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MF increases accuracy, resolution

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Although depth migration has become almost mandatory in areas of complex geology because it accounts for travel-time non-hyperbolic moveout, it has, in fact, quite a limited purpose — to convert seismic data from one form to another for a given velocity model. Time imaging provides sufficient information for a variety of subsurface models of moderate complexity. Moreover, even for complex models that require depth migration for correct subsurface imaging, time imaging usually constitutes a key first step, facilitating the estimation of a velocity model for depth imaging. For these reasons, improving the quality of time imaging remains the focus of intensive research. A recent advance is multifocusing (MF), a method developed by Geomage, which has the potential to greatly improve time imaging quality.

New moveout correction

Many researchers have sought to improve the accuracy of moveout correction. In particular, different travel-time equations have been proposed with the goal of improving the quality of common midpoint (CMP) stacking through a better alignment of reflection events within a single CMP gather. It has long been recognized that for a horizontally layered and isotropic overburden, the standard normal movement (NMO) equation is a second-order approximation (in offset) of the full travel-time expansion that can be represented by an infinite, evenly powered Taylor series. The use of higher-order approximations of this series for NMO corrections is also possible; such approximations have proven to be useful for analyzing individual CMP records. Higher-order approximations are of little use in stacking procedures, however, mainly because when performing a multiparameter search based on the same amount of data (CMP gather), the stacking procedure becomes less robust.

Studies of different travel-time equations, as mentioned above, were aimed at improving the quality of CMP stacking through better alignment of reflection events within a single CMP gather. By contrast, in the MF approach developed by Geomage, each zero-offset trace is constructed by stacking traces that need not belong to the same CMP gather but rather whose sources and receivers are within a certain vicinity of the central point. Since the traces being stacked no longer belong to the same CMP gather, such a procedure requires a more general moveout correction than the one used in conventional CMP stacking. For a given source-receiver pair, the multifo-

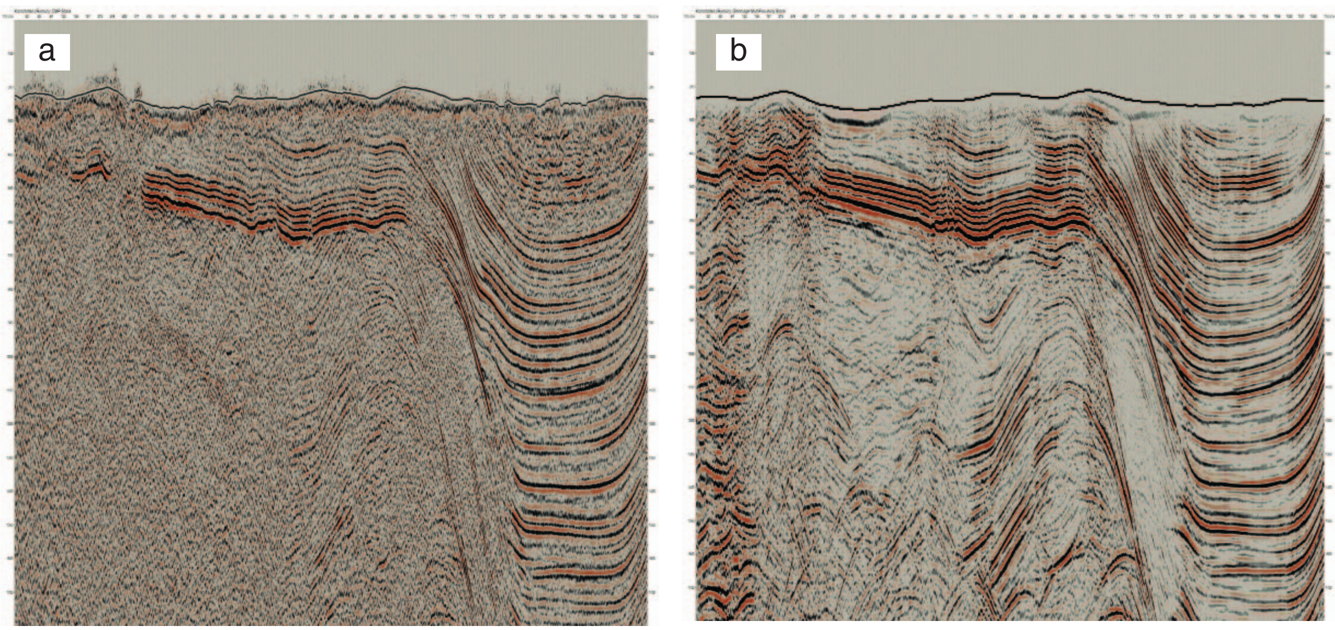

Figure 1. *CMP (a) and MF (b) stacks of 41-fold data from Kamchatka (Russia). (Images courtesy of Geomage)*

cusing moveout equation is based on the spherical approximation of a reflection event's wavefront near the observation surface.

