Anisotropic prestack depth migration using the equivalent offset method

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ABSTRACT

The principles of equivalent-offset prestack time migration are applied to anisotropic depth migration. This is accomplished with the use of source and receiver anisotropic traveltime maps of depth migration to define the two-way traveltime to a scatter point. This time is then equated to a hyperbolic moveout equation that defines the equivalent offset for the scatter point. Samples from all input traces are mapped to a common scatter point (CSP) gather for each vertical array of scatter points. After the CSP gathers are formed, hyperbolic Kirchhoff NMO and stacking completes the prestack depth migration.

INTRODUCTION

Equivalent offset migration (EOM) was initially introduced as a prestack time migration (Bancroft and Geiger 1994, Bancroft et al. 1998). The time migration method combined the source and receiver raypaths (to and from a scatter point) into a single two-way raypath with zero-offset. The equivalent offset h_e, the surface distance from the scatter point to the source-receiver location, was chosen to maintain the same two-way traveltime T. Consequently, the double square-root equation for prestack traveltimes is reduced to a single square root in equation (1), i.e.

$$T^2 = T_0^2 + \frac{4h_e^2}{V_{rms}^2}, \tag{1}$$

where T_0 is the vertical two-way traveltime and V_{rms} the RMS velocity at T_0.

The value of h_e can be solved exactly from the trace geometry and RMS velocity. Energy from a scatter point at T may then be summed into a CSP gather at (h_e, T), a point that lies on the hyperbolic path of the single square root defined by equation (1). Energy from the same scatterpoint will occur in all input traces at different times and all will map to the same hyperbolic path. After all input traces have been summed into the CSP gather, Kirchhoff NMO (NMO correction that includes the scaling and filtering of Kirchhoff migration) and stacking complete the migration of the trace.

The equivalent offset h_e is time (and slightly velocity) dependent and samples from an input trace may span a number of offset bins of the CSP gather. Only those transition times when the samples change to a new bin require calculation. Consequently, input data are summed into the CSP gather with a summation loop for each offset bin. Kirchhoff NMO is delayed until the CSP gathering is complete.

Depth migration

More recently, Chernis (1998) extended the equivalent offset method to include prestack depth migration. The two-way traveltime T (approximated from the RMS velocities and the double square root equation) is computed after raytracing, or from traveltime computations.

The traveltimes of offset raypaths define the two-way traveltime T to a scatter point at a depth z_0. A hyperbolic equation may be used to define the equivalent offset h_e as

$$T^2 = \hat{T}_0^2 + \frac{4h_e^2}{\hat{V}^2} \qquad (2)$$

where $\hat{T}_0$ is an arbitrary time and $\hat{V}$ an arbitrary velocity. Choosing $\hat{V}$ to be the average velocity V_{ave}, enables $\hat{T}_0$ to be defined as the vertical two-way time to a scatter point at depth z_0, i.e.

$$\hat{T}_0 \equiv z_0 V_{ave} \quad . \qquad (3)$$

The CSP gathers may be formed in the offset - time domain (h_e, t) by summing the input traces (with no times shifting) at the equivalent offset. All the energy from a scatter point in all input traces will align on the hyperbolic path at offsets that continue to approximate the original geometry of the raypaths. When the gathering has been completed, Kirchhoff NMO and stacking create the migrated trace in time, which is then vertically stretched to depth, completing the prestack depth migration.

One advantage of the method is the reduced computations for moving each input sample to the depth location (see Chernis). Another advantage is that scattered energy is placed at an equivalent offset that is similar to the geometry of the original offset trace. Now, errors in the initial velocity model are manifested by the time location of input energy relative to the ideal hyperbolic path.

When the velocity model is relatively accurate, the CSP gather may be formed in depth (h_e, z). The equivalent offset h_e can be calculated in a manner similar to equation (2), but the energy summed directly to the point at depth z.

ANISOTROPIC DEPTH MIGRATION

The anisotropic traveltimes are computed for each source and receiver by propagating wavefronts through a gridded velocity model (Vestrum et al., 1999). Each time-increment points along a wavefront curve and is projected forward using an anisotropic ray velocity, which is generally oblique to the wavefront normal. Once the anisotropic wavefront curves have been computed for each source and receiver, a migration traveltime field for a given input trace is then calculated by adding the shot and receiver traveltimes for each point on the grid. Each input sample at time T is mapped to all depth locations (x, z) with the same traveltime.

Rather than perform the direct migration, the input data may be summed into CSP gathers at each x location using the equivalent offset defined above. Inclusion of the anisotropic parameters into the traveltime computation T passes the anisotropic effects to the CSP gathers. The application of Kirchhoff NMO, using V_{ave} followed by stacking, will complete the anisotropic prestack depth migration.

Once the CSP gathers have been formed from all the input traces, each input trace may then be correlated with model traces extracted from each CSP gather. Correlation errors correspond to the traveltime errors of the velocity model. It is hypothesised that these traveltime errors will aid in updating the anisotropic velocities of the model.

