the interfaces is ray migration. First the major reflections are picked from the Zero Offset data (or from a CMP substack) by using a tracking algorithm (Fig. 5). By ray migration (inverse raytracing) with the already estimated macro interval velocities the picked interfaces are converted from time to depth (Fig. 6). The depth conversion method is a top-down approach.

Now the macro model is updated. To verify the correctness of the updated model the velocity analysis is repeated. The macro model is correct if all foci in the vertical focus panels occur at t=0. This means that in the CDP-gathers aligned events occur at t=0 only, or equivalently, in the image gathers all events are horizontally aligned. If the alignment condition is not met, the procedure is repeated until convergence occurs. Once the final model is estimated (Fig. 7) a prestack depth migration can be done (Fig 8). In target oriented processing it is more efficient to do a large redatuming step to the upper boundary of the target zone (Fig. 9) followed by depth migration in the target zone, yielding comparable results.

CONCLUSIONS

An efficient and accurate macro model estimation method is presented that uses alignment analysis in CDP–gathers (and image gathers) to estimate the macro interval velocities. Next, ray migration of the picked macro time horizons is carried out using the estimated macro interval velocities. The method is capable of estimating complicated subsurface structures since no assumption is made on the moveout in the data. The scheme is very efficient since the extrapolation is done to sparsely sampled (vertical) datums in a non–recursive step. Because the multi-component data are decomposed prior to macro model estimation, the P and S macro model can be estimated separately.

The main advantage of using a shot record scheme is that it enables us to analyze the data before as well as after CDP–stacking, resulting in analysis techniques on CDP–gathers as well as image gathers. Especially in problem areas this will be important. A practical advantage is that data reordering during the redatuming process is avoided, which is crucial when 3–D applications are considered.

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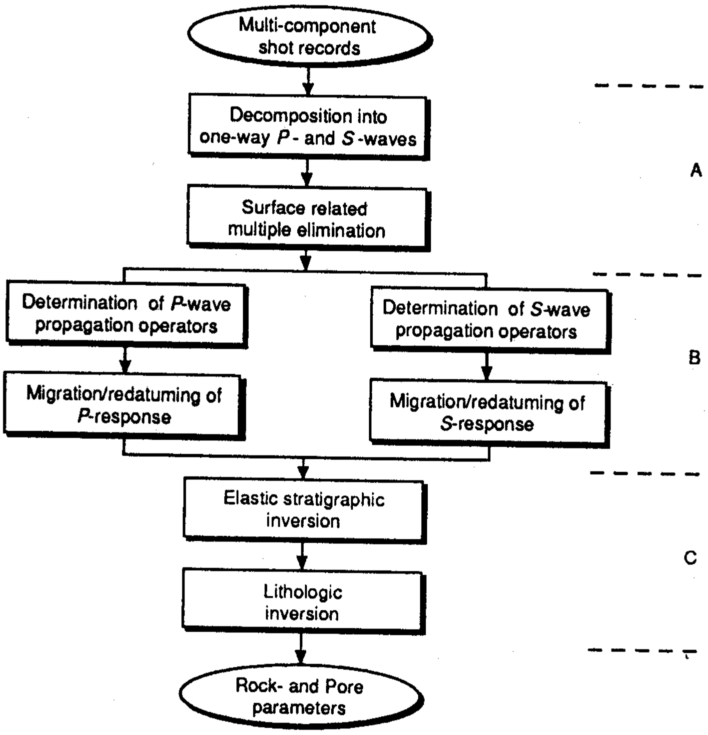


Figure 1:

The DELPHI inversion scheme is divided into separate consecutive steps related to the surface (A), the overburden (B) and the target (C) respectively.

