Migration of Shallow Reflection Data

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SUMMARY

We present an analysis of migration effects on seismic reflection images of very shallow targets. Reflection objectives in engineering, groundwater, and environmental investigations commonly occur at depths between 2 and 50 m. Because the observation surface is near these imaged reflectors, optical distortion may be so small that migration will not have any effect on the seismic image and may therefore be unnecessary. Also, because of low stacking velocities that are often encountered, vertical exaggeration of the shallowest parts of some seismic sections may make dips appear sufficiently steep to require migration. An interpreter looking at only the stacked, unmigrated section may erroneously conclude that the data should be migrated. Because shallow survey data are often processed on personal computers, unnecessary migration of a large data set can be prohibitively time-consuming and a needless use of resources. A simple set of calculations based on the "migrator's equation" predicts whether migration of an arbitrary shallow seismic section is advisable.

INTRODUCTION

In this paper we examine the apparent need to migrate very shallow, high-resolution seismic reflection data in areas of low, near-surface seismic velocities. Although typical shallow-reflection sections often show sufficient apparent dip of the bedrock surface to indicate that migration processing appears to be necessary to put the reflections in proper perspective, migration can have negligible effect on reflector geometry.

If a reflector is shallow enough, the migration operator will shift the position of data points horizontally by less than a single trace or vertically by less than a time sample. In such cases migration does not have any effect on the seismic image. Calculations based on the migrator's equation (Stolt, 1978; Robinson, 1982; Chun and Jacewitz, 1981; Uren et al., 1990) can be used to predict the degree of need for migration of shallow-reflection data.

PROBLEMS ASSOCIATED WITH SHALLOW REFLECTIONS

Targets for engineering, groundwater, and environmental projects commonly occur at "shallow" depths between 2 and 50 m. At these depths, one of the primary problems encountered is that interval velocities can vary by over an order of magnitude within individual data sets (Steeples et al., 1990). For this reason, such reflection data usually require special treatment in acquisition and processing, due to problems of scaling down from "conventional" seismic reflection surveys to a typical shallow reflection survey (Knapp and Steeples, 1986).

A second basic problem is that commonly used display parameters (in seconds/inch and traces/inch) for shallow reflection data are often different from those used to display conventional seismic reflection data, because of the small geophone group intervals and high frequencies involved. However, the ratio of reflection time (not reflection depth) to horizontal distance on a typical seismic section is about the same for the two data types.

The net result of the velocity and display scaling problems is that the vertical exaggeration of the final seismic section is often much greater for shallow surveys than for conventional surveys. Conventional surveys are commonly displayed at a vertical exaggeration of between 0.5 and two, whereas shallow reflection surveys are commonly displayed at vertical exaggerations of three to five. An interpreter who sees only the stacked, unmigrated section may erroneously conclude that migration is needed.

QUANTITATIVE EFFECTS OF MIGRATION

There are several basic principles associated with the effects of the migration process. Three of these principles govern the geometric relationship between a dipping reflector segment before and after migration (Chun and Jacewitz, 1981; Yilmaz, 1987). Migration (1) steepens reflectors, (2) shortens reflectors, and (3) moves reflectors in the updip direction (Figure 1). These principles are only approximations, because migration does not perform a strict point-to-point mapping. However, these ideas are useful tools for discussing the approximate behavior of dipping events and individual points on finite-length reflectors during the migration process.

The qualitative seismic-event migration described above can be quantified using methods derived from the so-called migrator's equation (Stolt, 1978; Robinson, 1982; Chun and Jacewitz, 1981; Uren et al., 1990). Chun and Jacewitz (1981) modified the migrator's equation to derive several simple formulas that describe the approximate movement of points on a dipping reflector from unmigrated to migrated time and depth sections. The formulas describing this movement for true depth migration in x-z space are:

$$d_x = z \sin \Theta_{mz} , \quad (1)$$

and

$$d_z = z (1 - \cos \Theta_{mz}) , \quad (2)$$

where Θ_{mz} is true dip angle on the depth section, d_x is the distance the point moved in the x-direction during migration and dz is the distance the point moved in the z-direction during migration (Figure 1). These formulas show that both components of movement during depth migration are linearly scaled by depth (z), which is one fundamental reason that migration of shallow reflection data may not be necessary.

