Common-Offset Depth Migrations and Traveltime Tomography

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SUMMARY

Many methods of depth migration velocity analysis emphasize well-focused images. Others linearize and invert the effect of perturbed velocities on migrated images. We prefer to use developed methods of reflection traveltime tomography by converting picked migrated reflections into equivalent multi-offset traveltimes.

Migration benefits prestack picking by simplifying reflections and diminishing noise. Depth migration does not add information to reflections, however. In fact, the bias of a poor velocity model should be removed. Conventional dynamic ray methods, or extrapolated traveltime tables suffice for the estimation of prestack traveltimes (geometric modeling). We need only find the midpoint that reflects from a migrated point at the correct angle and offset.

Constant-offset sections of a North Sea line were independently migrated in depth and viewed on a 3D interpretive workstation. One reflection at the base of chalk imaged at inconsistent depths over offset. This and other reflections were picked over a range of offsets. Equivalent prestack traveltimes were modeled through the migration velocity model. The chosen method of traveltime tomography implicitly encouraged consistency in common-reflection points for raypaths at various offsets. The final estimated velocity model showed an increase in velocities near the base of the chalk, then a decrease in velocities below. Remigration of the data with the revised velocities greatly increased the visibility of the reflection at the base of the chalk.

INTRODUCTION

Velocity analysis of seismic data after prestack depth migration has largely concentrated on better focused images of reflectivities (e.g. Jeannot et al, 1986; Al-Yahya, 1989; and MacKay and Abma, 1989). Others have formulated tomographic methods that directly optimize the effect of velocities on migrated depths (Fowler, 1988; Etgen, 1990; van Trier, 1990). Velocity models are expected to produce consistent images in depth from independently migrated gathers: common-offset, common-shot, or even common-midpoint. Iteratively linearized inversions can perturb velocity models and reduce these inconsistencies.

Alternatively, we prefer to use prestack depth migrations as a source of information for methods of reflection traveltime tomography, such as Sattlegger et al (1981), Bishop et al (1985), Bording et al (1987), Sword (1987), Dyer and Worthington (1988), Sherwood (1989), Harlan (1989), and Stork and Clayton (1991). Researchers who previously picked unmigrated traveltimes can improve the quality of their data. Those interested most in depth migration can benefit from simpler algorithms, with broader application, and without loss of accuracy.

AN EXAMPLE OF DEPTH MIGRATION ERRORS

Figure 1 displays the prestack depth migration of a line from the Netherlands' North Sea (spanning 11 km of midpoints and 5 km depth). Constant-offset sections were migrated independently, then stacked over offset to produce a single image. The original velocity model was largely stratified and only increased with depth.

When the unstacked cube of migrated data was examined on a 3D interpretative workstation, some reflections were seen to align poorly over offset. Figure 2 shows the picks of migrated reflections at various offsets. The reflector near 2500 m depth lies beneath a 1000 m thick interval of chalk and shows considerable inconsistency. The chalk velocity cannot be adjusted to flatten this one reflection, without spoiling the images of deeper reflectors. Although the result may appear close to a solution, it is not.

MIGRATING FOR SIGNAL ENHANCEMENT

After prestack depth migration, a cube of unstacked reflection seismic data can become considerably easier to interpret and pick. Migration improves signal-to-noise ratios by averaging random noise over midpoint. Migration also simplifies reflections from structure with high curvature (particularly diffractions), reduces overlapping of events, and allows easier correlation over offset.

Depth migration does not add information to observed reflections, however. If anything, depth migration adds the bias of a particular velocity model that, good or bad, describes only our previous assumptions. If we choose migration velocities only to improve the quality of picks, then we may prefer to initialize a tomographic algorithm with other models. A visible reflection carries the same traveltime information no matter what migration velocities are used.

REFLECTION TIMES FOR TOMOGRAPHY

To remove the bias of the first velocity model from the picks in figure 2, we need only convert to equivalent prestack traveltimes. In other words, we use geometric constant-offset modeling: find surface midpoints that reflect from picked reflectors at the proper locations, angles, and offsets. The prestack traveltimes (and their spatial derivatives) are given by the estimated raypaths through the reference velocity model.