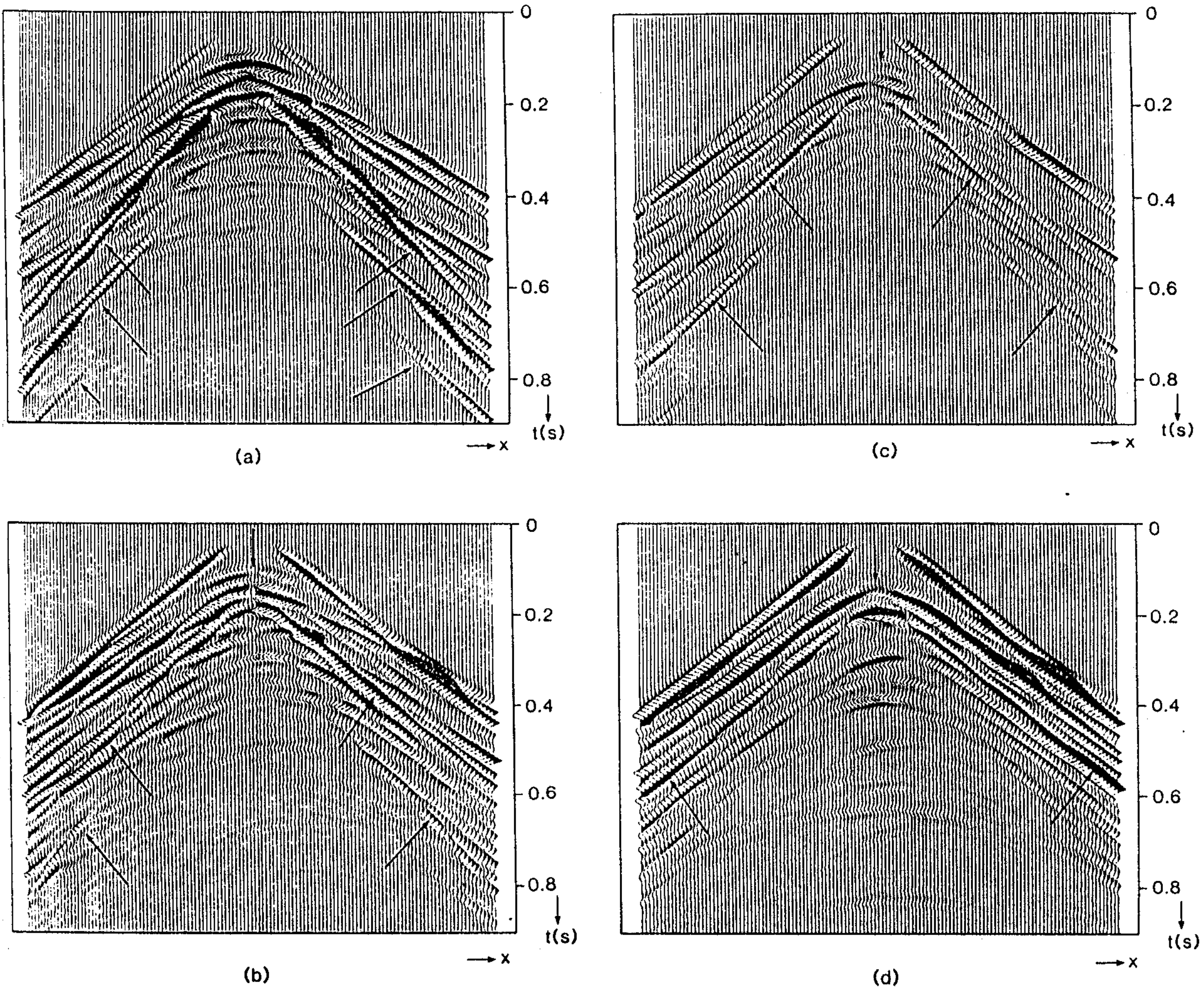


Figure 2:

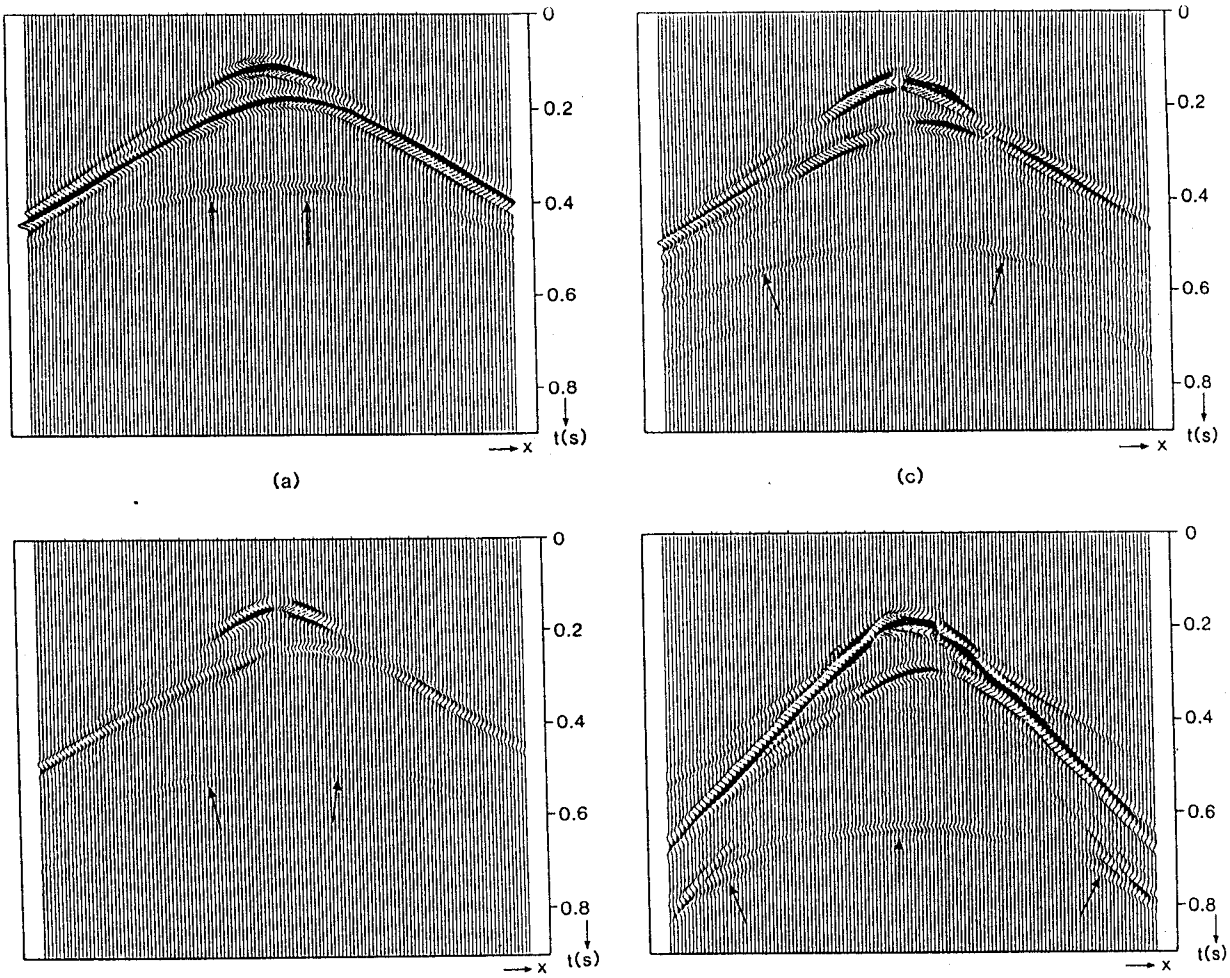
Multi component shot records before surface related processing (after removal of the ground-roll). Each shot record contains a mixture of P reflections, S reflections and strong (surface related) multiples. The arrows indicate spurious events.

a. Pseudo P-P data

b. Pseudo S_y-P data

c. Pseudo P-S_y data

d. Pseudo S_y-S_y data



(a) (c)

(b) (d)

Figure 3:

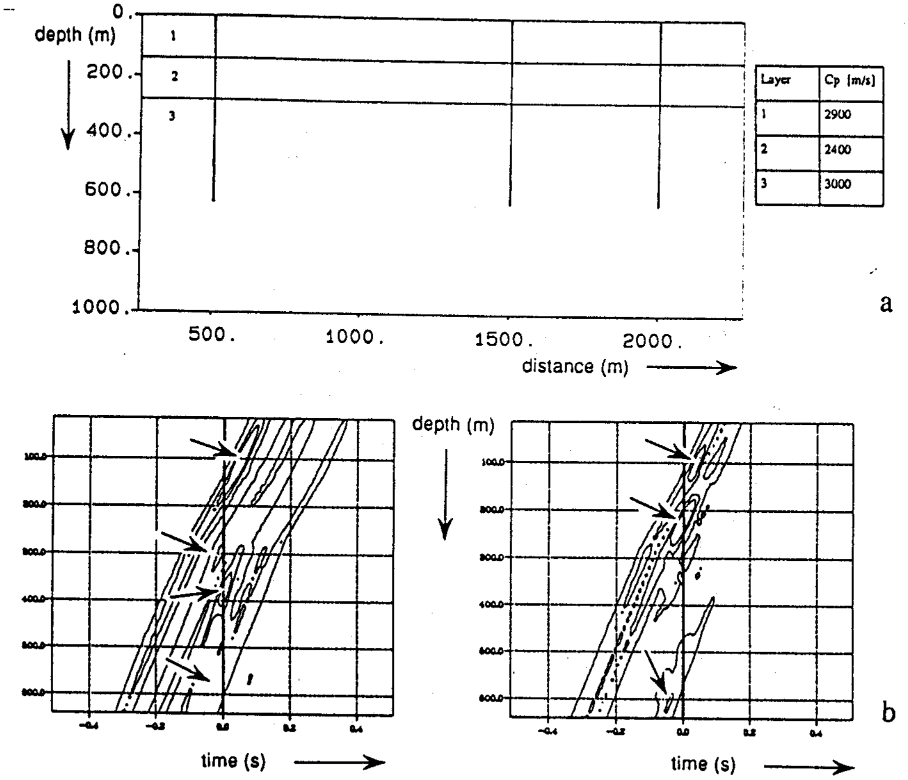
Multi-component shot records, after elastic decomposition and multiple elimination. Internal multiples and multiply converted waves are still present, but they are of second order. The arrows indicate the response of the target reflectors.