The problem with using the depth factor for analysis is that the vast majority of seismic work is performed using seismic time sections, not depth sections. The formulas (modified from Chun and Jacewitz, 1981) can be rewritten in time-migration terms as:

$$\begin{aligned} d_x &= (v^2 t \tan \Theta_{ut}) / 4 , \\ &= v^2 t\, D_{ut} / 4 , \\ &= vz\, D_{ut} / 2 , \end{aligned} \quad (3)$$

$$\begin{aligned} d_t &= t \{ 1 - [1 - ((v \tan \Theta_{ut}) / 2)^2]^{1/2} \} , \\ &= t \{ 1 - [1 - (v D_{ut} / 2)^2]^{1/2} \} , \end{aligned} \quad (4)$$

where v is the rms velocity, t is two-way traveltime, and Out is the apparent dip angle of the reflector on the stacked, unmigrated time section. Θ_{ut} is an awkward value to work with because of the mixed units on the time section. The value Dut (equal to tan Θ_{ut}) is a more intuitive measure of the time dip. D_{ut} is the dip on the unmigrated time section expressed in s/m. Again, the result dx is the distance a given point (x,t) is moved by a migration in the x-direction, and dt is the equivalent distance moved in time. Obviously, if d_x and dt are less than the CDP spacing and the time sampling interval, respectively, then migration makes no discernible change in the stacked section. The CDP spacing and the sampling interval are thus the absolute limits on migration resolution. In practice, if d_x and d_t are equal to only a few sample intervals, the changes made in a section by migration are significant only if a detailed stratigraphic interpretation is required.

Chun and Jacewitz (1981) were also able to plot the relative change in position for different velocities and constant apparent dip. A plot similar to theirs (Figure 2a) illustrates the effect of velocity on the combination of d_x and d_t discussed above. Migration moves the apparent position of a point on a dipping reflector updip an amount (d_x,d_t) in x-t space. The updip change in apparent position is a function of velocity (Figure 2a). As the migration velocity is increased, the position of the point traces an arcuate path away from the unmigrated position in x-t space.

REAL DATA EXAMPLE

As a practical example, we will use an unmigrated seismic section presented by Miller et al. (1989) that shows prominent bedrock reflections from depths of about 10 m (Figure 3). Although this typical shallow-reflection section shows sufficient apparent dip of the bedrock surface that migration processing appears to be necessary to put the reflections in proper perspective, migration has negligible effect on its appearance (Figure 4).

A plot similar to figure 2a (Figure 2b) was made using parameters similar to those associated with the data from figures 3 and 4. Assuming the reflector is at 0.067s, with the maximum apparent dip seen in figure 3, the change in position with two different migration velocities were compared. Although the position of a point on the reflector at 0.067s changes greatly when migrated with an unrealistically high velocity of 3000 m/s, the point is barely moved using the true migration velocity of 300 m/s (Figure 2b).

The change in position was also compared with the limits of resolution (Figure 2b) for common shallow, very-high-resolution survey parameters used in acquisition of the example data (0.6 m CDP spacing, 0.5 ms sample interval). The change in position is significant for the high-velocity case, but is actually less than the absolute resolution limits of the data in the low-velocity case. In practice, a change in position would have to be several traces and/or several time samples in magnitude to be noticeable on most seismic sections.

CONCLUSIONS

Shallow targets less than 50 m deep are being imaged regularly with seismic reflection methods. In many cases the stacking velocities used in these surveys are an order of magnitude lower than velocities found in standard petroleum surveys. Commonly used plotting parameters result in a vertical exaggeration factor of three to five on shallow seismic sections. As a result, dips appear to be three to five times steeper than reality.

In a constant-velocity medium with fixed reflector dip, the lateral movement of the reflected energy during migration depends only on the reflector depth. Shallow reflectors are sometimes sufficiently close to the earth's surface that migration provides little if any image improvement for the interpreter. This effect is analogous to a person standing close enough to a distortional mirror that the distortion is negligible. The closer the seismic line is to the target, the less the need for migration.

By applying simple formulas, such as a modification of those derived by Chun and Jacewitz (1981), it is possible to predict whether a standard migration operator will significantly affect the interpretation of a stacked section.

Because many large, shallow-reflection surveys are processed commercially on personal computers, unnecessary migration can waste significant amounts of computer and personnel time. Analysis of the type described here predetermines whether migration should be included in the contracted processing flow.

