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Implicit static corrections in prestack migration of common-source data

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ABSTRACT

Static effects due to surface topography and near-surface velocity variations may be accurately compensated for, in an implicit way, during prestack reverse-time migration of common-source gathers, obviating the need for explicit static corrections. Receiver statics are incorporated by extrapolating the observed data from the actual recorder positions; source statics are incorporated by computing the excitation-time imaging conditions from the actual source positions.

INTRODUCTION

The standard poststack processing sequence for two-dimensional (2-D) seismic data (cf., Hatton et al., 1986; Yilmaz, 1987) involves a number of fundamental assumptions. One of tion (cf., Wiggins, 1976). While some augmentations such as dip moveout (cf., Yilmaz and Claerbout, 1980) or wave-equation datuming (Berryhille, 1979) alleviate these problems to some degree, more exact treatments are possible with prestack rather than postack processing.
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When recording apertures are large, lateral velocity variations produce nonhyperbolic moveouts and static corrections become functions of the emergent and incident angles of the waves at each source and recorder point; these effects cannot be corrected in poststack processing.

Surface topography and near-surface velocity variations may be explicitly incorporated into the 2-D velocity model through which extrapolation is done during prestack reverse-time migration of common-source data. Then, all the effects usually approximately included in standard statics formulations are implicitly included, in a more correct way, during prestack migration of common-source data.

PREVIOUS RESEARCH

There are a number of algorithms available for 2-D prestack migration of acoustic common-source data (cf., Reshef and Kosloff, 1986; Chang and McMechan, 1986; Esmersoy and Oristaglio, 1988). For the present study, we use the reverse-time algorithm of Chang and McMechan (1986), which uses second-order explicit 2-D acoustic finite differences for extrapolation of the recorded wave field, and ray tracing from the source point to compute the excitation-time imaging condition at each point in the finite-difference grid (the one-way traveltime from the source to each point). In these algorithms, there is no inherent restriction on the source or receiver locations. In the examples below, we illustrate the specific case where the recording array is on the arbitrarily variable surface topography of the (acoustic) earth.

Wave-equation datuming (Berryhill, 1979) has been used in a velocity-replacement context to do static corrections of zero-offset (stacked) sections and has the distinct advantages that all wave effects, such as refraction on crossing of interfaces, are correctly handled and the velocities involved are always interval velocities. A fact that is often overlooked in such applications is that accurate statics corrections are a prerequisite both to estimation of the velocity through which extrapolation is done and to the production of a coherent stacked section. Thus it is more appropriate to perform wave-equation datuming before final velocity estimation and stacking as described by Berryhill (1984), which was presented in the context of preparing data for a standard processing sequence.

Here we generalize the concept of wave-field extrapolation, as a technique for correction of topographic and near-surface effects, and incorporate it directly into a fully prestack approach, where such operations are not separate explicit steps in processing, but occur implicitly and simultaneously during the same extrapolation that is involved in prestack migration of common-source gathers. There is no distinction in this approach between long and short-wavelength statics; all are treated simultaneously in an internally consistent form. This formulation is expected to have strong practical benefits as well as being theoretically more correct and intuitively simple.

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EXAMPLES

To illustrate the automatic incorporation of static effects during reverse-time prestack migration of common-source data, we present three examples. The first has strongly variable topography over a simple subsurface structure, the second has flat topography over a strongly laterally variable near-surface velocity distribution, and the third has both strongly varying topography and subsurface velocity. Synthetic seismograms are computed using 2-D acoustic finite-difference software similar to that described by McMechan (1985); migrations are performed by the algorithm described by Chang and McMechan (1986).

Example 1: Variable surface topography

The model in Figure 1a contains a simple 2-D velocity structure and a recording surface (the free surface) that will produce both short- and long-wavelength source and receiver statics. Synthetic acoustic, common-source data for the two representative source points A and B (Figure 1a) are shown in Figures 2a and 2b. In acoustic computations, the free surface may be easily defined by setting the acoustic pressure to zero everywhere along and above that surface. After the usual premigration data processing [including muting of the direct arrival and tapering the edges of the data aperture (Chang and McMechan, 1986)]. data for all 13 source points (Figure 1a) are individually migrated (see Figures 2c and 2d for sample partial images); the partial images are then stacked to produce the final composite image (Figure 1b). The velocity distribution is smoothed to reduce artifacts associated with secondary reflections during extrapolation (Loewenthal et al., 1987).