Conventional methods of dynamic ray shooting or relaxation suffice for this modeling step. Explicit extrapolation and tabulation of traveltimes are recommended for their simplicity and speed (Vidale, 1990; van Trier, 1990; and Moser, 1991).

The chosen method of reflection traveltime tomography must implicitly encourage consistent images of common-reflection points. For example, Harlan et al (1991) minimize the variance of displacements necessary for a reflection point to fit traveltimes at various offsets.

Figure 3 shows estimated transmission velocities and reflection geometries. The estimated raypaths fit modeled traveltimes to within a quarter wavelength. Note that velocity increases near the bottom of the chalk, then decreases again below. Well logs in the area show chalk with similar changes.

Figure 4 shows a remigration of the data with revised velocities. This time, the reflection at the bottom of the chalk appears very strong, as it does before stack. No further iteration was necessary. If inconsistencies had remained over offset, then repicking would not have helped unless new reflections became visible before stack. In this case, revised velocities affected only the migrated depths of reflectors before stack, not their coherence or strength.

CONCLUSIONS

Already existing tools for reflection traveltime tomography are easily adapted to prestack migrated data. Migration eases picking by improving signal-to-noise ratios and by simplifying the appearance of reflections. Those interested only in migrated images will benefit from using a more general algorithm, capable of incorporating traveltime information from other sources. For example, migrated impulsive noise can create large arcs, or "smiles," which interfere with picking. Post-migration picks can be converted and combined with pre-migration picks, with picks from automatic velocity analyses, etc. One tomographic algorithm can serve for many varieties of data.

No repicking of data appears ever to be necessary, unless to remove multiples, cycle skipping, or other mistakes. Traveltime tomography is sufficiently iterative to allow for the non-linearities of ray-bending, constrained velocities, and so on. If tomographically estimated velocities and reflectors do not fit the picked data, then the picks may not be consistent with the physical assumptions. Some reflections may be sideswipe (out of plane), multiples, or influenced by anisotropy. Tomography provides the best estimate of migrated depths from surface information alone. Focusing analysis can remove any remaining unexplained inconsistencies.

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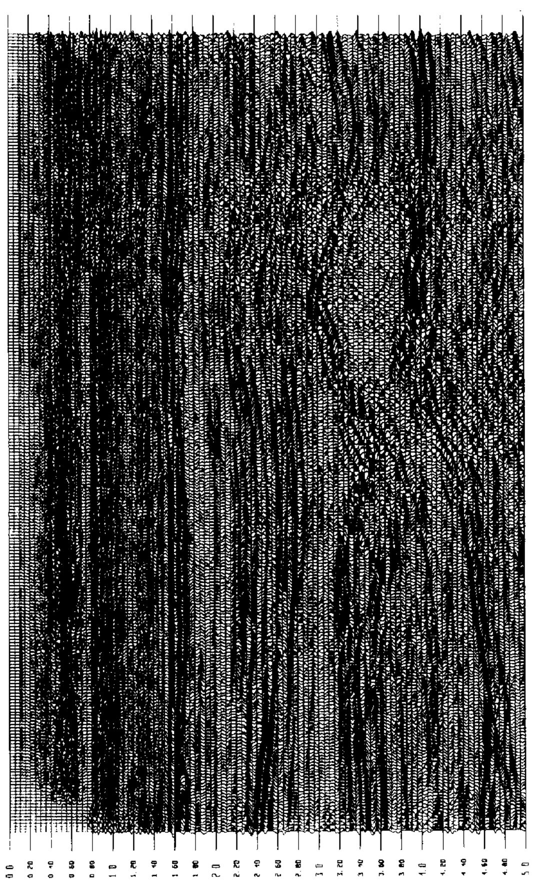

FIG. 1. Prestack depth migration of Netherlands North Sea data with simple stratified velocity model. Spans 11 km.