Example

The effect of including anisotropy in the computation of traveltimes is illustrated using both modelled and real data. The modelled data were acquired from a physical model of dipping anisotropic material (Isaac and Lawton 1998), which consisted of a block of transversely isotropic (TI) phenolic material, with a slow velocity axis of symmetry that dips at an angle of 45 degrees. The scaled thickness is 1500m and the anisotropic effects of the dipping beds produce a 300 m lateral displacement at the base.

Figure 1 contains two-sided CMP and CSP gathers that are normal moveout (NMO) corrected, and are ready for stacking. Figures 1a and 1b are CMP gathers, which have been formed using an isotropic and anisotropic algorithm. Similarly, Figures 1c and 1d are CSP gathers that have also been formed using isotropic and anisotropic algorithms. The offset of the CMP gathers range from –2000m to +2000m, while the CSP gathers range from –4000m to +4000m.

The effect of anisotropic migration can be observed in the difference in amplitudes on the left and right sides of the two-sided CMP gathers in (a) and (b).

The energy in the isotropic CSP gather (c) is not flat. This is most probably due to velocity errors caused by the isotropic assumption. Also note that the data appears to be symmetric around zero offset. The anisotropic CSP gather (d) has laterally displaced energy which is flatter, because the migration has moved the data to the left or in the down-dip direction of the anisotropic overburden (see Isaac and Lawton, 1998).

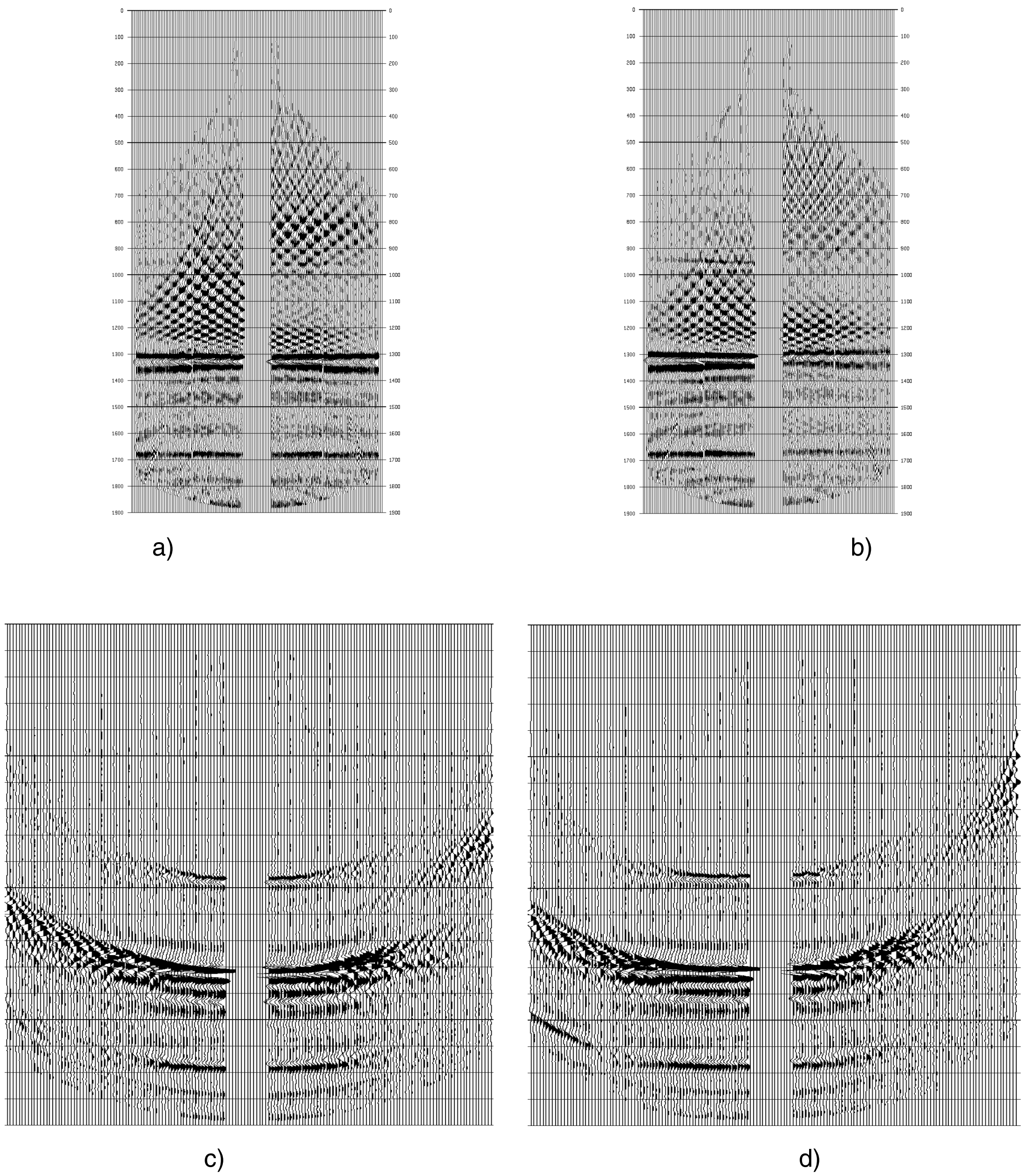
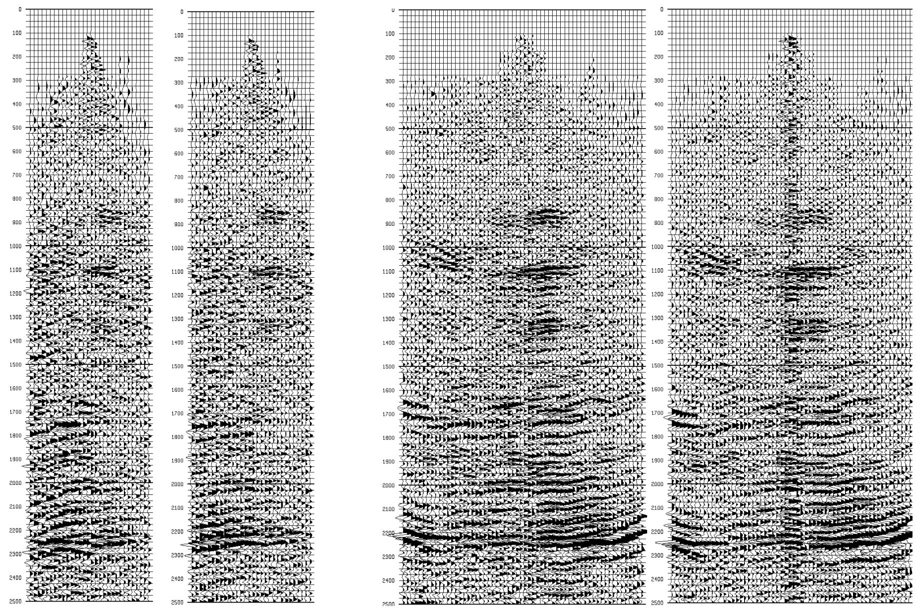


