Efficient Macro-Model Estimation

SP 5.3

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Summary.

In this paper a macro model estimation technique is presented based on non–recursive wave field extrapolation used in a shot record redatuming scheme.

By shot record redatuming, using an initial macro model, genuine Common Depth Point gathers are generated at grid points on one or more vertical datums (which may be widely spaced). By analyzing, after extrapolation, in which CDP-gather an event is aligned, and at what time this alignment occurs, it is possible to determine the errors in the macro model. The interval velocities are estimated as well as a sparse set of updated interface coordinates at the vertical datums. To obtain the complete model, the interface coordinates have to be interpolated. This can be done by tracking the major time horizons and apply ray migration using the derived interval velocities.

Introduction.

To obtain a depth image of the subsurface the time horizons in seismic data have to be converted to geologic depth horizons. In cases of simple subsurface structures this time to depth conversion can be done after (prestack or poststack) time migration. Prestack depth migration is required when the subsurface is complex. Time to depth conversion is then taken care of by the migration process. In any of these processing schemes a macro model is needed that contains the major boundaries in the subsurface and the velocities in between them. In fact, the macro model describes the propagation effects of the seismic waves in the subsurface.

In the past a significant amount of research has been carried out to obtain an accurate description of the velocity model. Conventionally velocity analysis is done directly on the surface measurements (CMP-gathers). Dix (1955) has developed an efficient estimation method assuming hyperbolic moveout and plane horizontal interfaces. In the extensions made by Hubral (1976) the plane interfaces are allowed to have arbitrary dip, but the assumption of hyperbolic moveout is not abandoned.

In recent years vector computers have become so powerful that prestack depth migration is feasible now, resulting in more insight in the requirements of the macro model. If the macro model is wrong the prestack depth migration will be inadequate as well. Since model errors are expressed in the migration result the migration process itself can be used to determine these errors (Jeannot et al., 1986).

In the macro model estimation method presented in this paper no assumption whatsoever need be made on the moveout of the data. It uses alignment analysis in "post–redatuming" Common Depth Point (CDP)–gathers to estimate the interval velocities. The analysis can be done before or after CDP–stacking. By CDP-stacking genuine ZO–data is generated on the new datum and the alignment analysis reduces to a simple focussing analysis. The delineation of the macro boundaries is then done by ray migration of zero offset traveltimes, using the estimated velocities.

The method.

Our method is based on the following considerations. For velocity analysis we only need to analyze the data at a few sparsely sampled lateral locations (as is also done in conventional velocity analysis). To recover the structural properties of the macro model the major interfaces have to be depth converted by using the derived interval velocities.

First we will explain how the extrapolated data is used to estimate the interval velocities as well as a sparse set of updated interface locations. Secondly, to obtain the complete model, a dense set of interface coordinates is derived to delineate the macro boundaries.

The method is explained with an example. Prestack data were available from a water tank experiment (Figure 1a and 1b). It was known that conventional velocity analysis broke down on these data, because of highly non-hyperbolic moveout in the CMP–gathers.

Estimation of the interval velocities.

The velocity analysis is done at a sparse set of lateral positions. Therefore, with an initial macro model (figure 2) CDP–gathers are generated by wave field extrapolation to depth points lying on a vertical line below the lateral position of interest

(Figure 2a). Since, in general, the 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! By CDP–stacking a ZO–section is obtained on this vertical datum (from which the contours are shown in Figure 2b). 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 vertical ZO–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 ZO–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 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. 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. Using the estimated velocity in the first layer genuine ZO–data are constructed by redatuming to a horizontal datum just beneath the surface (Fig. 3a). Then the major reflections in the Zero Offset data are picked using a tracking algorithm (Fig. 3b). By ray migration (inverse raytracing) with the estimated velocities the picked interfaces are converted from time to depth (Fig. 3c).

The depth conversion method can also be applied on CMP–stacked data instead of genuine ZO–data. However, in geologically complicated situations problems such as conflicting dips and non hyperbolic moveout curves occur. Therefore in those cases a small redatuming step is preferred to obtain genuine ZO–data and so avoiding the problems introduced by CMP–stacking.

Now the macro model is updated. To verify the correctness of the updated model the velocity analysis is repeated. If all foci occur at t=0 in the vertical ZO–sections (or equivalently if alignment in the CDP–gathers only occurs at t=0) the model is correct. If not, the procedure is repeated until convergence occurs. Once the final model is estimated (Fig. 4a) a prestack depth migration can be done (Fig 5). In target oriented processing it is more efficient to do a large redatuming step to the upper boundary of the target zone (Fig. 6a) and then apply depth migration (Fig. 6b) for the target only, yielding comparable results.

Conclusions.

An efficient and accurate macro model estimation method is presented that uses alignment analysis in CDP–gathers to estimate the interval velocities. Next, ray migration of the picked main time horizons is carried out using the updated 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.

The advantage of using a shot record scheme is that it enables us to analyze the data before and after CDP–stacking. CDP–gathers may serve as an additional quality control tool for the foci that are to be picked in the focussing analysis. Especially in problem areas this can be important.

A second advantage is that data reordering during the redatuming process is avoided which is crucial when 3–D applications are considered. This important advantage of shot record oriented processing is not always fully appreciated (Jeannot,1988).