a. True P-P data

b. True S_y-P data

c. True P-S_y data

d. True S_y-S_y data



Layer	Cp (m/s)
1	2900
2	2400
3	3000

Figure 4:

a. Initial P wave macro model.

b. Focus panels at x=500 m and x=1500 m.

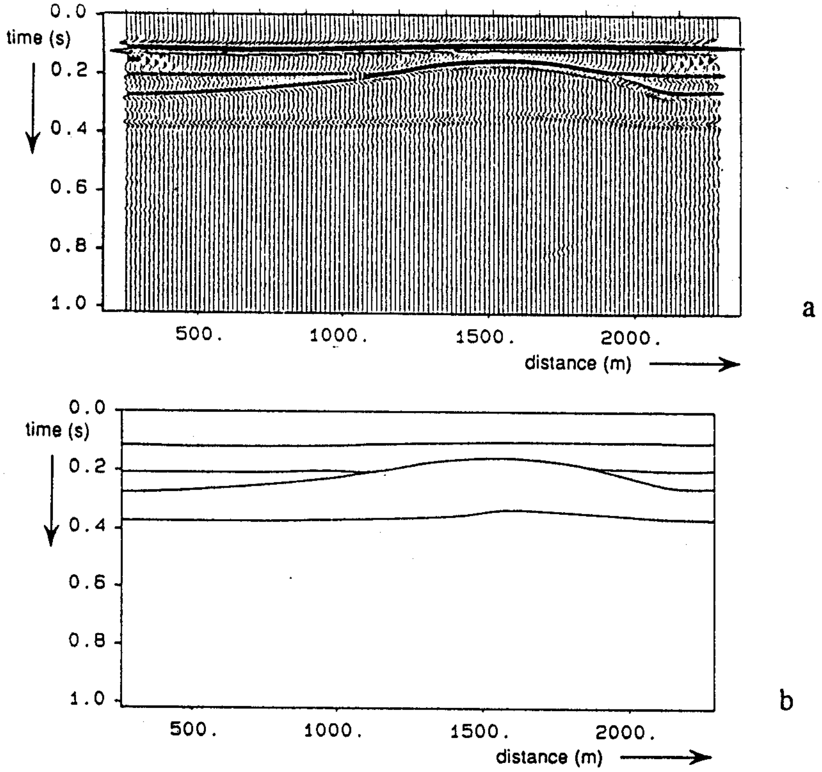


Figure 5:

a. Zero Offset section (PP).

b. Tracked horizons from the Zero Offset section.