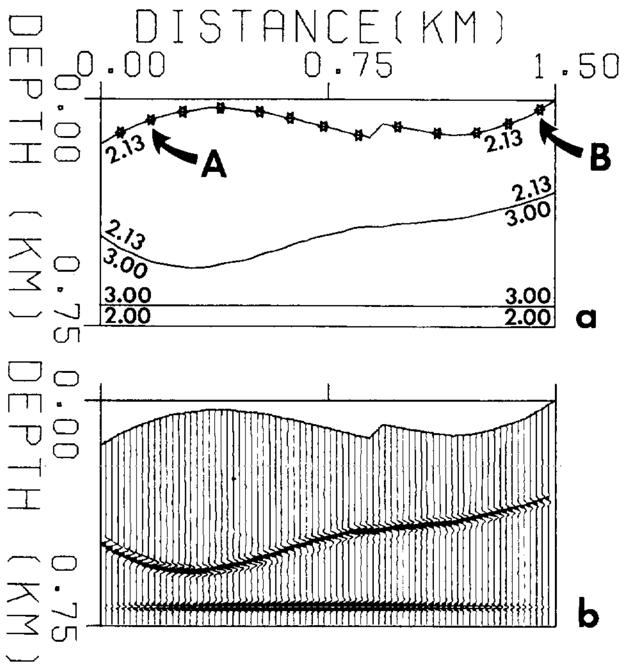

FIG. 1. Prestack migration for data collected on a surface of variable elevation. In (a), stars are source points located along the (variable elevation) free surface, solid lines are reflectors, and the numbers along the top and bottom of the reflectors are velocities in km/s. Representative common-source gathers for source points A and B and the corresponding prestack migrations are shown in Figure 2. (b) contains the final migrated section obtained by stacking partial images for all 13 sources in (a). Elevation corrections are automatically and implicitly applied during migration.

