Building High-Resolution Velocity Models in the Gulf of Mexico with Wave-equation Depth Migration

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Summary

Obtaining an accurate velocity model is fundamental to successfully imaging complex salt bodies in the deep Gulf of Mexico. With the introduction of faster, full volume wavefield solutions that output finely-sampled angle gathers, velocity models can be constructed allowing the full potential of the wavefield method to be applied to our most complex subsurface problems. We present a case history of building a high-resolution velocity model in the Gulf of Mexico, using multiple iterations of wave-equation migration and angle common image gathers (ACIG). We show how in certain instances picking in depth slices can build more detail in the velocity model, and how we integrated well log information and other stratigraphic geological information into the velocity model in collaboration with the interpreter team, to produce an optimal depth migrated image.

Introduction

In his observations on the SEG 2002 Annual Meeting, Ritchie (2003) discusses the imaging trends in the industry, and makes the points that as the depth imaging methods move from ray-based (Kirchhoff) to wavefield schemes:

- Finely-gridded angle gathers are needed to build the velocity model to precisely define local velocity details.
- The velocity model integration in the wave-equation workflow is critical. In other words combining Kirchhoff-produced sparse offset gathers to build the velocity model with wave-equation imaging may not capture all the details in areas where multi-pathing occurs.
- Shot-Profile shortcuts like data decimation, reduced aperture or the inability to produce gathers are not acceptable by the knowledgeable clients.

An accurate velocity model is essential in successful subsurface imaging (Fliedner et al., 2002; Liu et al. 2001). Algorithm comparisons on model data where the velocity model is known are interesting but don't address the real problem: under complex geologic conditions, how do we find the velocity model to drive the algorithm? We need to fully represent high contrast and short wavelength velocity variation details by performing full volume depth migration with *finely sampled* velocity analysis (25 x 25m, not 500 x 500m). We need to rely heavily on automated picking tools with graphical aids to easily and quickly high-grade results, as the number of ACIGs is in the tens of millions. Using gridded, not layered, models is a more natural, easier to control, well-resolved representation. Model updating flexibility is required, as 3-D tomography becomes a standard tool. The interpreter's input in the construction of the velocity model is important for sub-regional detail and geologic plausibility. We need to include anisotropy corrections for accurate spatial positioning.

Data regularization for wave-equation imaging

Azimuth moveout (Biondo et al., 1998) is a wave-equation correct re-gridding algorithm that handles dipping geological strata and variable velocity accurately, and is an

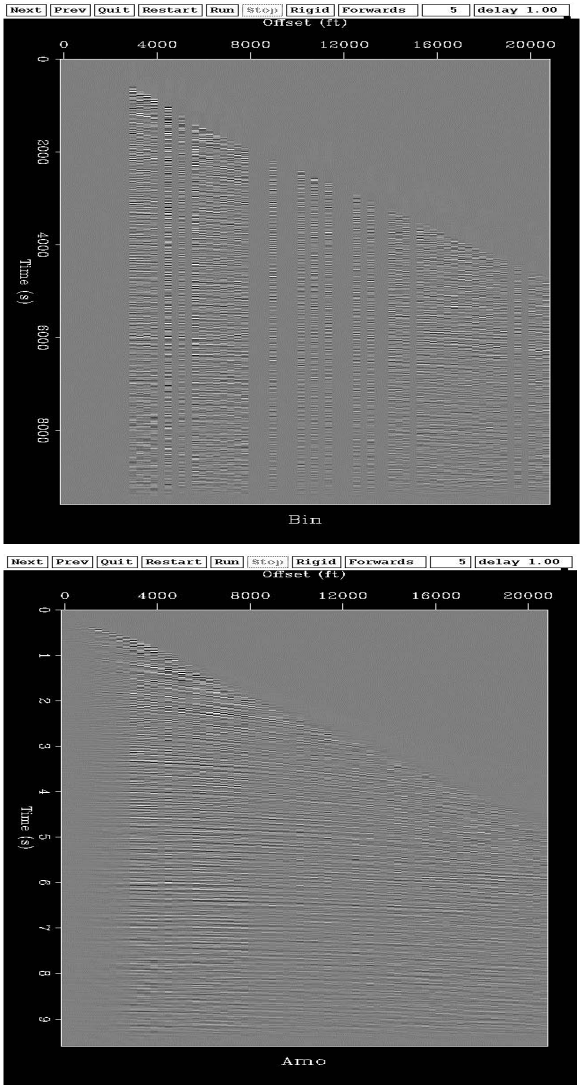

Figure 1: CDP gather before and after AMO.

essential tool for preparing data for any wave-equation migration method. The resulting 3-D prestack dataset can be used as input to wave-equation 3-D prestack migration algorithms like Common Azimuth Migration (Biondi and Palacharla, 1996). Figure 1 shows comparisons of CDP gathers before and after AMO.