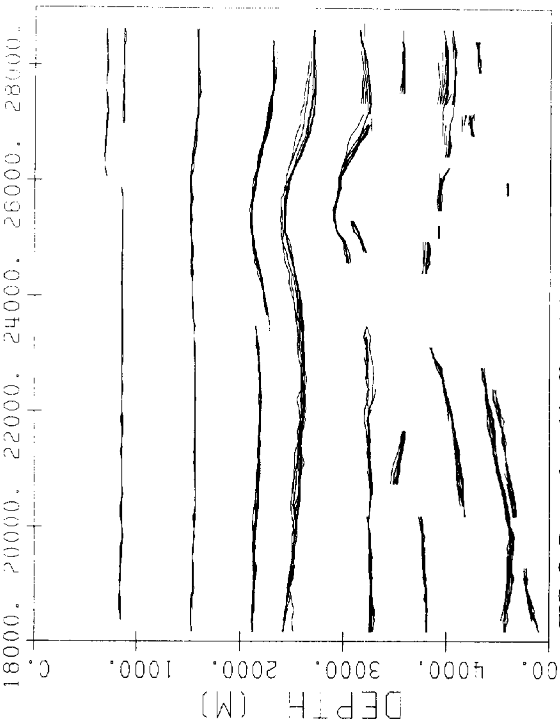

FIG. 2. Prestack multi-offset picks of reflectors after depth migration. Reflector at 2500 m depth is most inconsistent.

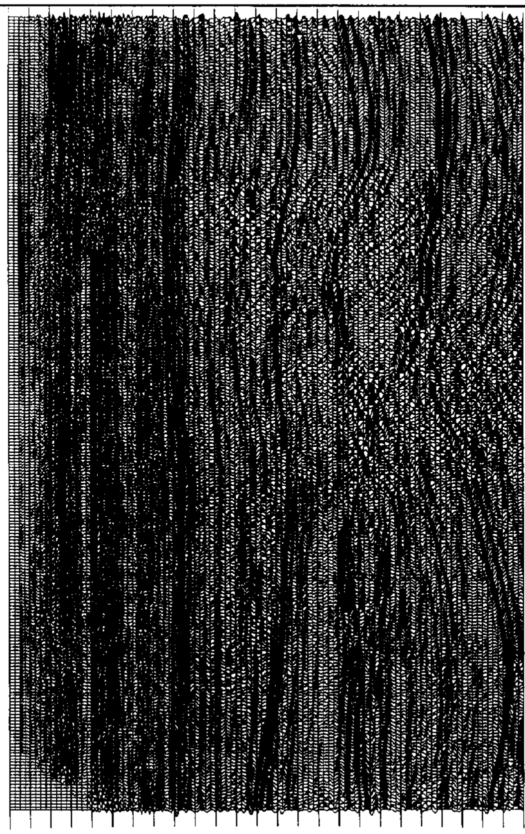

FIG. 4. Prestack depth migration with revised velocities. Local gain applied. (All sections span same dimensions.)

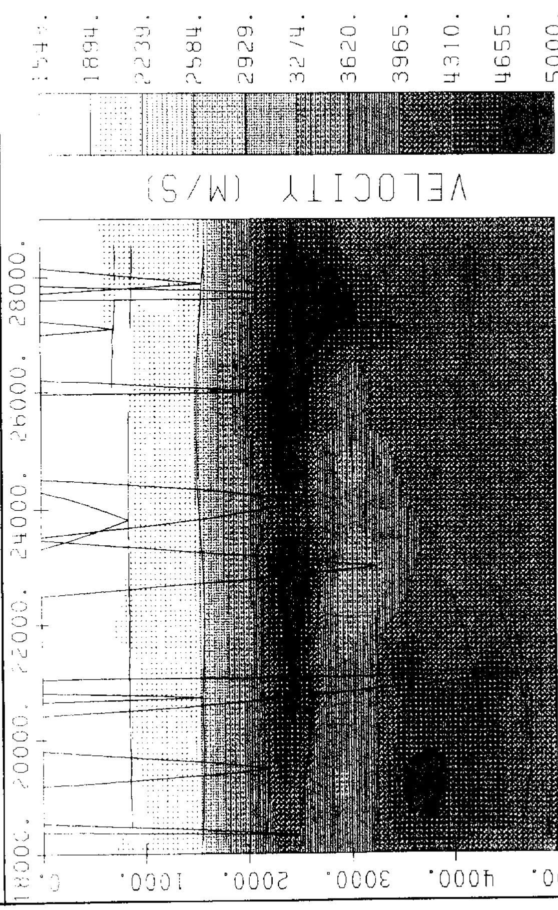

FIG. 3. Estimated transmission velocities and reflectors.