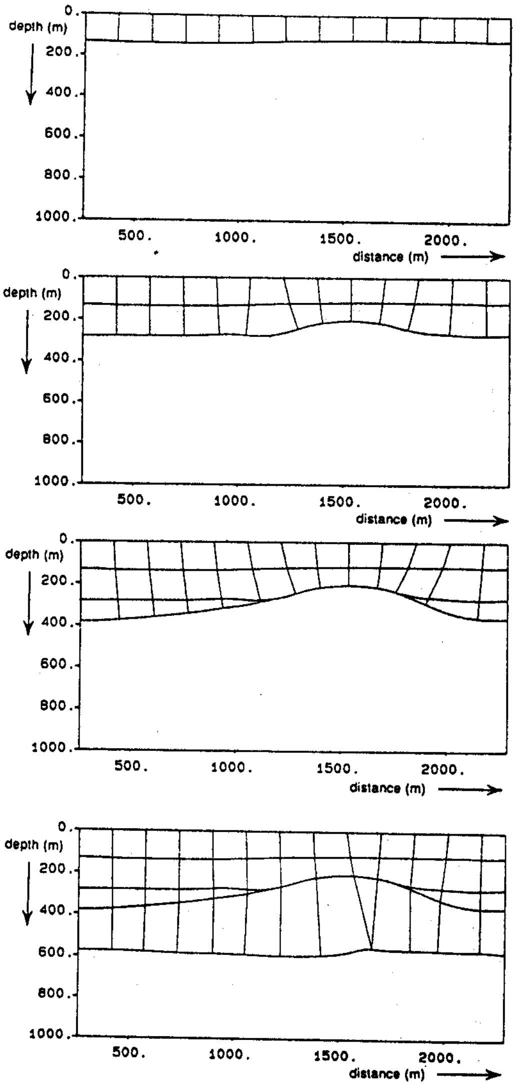
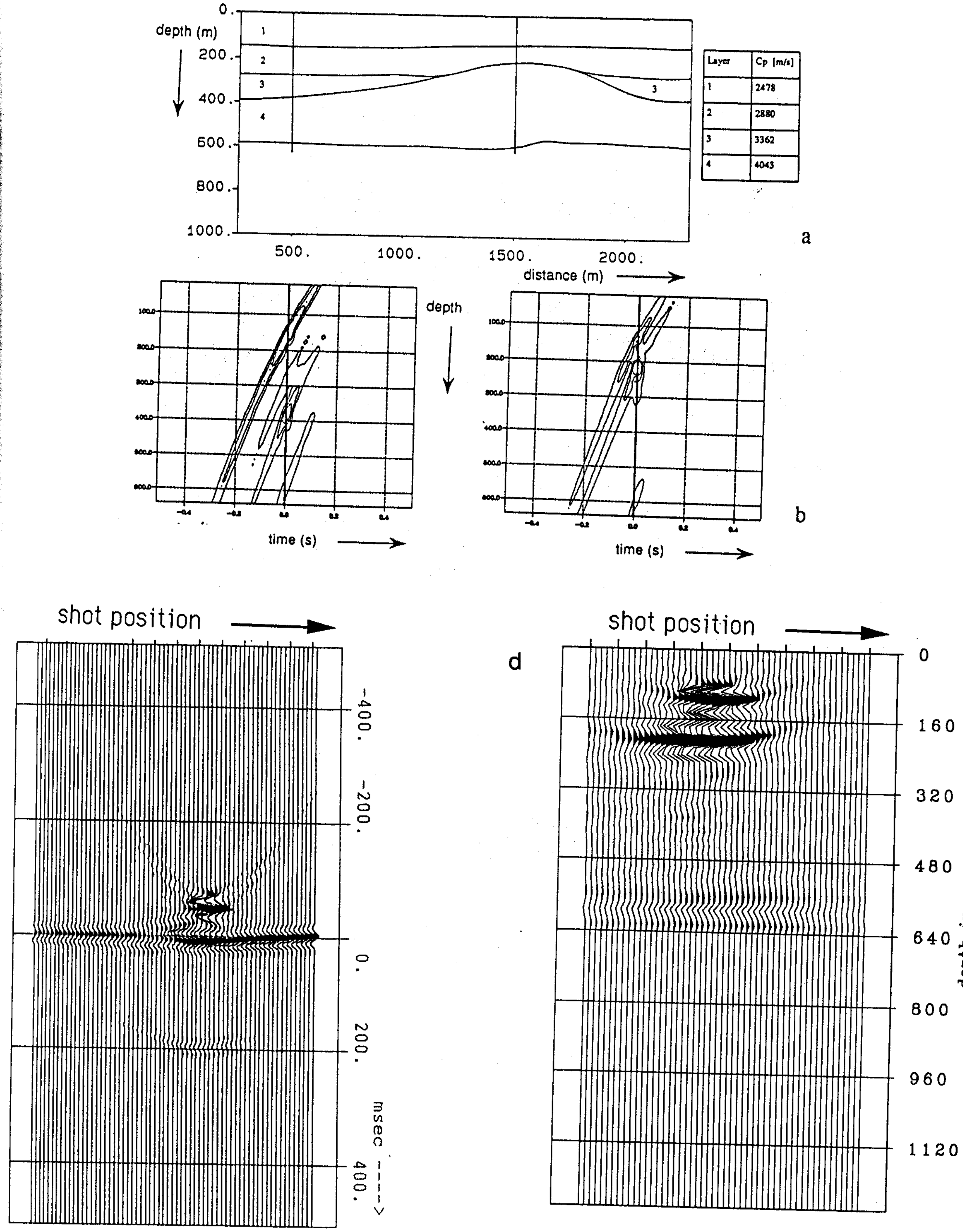


Figure 6:

Depth conversion of the tracked time horizons by horizon migration is a top-down approach.