Wave-equation imaging improvements and steep dips

Common Azimuth migration (ComAz) allows many more fine grained velocity iterations than Shot Profile migration (SPM). ComAz can generate accurate gathers (SPM cannot without substantial extra cost), does not require data decimation, handles higher dips, and can output to a finer grid. All these features make ComAz an essential tool for iterative migration velociy analysis.

A production quality wave-equation implementation has to address many geophysical and software engineering issues to obtain a high resolution, accurate image as well as angle gathers without aliasing due to data decimation or shot aliasing (Popovici, 2000). Offset aliasing, zero-offset and near-offset trace interpolation, frequency attenuation with depth, velocity sampling and interpolation in depth, depth interval frequency dependence, offset sampling with depth, are some of the features that need to be addressed in a longer list. An important issue is the aperture used for downward continuation. An essential difference between a shot-profile vs. shot-receiver wave-equation implementation is the aperture used for downward continuation.

Figure 2 shows schematically the importance of using enough aperture to image deep, and steeply dipping events. The reflected energy from such events is captured at a large distance from the imaging target, and shot-profile runs need to increase the receiver downward continuation aperture to image deep, steeply dipping events.

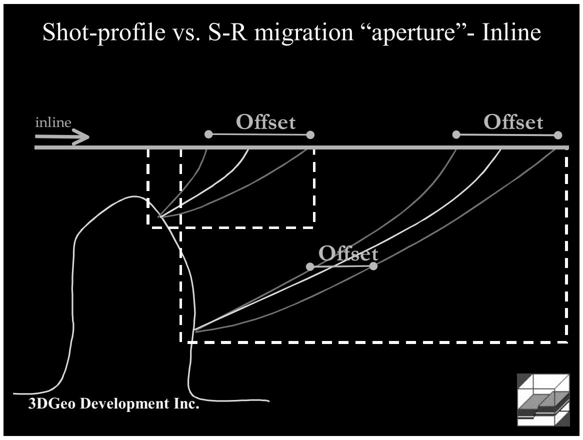

Figure 2. Illustrating the importance of using a large aperture to capture deeper, steeply dipping events.

Many times the steep dips missing in shot-profile imaging results are due to the use of too small an aperture. Figures 3 and 4 show the difference between two wave-equation imaging results due to aperture limitations. The result in Figure 3 was obtained in an earlier iteration when the radial aperture was only 3 km. Figure 4 shows the presence of much steeper dips for a radial aperture of 10 km.

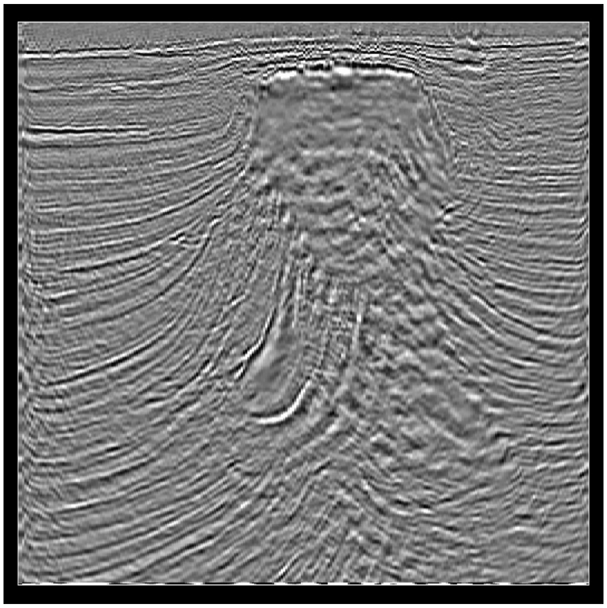

Figure 3. Wave equation imaging using a 3 km radial aperture.

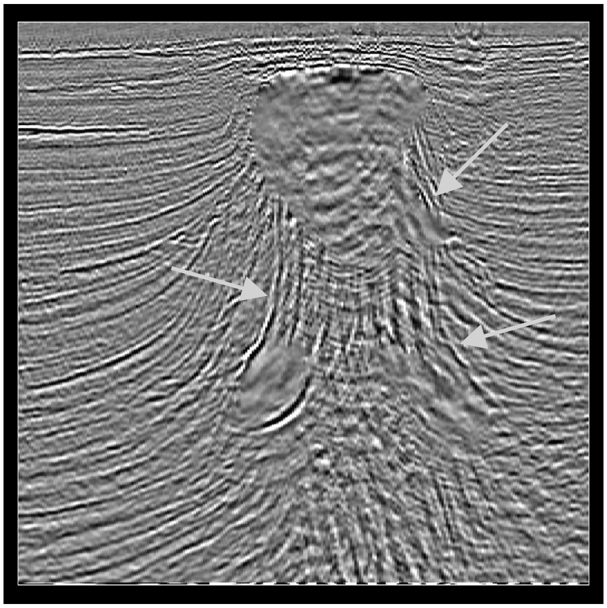

Figure 4. Wave equation imaging using 10 km radial aperture. Notice the imaging of the steeply dipping events in the areas pointed by the arrows.