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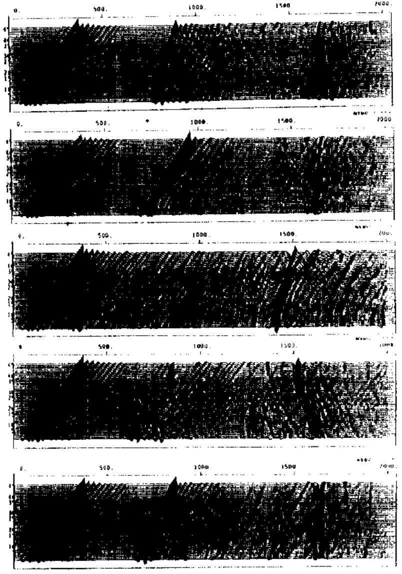

FIG. 1a Some shot records from water tank experiment.

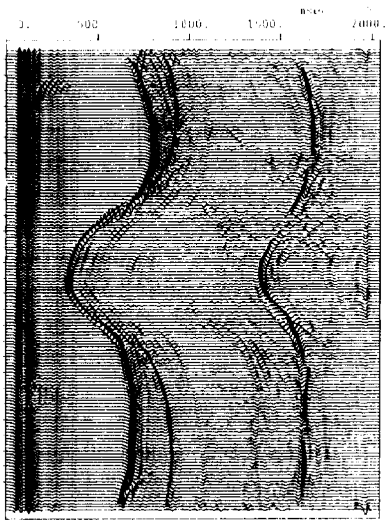

FIG. 1b. Near offset section [offset: 243.84 m (800 ft)].

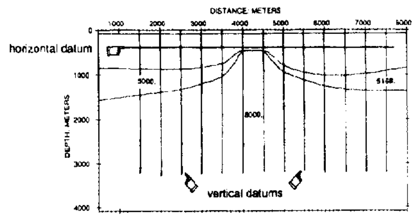

FIG. 2. Initial model. Indicated are vertical datums (used in velocity analysis) and a horizontal datum (used for interface delineation).

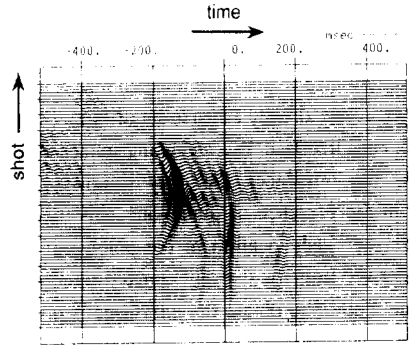

FIG. 2a. CDP gather at depth point $x = 1500$ m, $z = 2000$ m.

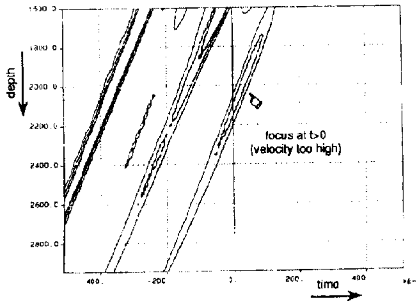

FIG. 2b. Contoured vertical ZO section at $x = 1500$m.

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[1] The model was designed and created by Marathon Oil Company. Marathon does not necessarily endorse our procedures.

FIG. 3a. ZO data at horizontal datum (z=400m.)

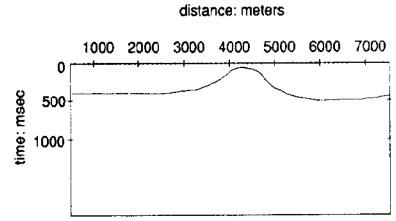

FIG. 3b. Time horizon picked in ZO section of Figure 3a.

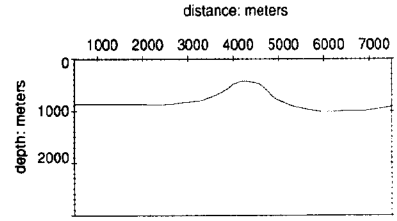

FIG. 3c. Depth converted time horizon of Figure 3b.

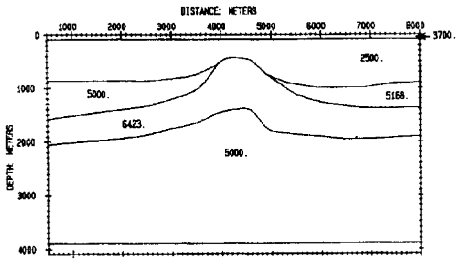

FIG. 4. Final estimated model.

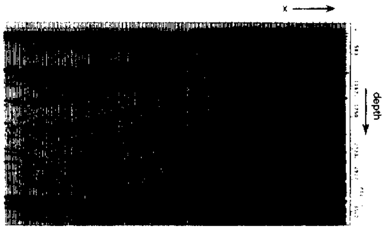

FIG. 5. Prestack depth migrated section.

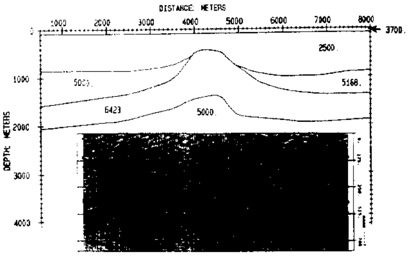

FIG. 6a. ZO data after redatuming to a target level of z=2200 m.

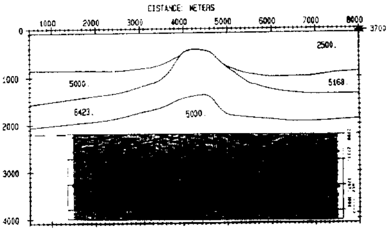

FIG. 6b. Result after depth migration of ZO data in Figure 6a.