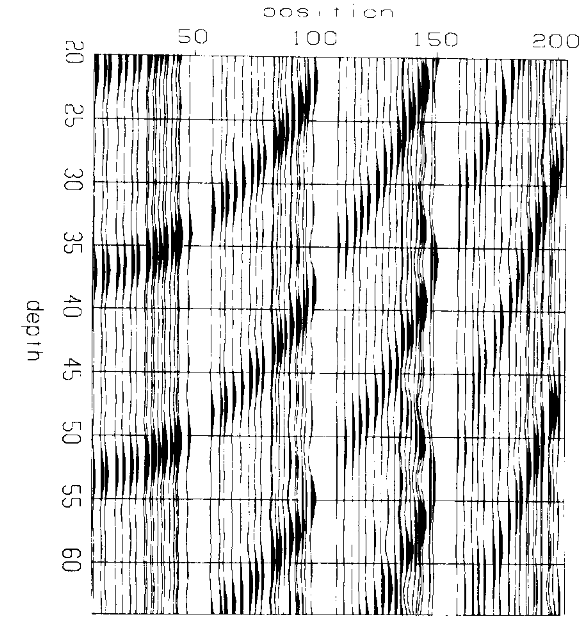

FIG. 2. Waves propagating from a point source using 15-degree finite-differencing on very irregularly sampled grid. Depth axis runs from top to bottom, and irregularly sampled space axis runs from left to right. This can be viewed as a snapshot of wave field at an instant in time.

parent. For the higher dips found on the right side of the plot, reflections from irregularities in the grid spacing are higher in amplitude. In general, the modeling will break down in regions where there is significant energy beyond the spatial Nyquist frequency.

Practical Aspects of 3-D Prestack Migration S7.5

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This paper starts with a brief review of the principle of prestack migration by single-shot record inversion (SSRI). Prestack migration by SSRI is very laborious when applied in three dimensions. However, in many practical situations seismic interpreters are mainly interested in a high-resolution image of a prespecified target zone. Hence, realistic processing times can be obtained by applying 3-D "target-oriented" prestack migration, without the need to make compromises with respect to the underlying principles. Preliminary results, obtained from scale model data, demonstrate the validity of the target-oriented approach.

Introduction

In areas with complicated 3-D geology, conventional 3-D migration techniques give a poor image of the subsurface. The ideal structural inversion procedure would be full prestack migration by 3-D single-shot record inversion (SSRI), followed by genuine common-depth-point (CDP) stacking. From a theoretical point of view this 3-D technique is not much more complicated than its 2-D counterpart, as discussed by Berkhout (1984). However, the problems related to the practical implementation of "just one more dimension" are significant. It is obvious that given the limitations of today's computational power, a more practical approach to 3-D prestack migration is required. In many practical situations seismic interpreters are mainly interested in a high-resolution image of a prespecified target zone (so only the macro features of the overburden need be inverted for). Hence, much work can be saved by applying target-oriented 3-D prestack migration without the need to simplify the underlying principles of the algorithm.

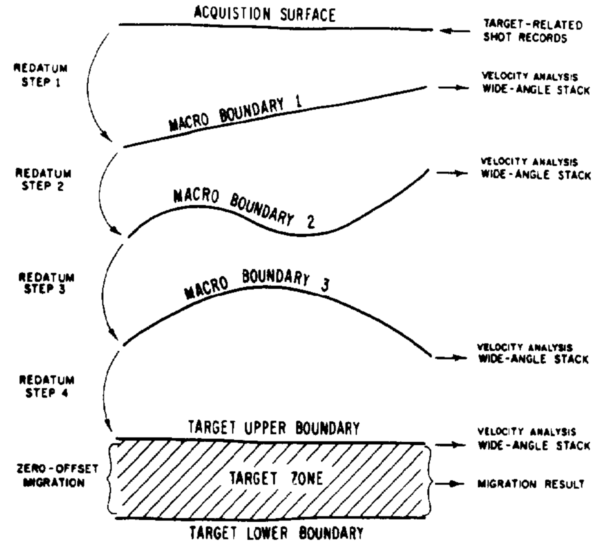

FIG. 1. Principle of 3-D target-oriented prestack migration.

Principle of 3-D target-oriented prestack migration

In this section we discuss the three basic steps of 3-D target-oriented prestack migration (see also Figure 1): (1) *Prestack redatuming*. Target-related common shotpoint (CSP) gathers at the surface are downward extrapolated in a 3-D sense via the boundaries of a macro subsurface model to the upper boundary of the target zone. (2) *Wide-angle CDP stacking*. At the macro layer boundaries and at the upper boundary of the target zone single-fold zero offset (ZO) gathers are formed by relating the downgoing source wave and the upgoing reflected waves. Genuine multifold ZO gathers are obtained by combining individual results (wide-angle CDP stacking). Optionally, these data can be used for velocity analysis based on model verification. A further discussion of velocity analysis is beyond the scope of this paper. (3) *ZO migration*. Full 3-D wide-angle ZO migration is applied within the target zone. In the following we discuss the different steps in more detail.