Building the velocity model

Building a high resolution, accurate and detailed velocity model in the Gulf of Mexico entails many iterations of wave-equation depth migration to define and refine the salt bodies. In areas where the top salt is well described in the initial velocity model, base salt and subsalt reflectors are clearly imaged by the wave-equation migration without the need of further enhancement. In areas with salt bodies that have complicated structures and not well-defined flanks, a project may require four, six, eight iterations to refine the small details in the salt body. Since the velocity structure of the Gulf sediments is fairly simple locally, the main improvements in image quality will come from a better delineation of the salt body in the migration velocity model. The sharper salt body image achieved by the common azimuth wave-equation migration enables us to pick the shape of the salt body in more detail. Because of the large velocity contrast between sediments and salt, even subtle changes in the shape of the salt body can lead to drastic improvements in the continuity of base salt and subsalt reflectors.

Building the salt surfaces can be done not only by picking top and bottom in line and crossline direction, but also by using depth slices that carry additional details and information. Figures 5 and 6 show salt boundary picks in depth slices, Figure 7 shows inline picks together with depth slices picks. Figure 8 shows inline, crossline and depth slices picks. By using all the projections to delineate the salt body, a higher level of accuracy and detail can be obtained.

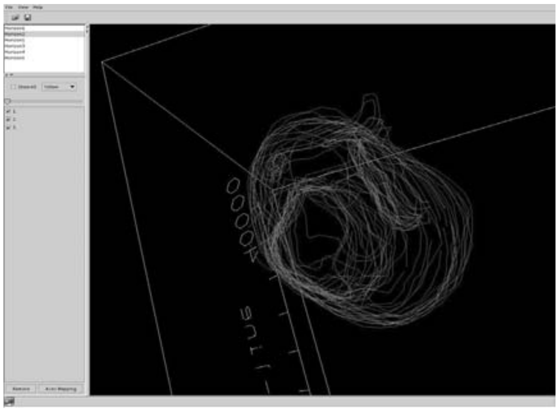

Figure 5. Depth slice picks of a salt body.

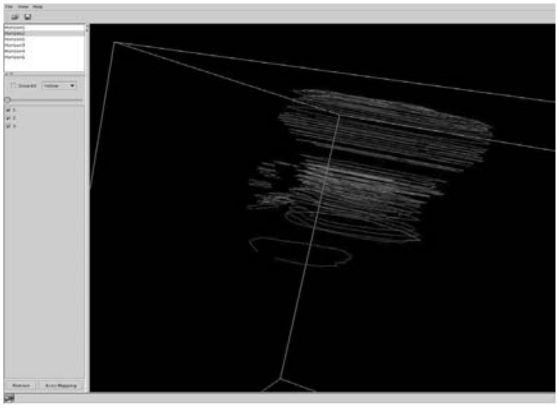

Figure 6. Projection of depth slice picks of a salt body.

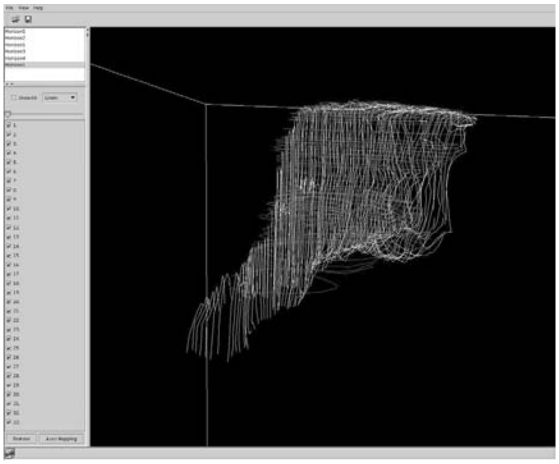

Figure 7. Inline and depth slice picks can be used to better constrain the salt surface and obtain more details.