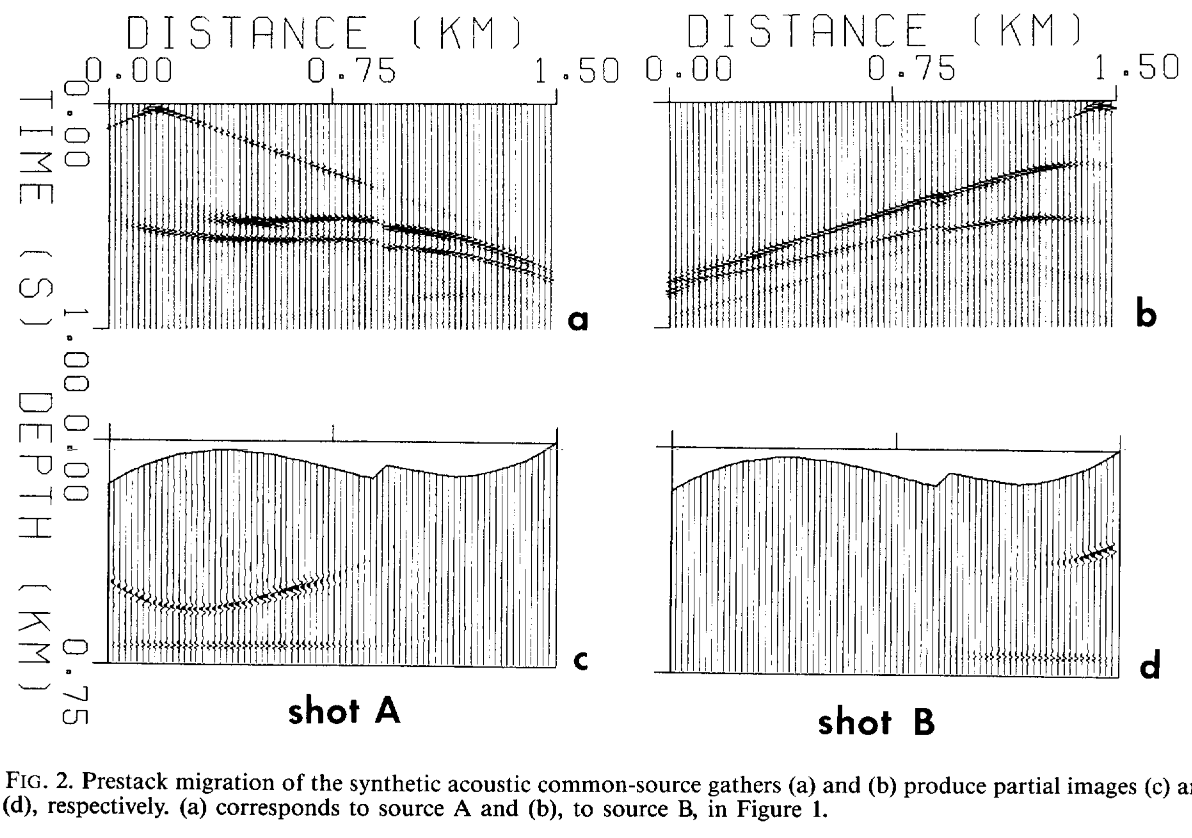

FIG. 2. Prestack migration of the synthetic acoustic common-source gathers (a) and (b) produce partial images (c) and (d), respectively. (a) corresponds to source A and (b), to source B, in Figure 1.

The key point in this example is that the common-source seismograms are extracted at grid points along (actually just below, because the pressure response is zero right on) the free surface, and so exhibit significant short- and long-wavelength shot and receiver statics. During reverse-time migration, the time reverse of these data synchronously drives the finite difference mesh from the same receiver points. Thus, a separate topographic correction is not needed since the topography is part of the model. A comparison of the migrated image (Figure 1b) with the correct solution (Figure 1a) indicates success.

Example 2: Variable near-surface velocity

The model in Figure 3a contains a strongly laterally as well as vertically varying near-surface velocity distribution beneath a flat free surface. After data preprocessing and prestack migration, as described above, the final composite migrated image is presented in Figure 3b.

In comparing the migrated image (Figure 3b) and the correct solution (Figure 3a), note that the lower reflection is correctly migrated even though no explicit static correction was applied for the complicated near-surface velocity variations. A separate velocity correction is not needed since the near-surface velocity is part of the model.

Example 3: Variable surface topography and near-surface velocity

The model in Figure 4a is a composite of that in Figures 1a and 3a; it contains strong variations in both free-surface topography and near-surface velocity. After data pre processing and prestack migration, as described above, the final composite migrated image is presented in Figure 4b.

Again, comparing Figures 4b and 4a reveals that all reflections are correctly migrated. No explict static corrections have been applied even though the topography along the line generated significant source and receiver statics in the data and there are strong lateral as well as vertical velocity variations in the near-surface (cf., Figure 4a). The fact that the lowermost (flat) reflector has been correctly imaged indicates that all effects of the complicated structures lying above it are completely compensated for, and implies that all deeper reflectors could also be correctly migrated.

DISCUSSION AND SUMMARY

The main remaining question is one raised in the section on previous research. How does one obtain a reliable estimate of the near-surface velocity distribution to insert into the model?