Prestack redatuming (step 1) of a CSP gather is formally described (in the frequency domain) by

$$S^+(x,y,\sigma_i,\omega) = W^+(x,y,\sigma_i,\sigma_{i-1},\omega) * S^+(x,y,\sigma_{i-1},\omega), \quad (1a)$$

and

$$P^-(x,y,,\sigma_i,\omega) = F^-(x,y,\sigma_i,\sigma_{i-1},\omega) * P^-(x,y,\sigma_{i-1},\omega). \quad (1b)$$

Relation (1a) describes forward extrapolation of the downgoing source wave, and (1b) describes inverse extrapolation of the upgoing reflected waves. The asterisk denotes a two-dimensional space dependent generalized spatial convolution along the x and y coordinates. σ_{i-1} and σ_i refer to arbitrarily curved macro layer boundaries. A discussion of the Kirchhoff-type operators W^+ and F^- is beyond the scope of this paper.

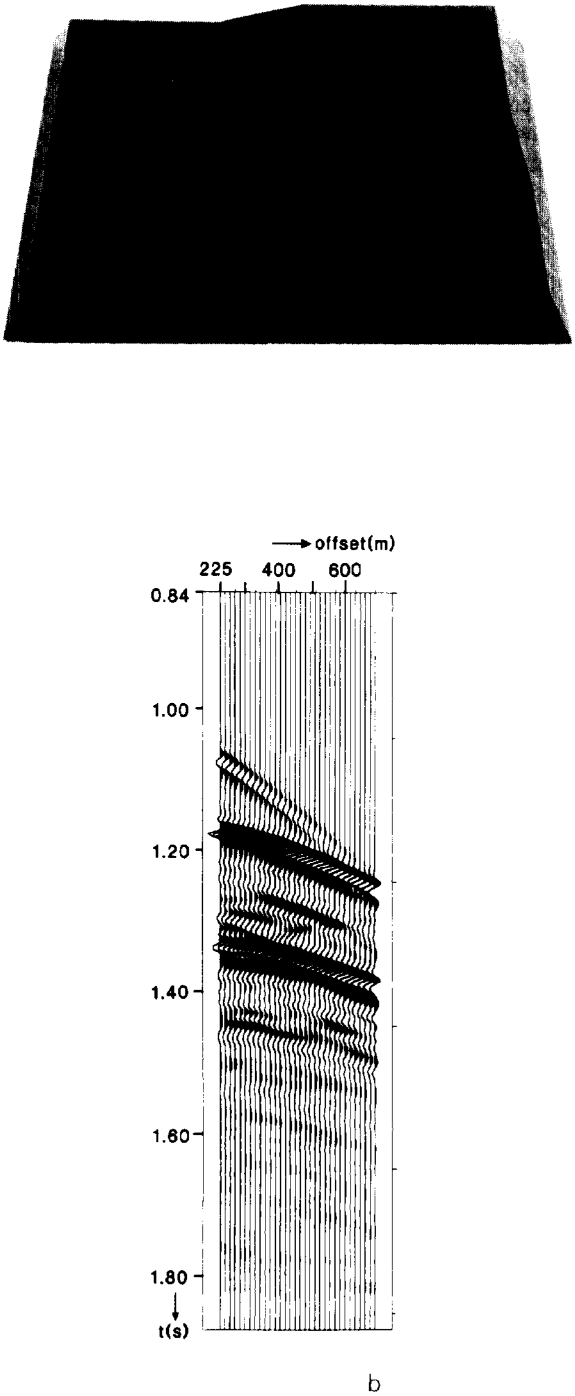

FIG. 2. Model tank experiment. (a) French model, (b) example of modeled CSP gather.

Wide-angle CDP stacking (step 2) takes place at the macro layer boundaries σ_i and upper boundary σ_t of the target zone. (Note that a plane "reference" boundary σ_t may be chosen which does not necessarily coincide with one of the macro layer boundaries.) After redatuming the downgoing source waves $S^+_{mn}(x,y,\sigma_i,\omega)$ and the upgoing reflected waves $P^-_{mn}(x,y,\sigma_i,\omega)$ are available. Here subscripts mn denote that wave fields are related to CSP gather mn, generated by a source located at (x_m,y_n,z_0) at the surface. The single-fold ZO impulse response at boundary σ_i is obtained by relating the downgoing and upgoing waves at σ_i as follows:

$$<X_{ZO}(x,y,\sigma_i,\omega)>_{mn} = \frac{1}{s^2_{mn}} P^-_{mn}(x,y,\sigma_i,\omega)[S^+_{mn}(x,y,\sigma_i,\omega)]^*, \quad \text{(2a)}$$

where

$$s^2_{mn} = \iint S^+_{mn}(x,y,\sigma_i,\omega)[S^+_{mn}(x,y,\sigma_i,\omega)]^* dxdy. \quad \text{(2b)}$$