In 2-D, this new time correction depends on three parameters measured at the central imaging point: the emergence angle of the normal ray and the radii of curvature and of the two fundamental wavefronts. In other words, the moveout correction expressed by the multifocusing formula is a three-parameter expansion of the travel-time in the vicinity of the central point. Hence, it is closely related to paraxial ray approximation.

MF travel-time formulas provide an adequate representation of arrival times for arbitrary source-receiver configurations just like the conventional NMO correction does for CMP gathers. The MF moveout correction is an appropriate basis for a stacking procedure as it can align reflection events in a large gather of seismic traces that spans over many CMP gathers. The MF correction formula is remarkably accurate even for strong curved reflectors. This can be attributed to the fact that it is not a simple hyperbolic Taylor expansion but a double square root. Implementation of the MF method is technically challenging because it requires defining three moveout parameters instead of a single parameter (stacking velocity) in standard NMO velocity analysis. Although in principle "mixing" reflection events from a number of CMP gathers (i.e., a number of depth reflection points) may compromise the spatial resolution of the resulting stacked section and make random noise appear as an interpretable signal, the Geomage implementation of a simultaneous three-parameter search mostly avoids this effect and minimizes artifacts.

Implementation

Practical implementation of MF requires the determination of three imaging parameters for each time sample. In a conventional NMO stack, the single parameter (namely, the stacking velocity) is usually determined by means of interactive velocity analysis. This analysis consists of calculating a panel of correlation measure (e.g., semblance) as a function of time and velocity and picking appropriate correlation maxima. A similar procedure for MF is impractical because an interactive procedure would have to involve displaying and picking the maxima of the correlation measure as a function of four variables.

Automatic mode is necessary. It is based on a coherency measure calculation and its analysis of the MF supergather. The procedure consists of data correction according to different travel-time curves using a time correction equation and finding parameters which correspond to the coherency measure maximum. The correlation procedure described above is repeated for each central point and for each time sample, producing an MF time section. Each sample on this section represents a stacked value corresponding to the optimal values of the MF parameters.

Advantages

There are numerous potential benefits of MF stacking as compared to the CMP stack:

- Stacking a large number of traces covering many CMP gathers can increase the stacking power and increase signal-to-noise ratio. Typically, the number of traces in the MF supergather exceeds the CMP fold by at least an order of magnitude.
- All time samples of a given reflection event on a given central trace in MF should have the same parameters within the wavelet. Thus, the moveout correction curve is parallel for all samples within the wavelet, and moveout-corrected signals are stretch-free.
- The MF moveout correction formula is a double square root equation that differs from the conventional NMO formula for CMP stacking. The formula describes travel-time behavior for a wider class of subsurface models.
- The definition of wavefront curvatures and emergence angles makes it possible to determine dip-independent velocities. Hence, MF incorporates the key property of dip moveout processing, and these velocities may be used for time migration.
- MF parameters may be estimated automatically.

Seeing is believing

The example shown in Figure 1 illustrates a case with high acquisition fold, with a dataset consisting of 1,770 shot gathers with a 246-ft (75-m) source spacing. Each shot includes 248 traces with 164-ft (50-m) spacing. The average number of traces per CMP is 96. The geology of the region is characterized by complex tectonics; it has a block structure satiated with fractures, narrow near-fault grabens, and volcano-sedimentary deposits. A complex billowy relief and outlet of basement to the surface, in addition to the geological structure complexity, result in a very noisy seismic wavefield. Standard CMP processing, including detailed velocity analysis with poststack Kirchhoff migration, provided satisfactory horizon tracing only in selected areas (Figure 1a).

Figure 1b shows the same data set after MF processing. The same preprocessing and poststack migration procedures were applied to the data. Substantial improvements over the conventional section (on the left side of the image) are obvious.

Conclusions

In summary, the MF method developed by Geomage consists of stacking seismic data with arbitrary source-receiver distribution according to a new moveout correction formula. The MF travel-time curve provides a better approximation of actual reflection travel-time than the standard hyperbolic one. In particular, MF is very effective for processing and reprocessing low-fold CMP data due to MF's noise suppression wavefield. Parameters obtained by the multifocusing method can be used for velocity model estimation and for time and depth migrations. E&P