T37 Optimal velocity models for wavefield continuation migration

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Summary
For optimal imaging results, velocity model updates must be based on image gathers derived from the same migration engine that is used in the final imaging. We demonstrate that Kirchhoff or hybrid velocity analysis schemes do not provide optimum velocity models for wavefield continuation depth algorithms, and that integrated wavefield continuation velocity modeling and imaging solutions produce the most accurate image where multipathing due to irregular interfaces with high velocity contrast are present. We show that the accurate and high resolution construction of the top salt is fundamental to subsalt imaging. To obtain high-resolution detail in the salt model we need to run wavefield continuation migration velocity analysis on a fine grid spacing. We show that wavefield continuation migration provides a sharper top salt image and reveals details unseen in the Kirchhoff image. This allows us to pick the salt body more accurately and to improve the image of the subsalt target with the corrected velocity model.

Introduction
The velocity model is the most important component of an optimal migration result; however, there is substantial disagreement as to what is the best way to build a velocity model. The recent proliferation of 3-D migration methods has led to various different velocity building strategies; in particular, many wave-equation migration imaging projects rely on velocity models that are built using Kirchhoff migration. These strategies typically involve preliminary target line or sparse CRP Kirchhoff migration, and subsequent velocity model updates based on residual curvature analysis from Kirchhoff migrated gathers.

We advocate a velocity model updating approach that relies on angle-domain common image gathers in the reflection angle domain output directly from the wave equation migration (Prucha et al., 1999). Residual velocity associated with each subsurface image point is determined from semblance scan of common image gathers over a plausible range of values followed by automated picking. The extracted residuals are then tied to geologic horizons and used to modify the velocity model via vertical, normal-ray, or tomographic update (Liu et al., 2001).

In this case study from the Foldbelt of the Gulf of Mexico, we show that common azimuth wavefield-continuation migration (Biondi and Palacharla, 1996) results in a better characterization of the salt-sediment interfaces, which in turn allows the construction of a more accurate velocity model and thus an iterative improvement of the seismic image. For optimal wavefield continuation imaging, the migration velocity model is built by iterative wavefield continuation migration. The limitations in 3-D Kirchhoff depth migration methods become obvious in this case study where a deep Gulf of Mexico salt body is characterized by rapid changes in topography and small-scale rugosity of its top surface. Common azimuth wavefield continuation migration sharpens the top salt image and reveals details unseen in the Kirchhoff image. This allows us to pick the salt body more accurately and to improve the image of the subsalt target with the corrected velocity model.

Kirchhoff and wave-equation imaging
This study uses a 3-D dataset acquired over an extensive salt body in the deep Gulf of Mexico. In absence of the salt body, the local velocity structure is fairly simple. The background sedimentary P-wave velocity model does not deviate significantly from a 1-D linear Gulf-of-Mexico gradient with 1700 m/s near the seafloor and reaching 3500 m/s at 12750 m depth below sea level. The salt body is modeled as a constant velocity body with a P-wave velocity of 4500 m/s. The salt body itself sits in a depth range between 2300 and 8000 m and has a complicated shape that changes rapidly both in the

inline and crossline directions. The top of salt is characterized by steep flanks, narrow canyons, and a generally rugose surface topography (Figure 1). The initial velocity model is based on previous best-effort Kirchhoff processing of the entire dataset.

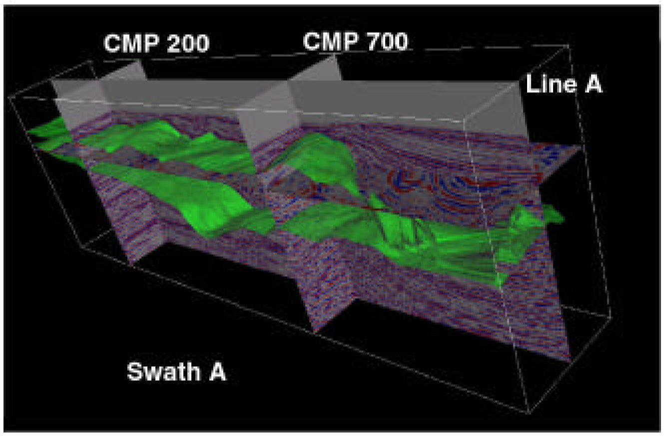

Figure 1. Perspective 3-D view of a swath through the Foldbelt data set. The Wave equation migration and salt body are shown. The rugose top and base salt surfaces are shown in green.