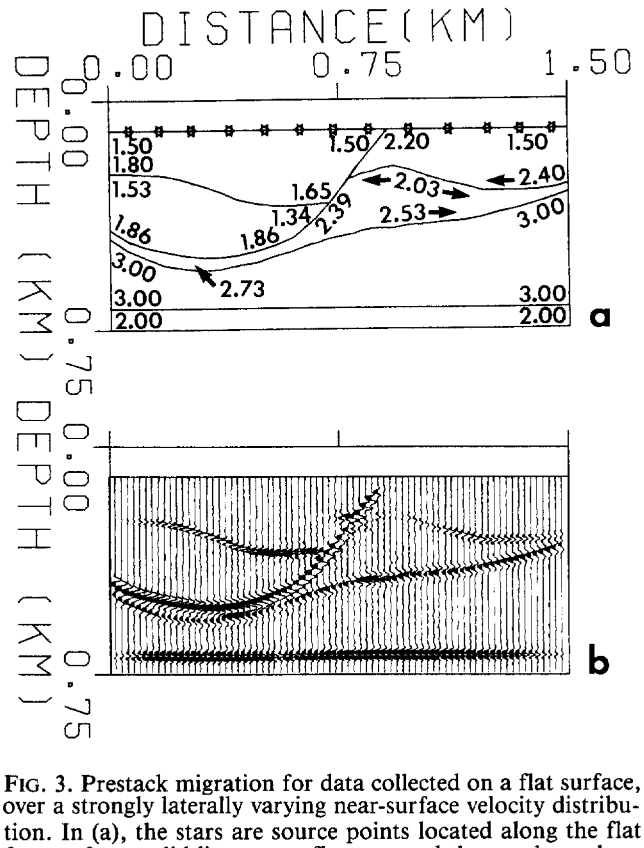

FIG. 3. Prestack migration for data collected on a flat surface, over a strongly laterally varying near-surface velocity distribution. In (a), the stars are source points located along the flat free surface, solid lines are reflectors, and the numbers along the top and bottom of the reflectors are velocities in km/s. Velocities at all other points are obtained by interpolation. (b) contains the final migrated section, obtained by stacking partial images for all 13 sources in (a). Near-surface velocity corrections are automatically and implicitly applied during migration.

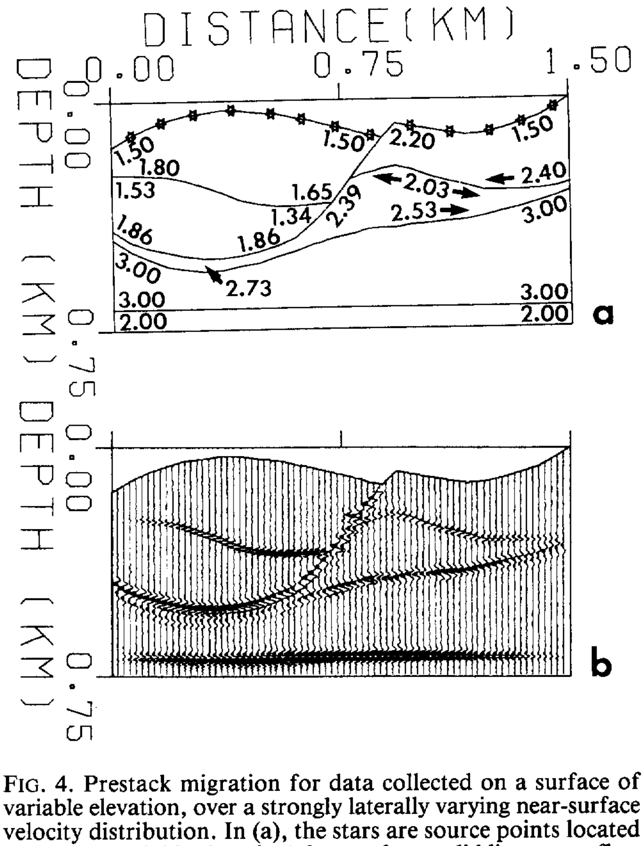

FIG. 4. Prestack migration for data collected on a surface of variable elevation, over a strongly laterally varying near-surface velocity distribution. In (a), the stars are source points located along the (variable elevation) free surface, solid lines are reflectors, and the numbers along the top and bottom of the reflectors are velocities in km/s. Velocities at all other points are obtained by interpolation. (b) contains the final migrated section, obtained by stacking partial images for all 13 sources in (a). Elevation corrections and near-surface velocity corrections are both simultaneously and autpmatically applied during migration.

Standard velocity estimation has statics corrections as a prerequisite and the latter are not available in the sequence suggested above. In the present context, statics per se are not required; only a reliable near-surface velocity distribution is. Independent velocity estimates may be obtained by refraction statics analysis or by doing a tomographic inversion for the velocity distribution (cf., Zhu and McMechan, 1989). These procedures use the first-break information that is muted prior to migration; it is interesting to note how these two parts of the wave field interact in a complete solution (cf., Mora, 1989). Tomography is also performed in the "field" coordinates without static corrections (cf., Zhu and McMechan, 1988). Thus one can visualize a completely "static-free" processing system.

While the implementation described above is 2-D, all the ideas generalize immediately to 3-D prestack acoustic (and elastic) reverse-time migration.

In summary, it is demonstrated, through synthetic examples, that static effects due to surface topography and near-surface velocity variations may be accurately included, in an implicit way, during prestack migration, rather than as separate processing steps; this requires that the topographic and velocity variations be part of the velocity distribution used for migration. Receiver statics are incorporated by extrapolating the observed data from the actual recorder positions; shot statics are incorporated by computing the excitation-time imaging condition from the actual source position.

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