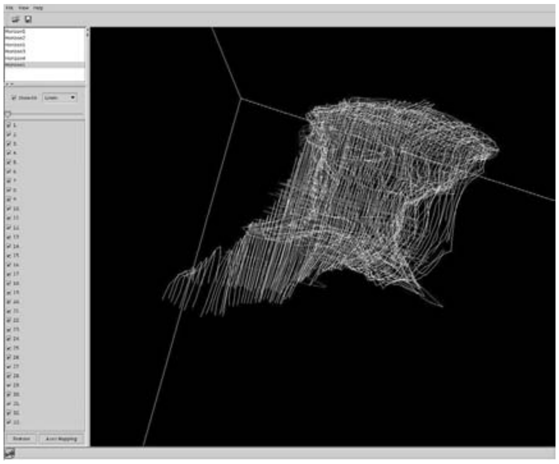

Figure 8. Inline, crossline and depth slice picks can be used to better constrain the salt surface and obtain more details.

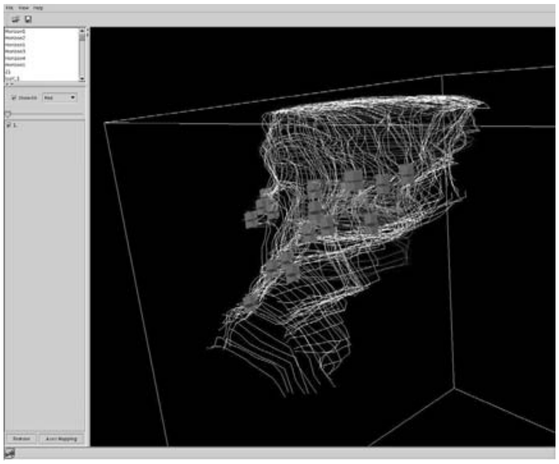

Figure 9. Well log information is incorporated in building the salt boundaries.

Figure 9 shows how well log or any other geological and stratigraphic information can be incorporated in the salt velocity model.

Conclusions

We present a case history of building a high-resolution velocity model in the Gulf of Mexico, using multiple iterations of wave-equation migration and angle common image gathers (ACIG). We show that wave-equation migration can dramatically improve the imaging of complicated salt/sediment interfaces. The wave-equation image reveals more details of the salt flanks, suppresses migration artifacts generated at sharp corners of the salt body, and allows for high-resolution picks in depth slices. The depth slices picks are then combined with inline and crossline picks, and additional well log and geological information is integrated into the final model in collaboration with the interpreter team. The interpreter team has continuous involvement in the model building via remote or direct collaboration, steering the project, validating the structural interpretation and maintaining a geologically coherent update direction.

The combination of integrating all perspectives available to the interpreter (inline, xline, depth) to carefully build the detailed definition of very complex salt bodies for insertion in the final velocity model, the clarity provided by wave-equation imaging, and the integration of geological information with the interpreter team are crucial ingredients to state-of-the-art wave-equation velocity model building.

Acknowledgments

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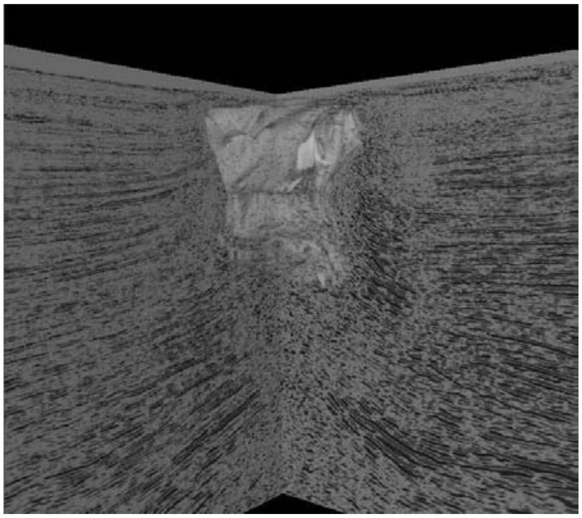
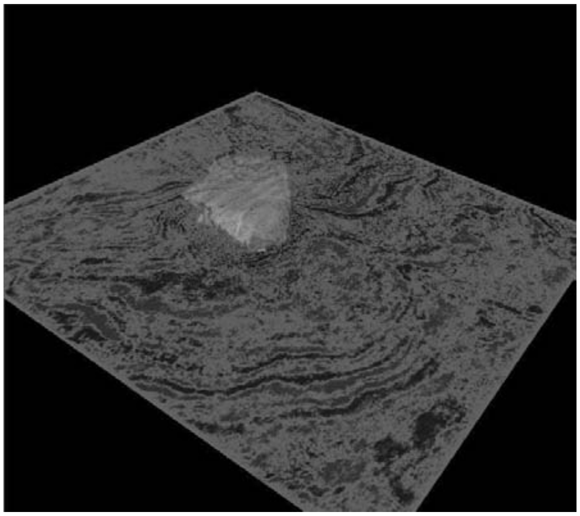


Inline and crossline view through the migrated image, salt body embedded.



Depth slice through the final image, with the top of the salt surface.

Figure 10. Inline, crossline and depth slices through the final image and the salt body.