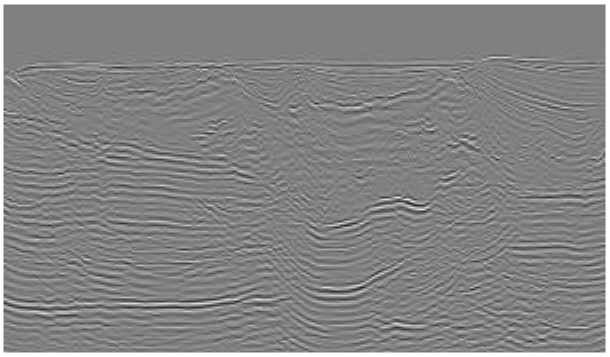

Figure 2: Target line Kirchhoff migration.

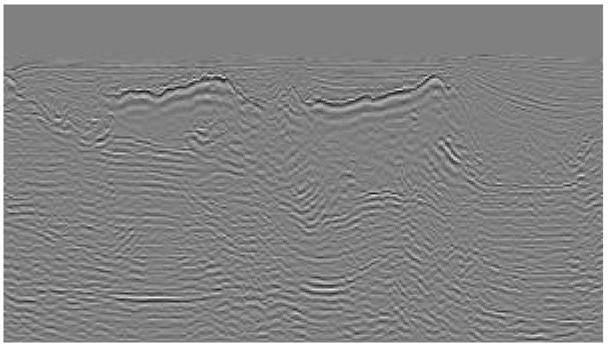

Figure 3: Wavefield continuation migration.

Figure 2 displays a line through the Kirchhoff migrated volume. Overall, the saltbody is well imaged, but the sub-salt sedimentary reflectors are disrupted by strong migration artifacts ("smiles") in several locations. The base salt reflector is not clearly delineated in several locations below these problematic top salt areas. The deterioration in subsalt reflector continuity can clearly be traced to the problems in defining the shape of the overlying salt body (Paffenholz *et al.,* 2002).

The wavefield continuation image of the same target line, migrated with the same velocity model as the Kirchhoff image, is displayed in Figures 3. A comparison with the Kirchhoff image shows improvements in the top salt reflector definition, and while the subsalt image also shows improvement, there is some deterioration in the base salt and sub-salt reflectors: clearly the same velocity model is not optimal for both types of migration. Furthermore, artifacts in the Kirchhoff image generated by sharp corners at the base of the salt body are clearly reduced in the wavefield continuation image. To effectively update the velocity model, the shape of the salt body must be delineated more accurately. The Kirchhoff migrated image cannot be used to repick the salt body because the top salt is sometimes blurry and key top salt reflections are sometimes missing in critical areas (Figure 4). Multiple raypath and focusing effects associated with the rugged top salt topography are better handled with wavefield continuation methods. Starting with the same initial velocity model, the image resulting from prestack wavefield continuation migration will be a better starting point for determining the shape of the salt body.