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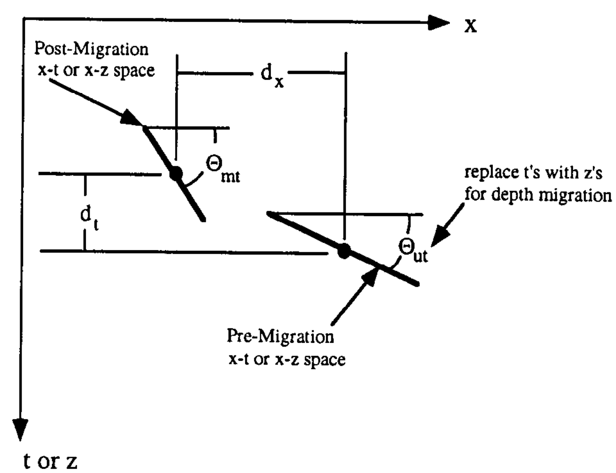

Figure 1) The approximate behavior of points on a reflection under migration (after Chun and Jacewitz, 1981). Migration moves points updip, steepens reflectors, and shortens reflector segments. The effect of migration on individual reflectors can be monitored by the calculation of change parameters dx,dt, and the change in dip. Formulas for the calculation of these parameters are given in the text.

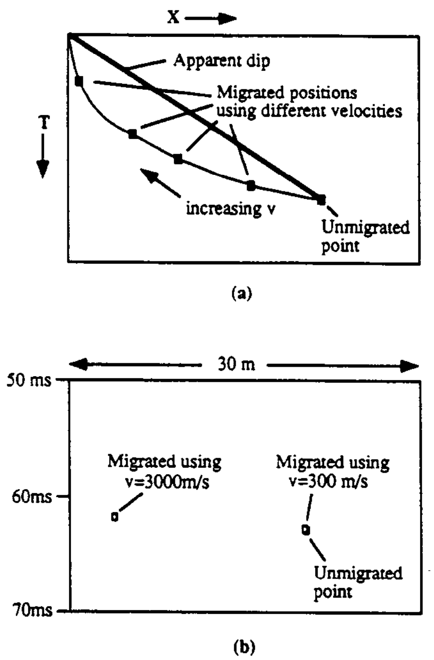

Figure 2) (a) Approximate behavior of a single point on a dipping reflector migrated in x-t space. Migration with higher velocities moves the point a greater distance in the x-t plane. (b) Detailed view of a portion of 'shallow' seismic x-t space comparing the behavior of a point on the steepest dipping reflector from figure 3 migrated with two different velocities, 300 m/s and 3000 m/s. The size of the points reflects the absolute limits of resolution on the seismic section of figure 3. Note that while the high-velocity migration significantly changes the position of the point, the low-velocity migration fails to move the point a resolvable distance.

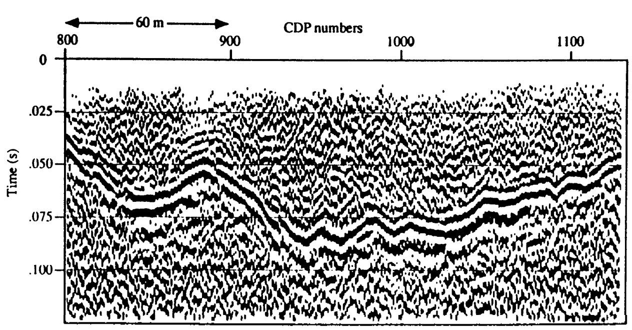

Figure 3) Stacked shallow, high-resolution seismic reflection section from the Texas Panhandle. Details are given in the text.

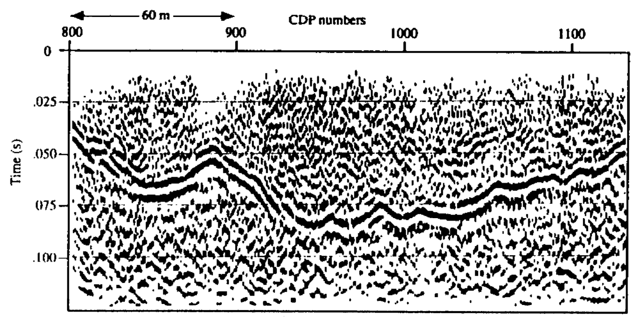

Figure 4) Constant velocity F-K migration of the stacked section shown in figure 3. Note that while changes in the section are obvious in areas of edge effects, there is little discernable change in the reflection character. In this case, subsurface interpretations based on the stack and the migration would not differ significantly enough to warrant migration of the data.