CDP gather at grid point (x=1500 m., z=208 m.)

Image gather at x=1500 m.

Figure 7:

a. The final macro model is obtained after three iterations.

The correctness of the model is verified by the focus panels shown in figure b (containing foci at t=0); the Image gather (figure c) contains horizontally aligned events and the CDP-gather shown contains an aligned event at t=0 only (figure d).

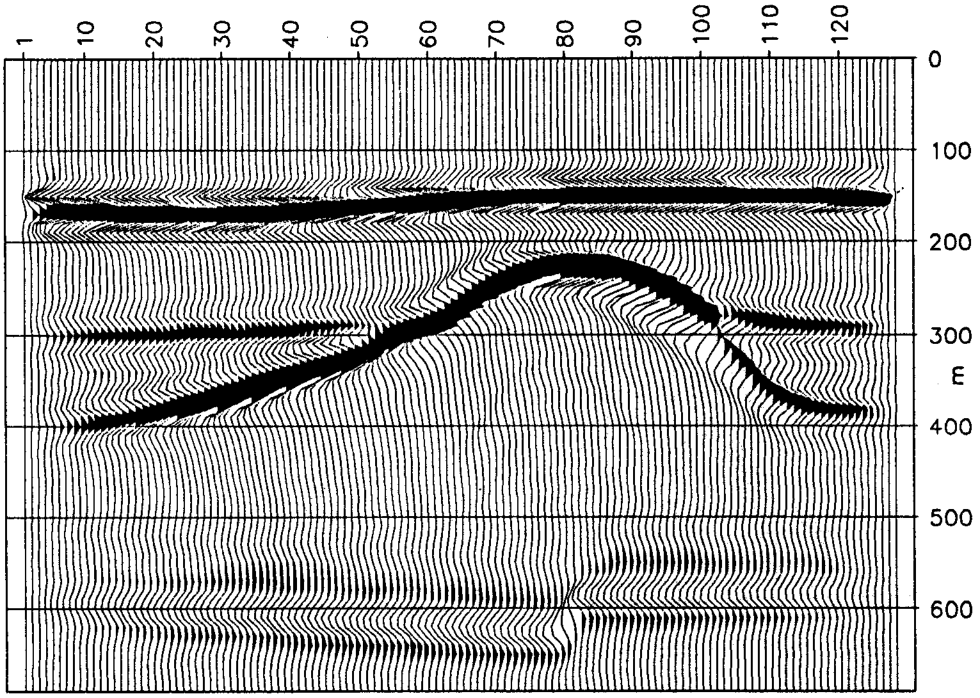


Figure 8:

Prestack depth migration with final model.

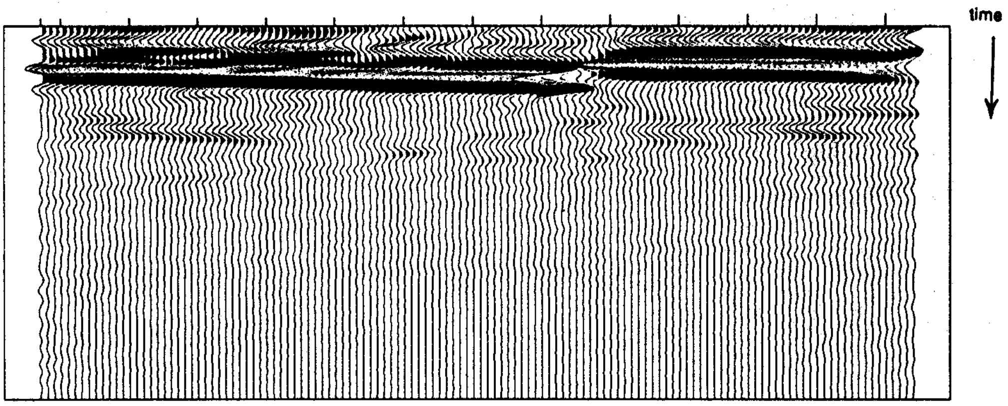


Figure 9:

ZO-data after shot record redatuming to the upper boundary of the target zone.