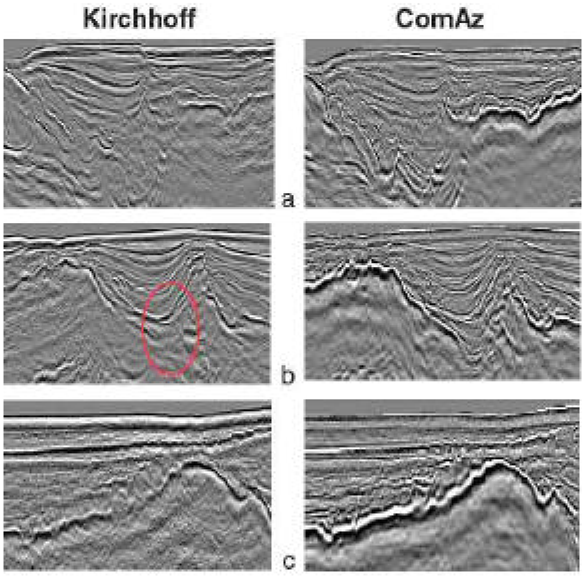

Figure 4. Closeup of top salt details for Kirchhoff on the left and wavefield continuation (ComAz) on the right. A detailed comparison of the top salt surface that is characterized by steep flanks (top), deep and narrow canyons (middle), and small-scale rugosity (bottom), reveals the limitations of the Kirchhoff imaging. The wavefield continuation image is sharper, more continuous and reveals details of the top salt topography. The clearer image of the deep and narrow canyon in the top of the salt body (Figure 2 middle) leads to a substantive revision in the interpretation of the top salt horizon.

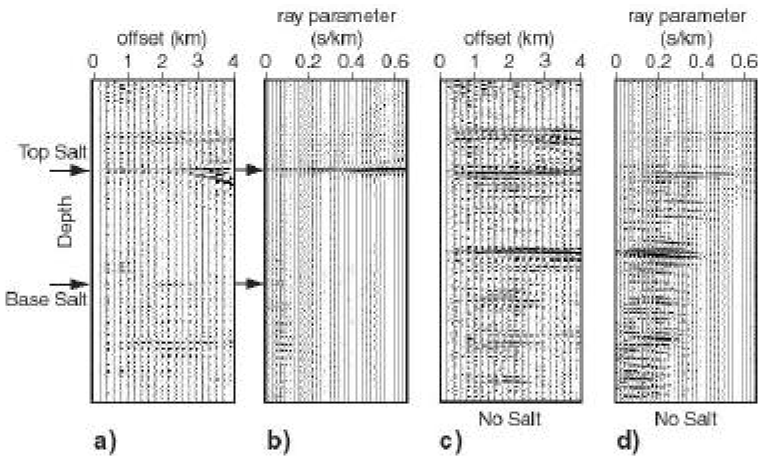

Figure 5. (a) Offset domain (Kirchhoff) CIG and (b) angle domain (ComAz) CIG with salt present; (c) offset domain CIG and (d) angle domain CIG without salt present. Note that angle domain CIGs show moveout on reflectors that are flat in the offset domain, an indication that Kirchhoff migration velocity analysis does not result in the optimal model for wavefield continuation imaging.

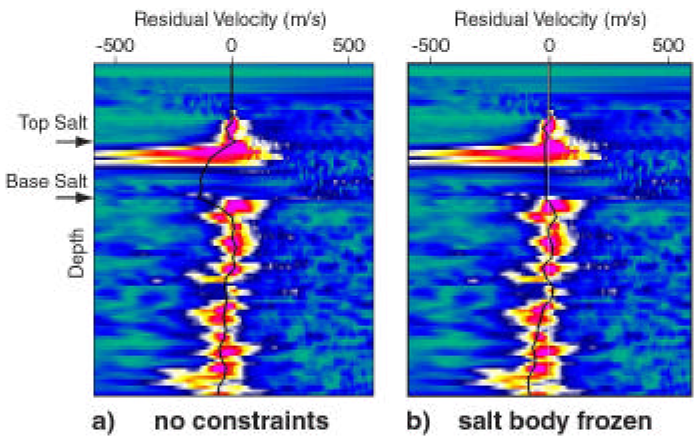

Figure 6. Residual velocity semblance spectra and automatic residual pick (black); (a) salt body included into picking, (b) salt body excluded from picking.

Wavefield Continuation Velocity Model Updating

In contrast to Kirchhoff migration, common azimuth wavefield continuation produces common image gathers (CIGs) in the ray parameter (angle of incidence) domain, not the offset domain. One of the advantages of angle domain gathers is that they show more clearly than offset domain gathers the narrowing of the data aperture with depth after the seismic signal passes through the high-velocity salt body (Figure 5) due to the fixed offset range at the surface.