The multifold ZO *reflectivity* at σ_i could now be obtained by imaging (summing over all frequencies) and CDP stacking (summing over all shots). For our purpose the imaging step is deleted, hence the multifold ZO *impulse response* is obtained by CDP stacking only, according to

$$X^{CDP}_{ZO}(x,y,\sigma_i,\omega) = \sum_m \sum_n <X_{ZO}(x,y,\sigma_i,\omega)>_{mn}. \quad \text{(3)}$$

High quality ZO traces can be obtained by applying an inverse Fourier transform from the frequency domain to the time domain. If the inverse Fourier transform is carried out *before* CDP stack-

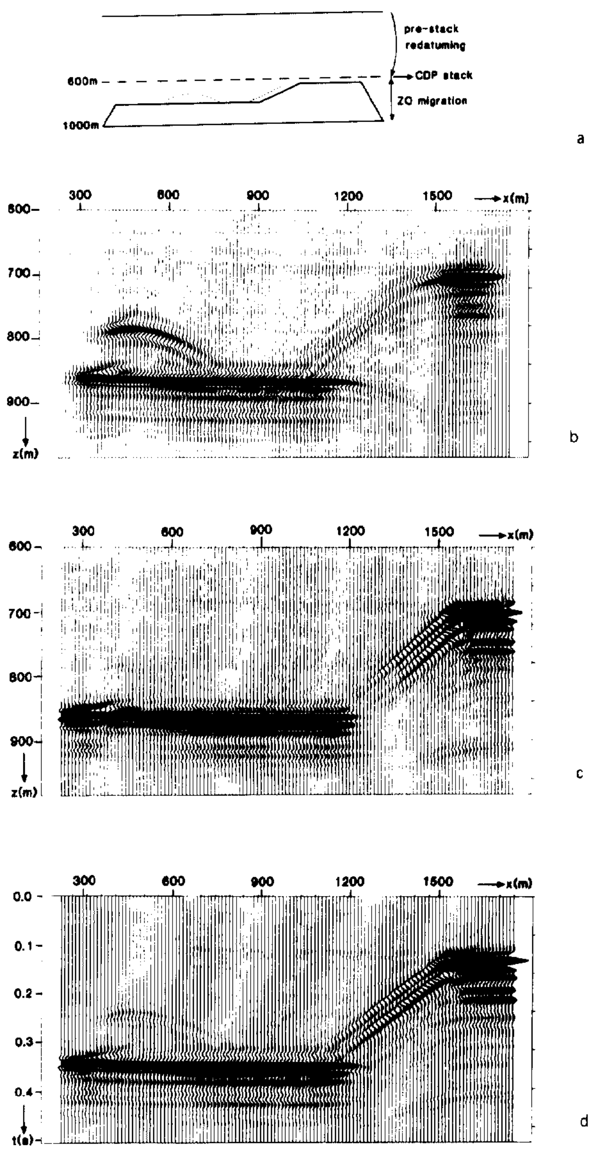

FIG. 3. Results of target-oriented processing. (a) Vertical 2-D slice of subsurface below line 2 (dotted lines indicate mispositioned events after 2-D processing, see (b) also). (b) Result after 2-D redatuming, wide-angle CDP stacking, and ZO migration. (c) Result after 3-D redatuming, wide-angle CDP stacking, and ZO migration. (d) Unmigrated result after 3-D redatuming and wide-angle CDP stacking.

ing, then residual normal moveout (NMO) corrections can be applied when the macro subsurface model, used in the prestack redatuming step, was slightly in error.

ZO migration (step 3). After prestacking redatuming and wide-angle CDP stacking, high quality ZO data are available at the upper boundary σ_i of the target zone. Because true CDP stacking was applied *after* downward extrapolation, these ZO data contain diffraction energy as well as wide-angle information related to the target zone. Therefore it is important to apply *a full 3-D wide-angle* ZO migration algorithm in order to obtain a high resolution image of the target zone. A further discussion of 3-D zero-offset migration is beyond the scope of this paper.