Figure 1. Comparison of CMP and CSP gathers that first ignore, then include anisotropic traveltime computations, i.e.: a) isotropic CMP gather; b) anisotropic CMP gather; c) isotropic CSP gather; and d) anisotropic CSP gather.

Figure 2 also contains CMP and CSP gathers, formed using isotropic and anisotropic velocities, from a foothills line at a location where dipping strata reaches the surface. The reflection data in the CSP gather of Figure 2d is flatter that that in figures (a), (b), and (c). Figure 3 shows conventional prestack migrations with a) having been produced with isotropic velocities and b) with anisotropic velocities. The vertical lines identify the locations of the CMP and CSP gathers of Figure 2.



a) b) c) d)

Figure 2. Foothills data example showing a) isotropic CMP gather, b) anisotropic CMP gather, c) isotropic CSP gather and d) anisotropic CSP gather.

Conclusions

Inclusion of anisotropy in traveltime computations enables CSP gathers to be accurately formed for depth migration. These CSP gathers may then be used to provide model traces for velocity analysis.

Acknowledgements

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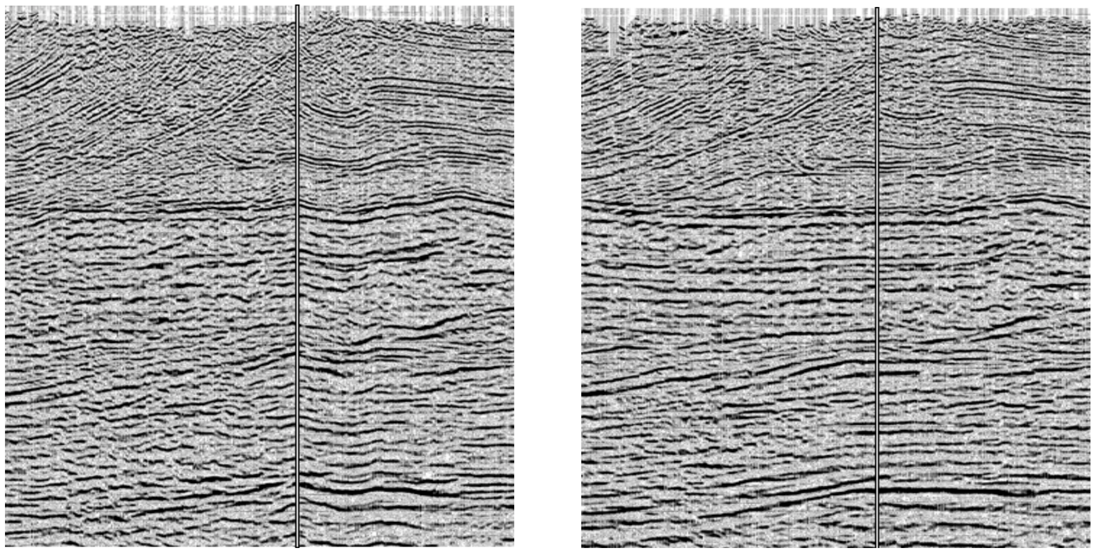

a) b)

Figure 3. Conventional depth migrated sections with a) using isotropic velocities, and b) using anisotropic velocities. The vertical lines indicate the location of the CMP and CSP gathers in Figure 2.