For residual moveout correction, we calculate semblance spectra for a subset of CIGs (Figure 6a). The generally small deviations of the semblance peaks from the zero residual velocity line outside the salt confirm that the simple background velocity model for the sediments is fairly accurate. From the semblance gathers, residual velocities are picked automatically (excluding the water layer and the salt body; Figure 6b). Properly smoothed, the velocity residuals are then applied to all CIGs as a hyperbolic moveout correction. After updating the velocity and remigration, the termination of the subsalt sediments against the salt keel and therefore the definition of the base of salt is improved and the strong sub-salt reflector is more continuous (Figure 7).

Since the velocity structure of the Gulf sediments is fairly simple and the salt body can be well approximated by a constant velocity body, the main improvements in image quality come from a better delineation of the salt body in the migration velocity model. The sharper salt body image achieved by the common azimuth wavefield continuation migration enables us to pick the shape of the salt body in more detail. We then insert the new salt body into the background (sedimentary) velocity model and remigrate (Figure 7). Because of the large velocity contrast between sediments and salt, even subtle changes in the shape of the salt body lead to substantial improvements in the continuity of base salt and subsalt reflectors (Figure 7).

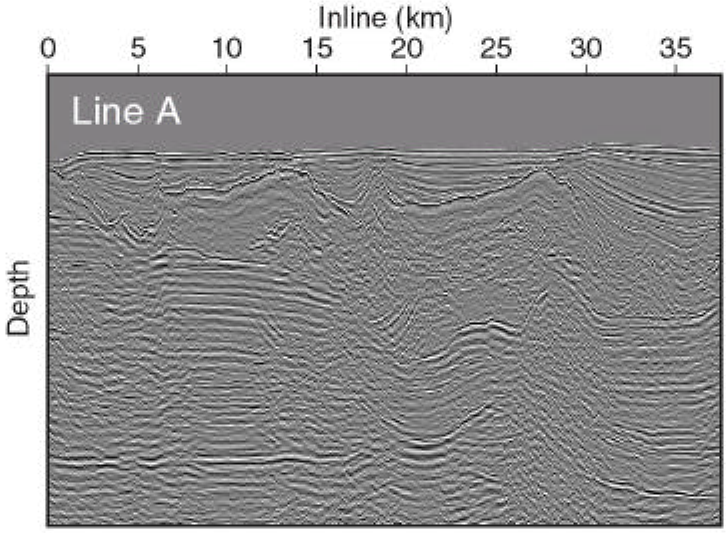

Figure 7. Wavefield continuation migration after velocity updating. The top salt and base salt are more clearly defined, and the truncation of sediments agains the base salt flank is now clearly imaged in comparison to Figure 2 and 3. Subsalt reflectors are more continuous, and interpretation of the subsalt sediments on the lower right changes dramatically.

Conclusions

We show that wavefield continuation migration by a common azimuth method dramatically improves the imaging of complicated salt/sediment interfaces compared to Kirchhoff migration methods. The initial velocity model derived from previous best-effort Kirchhoff processing does not provide an optimal velocity model for wavefield continuation migration. Velocity model building by iterative wavefield continuation migration is crucial for an optimal image. The wavefield continuation image reveals more details of the top salt topography and suppresses migration artifacts generated at sharp corners of the salt body. The resulting better delineation of salt bodies in the migration velocity model leads to better continuity of subsalt target horizons and sharper fault definition.

References

Biondo, B., and Palacharla, G., 1996, 3-D prestack migration of common-azimuth data, Geophysics, 61, 1822-1832.

Liu, W., Popovici, A., Bevc, D. and Biondi, B., 2001, 3-D migration velocity analysis for common image gathers in the reflection angle domain, 71st Ann. Internat. Mtg., Soc. of Expl. Geophys., Expanded Abstracts.

Paffenholz, J., Stefani, J., McLain, B., and Bishop, K., 2002, SIGSBEE_2A synthetic subsalt data set—image quality as function of migration algorithm and velocity model error: 64th Conference and Exhibition, EAGE, Extended Abstracts.

Prucha, M., Biondi, B. and Symes, W., 1999, Angle-domain common image gathers by wave-equation migration, 69th Ann. Internat. Mtg: Soc. of Expl. Geophys., 824-827.

Acknowledgments

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