Results

In the previous section the principle of a 3-D target-oriented prestack migration scheme was discussed. The practical implementation of the scheme can be realized on today's vector computers. However, at this moment much software development is still required before large real data sets can be processed. This is the subject of a new project (named Triton), carried out at Delft University. Here we discuss some results of a feasibility study, demonstrating the validity of the target-oriented approach. At the bottom of a water tank we placed the well-known "French model" (French, 1975; see Figure 2a) and we modeled 64 seismic lines with 64 CSP gathers each. One CSP gather (containing 32 traces) is shown in Figure 2b. A vertical 2-D slice of the subsurface below line 1 is shown in Figure 3a. The result after *2-D* prestack redatuming, wide-angle CDP stacking and ZO migration of line 1 is shown in Figure 3b. Note the strong side-swipe reflection of one of the domes and the mispositioned sloping edge. A 2-D slice below line 1 of the result after *3-D* redatuming, wide-angle CDP stacking and ZO migration is shown in Figure 3c. Note that the side-swipe reflection of dome 1 disappeared for the greater part and that the sloping edge is positioned correctly.

Finally, in Figure 3d we show a 2-D slice of the *unmigrated* 3-D wide-angle CDP stack (after 3-D redatuming) at the upper boundary of the target zone. Note that these ZO data in the *time domain* can be easily interpreted because they are simulated at a level just above the zone of interest (the propagation distortions of the overburden have been eliminated). In fact, these unmigrated data are very similar to the migrated data in Figure 3c! Hence, 3-D prestack redatuming and wide-angle CDP stacking at the upper boundary of the target zone represent a more costly but far superior alternative to conventional CMP stacking at the acquisition surface. It may be expected that the combination of redatuming and ZO-stacking will play a key role in future seismic processing.

References

Berkhout, A. J., 1984, Seismic migration, Vol. 14B, Practical aspects: Elsevier.

French, W. S., 1975, Computer migration of oblique seismic reflection profiles: Geophysics, **40**, 961–980.

Prestack Migration Velocities from Focusing Depth Analysis S7.6

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Prestack migration has proven to be an efficient method for imaging complex structures. Several algorithms have so far been successfully tested on synthetic or real data. Among them, alternate downward continuation of shots and geophones (S-G migration) offers a good compromise between accuracy and computational cost. However prestack migration schemes are particularly sensitive to the accuracy of the velocity model, and geologic consistency is of paramount importance to avoid spurious pullup or down effects. S-G migration gives us the opportunity to determine without additional computations the depth at which each reflector actually focuses to zero offset in the process of downward continuation. Moreover, for a flat horizontal reflector the true depth of the reflector is the geometric mean of the focusing and migration depths. This very simple formula remains a valid approximation for dipping events or a horizontally stratified subsurface. It provides an iterative procedure to refine the velocity model in the course of S-G migration: (1) updated depths are obtained by correcting the migrated depths using the focusing depth analysis, and (2) updated interval velocities are obtained by matching normal incidence traveltimes in the updated geometry with corresponding traveltimes in the initial velocity model.

Prestack depth migration is the ultimate in 2-D processing for structure. It is the only way to obtain a correct image of the subsurface in the presence of strong lateral velocity variations, when the concept of CDP breaks down. Whenever scientists are confronted with an increasing complexity they come up with a greater variety of solutions. Prestack migration is no exception to this rule. If we restrict ourselves to full prestack migration algorithms, several methods have been successfully implemented, each with its own approximations, limitations, and constraints: Kirchhoff summation, migration of individual shots, alternate downward continuation of shots and geophones (S-G migration).

The additional dimension introduced by migrating before rather than after stack requires shifting the emphasis toward computer efficiency. Denelle, Dezard, and Raoult (SEG 85) demonstrated the feasibility of S-G migration, describing the algorithm and its implementation on a Cray computer. The method proves efficient although affordable on full wave equation synthetic data where stack followed by migration fails to give a proper image. However, this requires prior knowledge of the propagation velocities, i.e., the shape and interval velocity of each layer.

We have to face the following paradox here: performing a correct prestack migration requires that the main features of the resulting seismic section in terms of layer geometry plus the interval velocities within each layer be input as processing parameters. Besides the diffraction operator performs in a single step both stacking and migration. One loses the flexibility inherent to CDP processing whereby geologically inconsistent rms velocities may be used to obtain the best possible stack while a different more realistic velocity field will provide the migrated section.

We propose a specific procedure to bootstrap oneself out of this vicious circle. It takes advantage of the S-G migration computational effort and provides simultaneous control of its stacking and migration effects. All that is needed is a better use of its intermediate computational steps. The principle of S-G migration is to downward continue both shot and geophone gathers to all depths of interest and to perform the imaging at time zero and zero offset. It means that the original 2-D wave fields $P(x, t, z=0)$, x representing either the s (shot) or g (geophone) relative coordinate (offset), are extrapolated to all values of z down to the maximum depth of migration. Thus the 3-D wave fields $P(x, t, z)$ are computed for each shot or geophone gather. The mi-