

T22 Building High-Resolution Velocity Models in the Gulf of Mexico with Wave-equation Depth Migration

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Summary

The deepwater Gulf of Mexico sub-salt regime has been a major focus of attention as 3-D pre-stack depth migration (PSDM) solutions have come of age. Many spectacular imaging examples demonstrate the value of PSDM in this arena, especially wave equation-based solutions capable of handling the multi-pathing of rays in the presence of highly irregular, high velocity contrast interfaces. PSDM also has valuable application in many other complex geologic regimes from overthrust, fault shadow and, in this case, the piercement salt dome environment of the Gulf of Mexico Shelf.

This paper discusses a role for PSDM on the Gulf of Mexico Shelf that remains a very active hydrocarbon province. PSDM was utilized to further reduce uncertainty in spatial positioning and extent of producing reservoirs in a mature field around a piercement-type salt body, and to identify additional reserves in the locality. Up to 25 wells had been drilled and several vintages of time-domain 2-D and 3-D seismic were available, none of which provided the definition required to fully evaluate the continuing hydrocarbon potential on the block.

Obtaining an accurate velocity model is fundamental to successful seismic imaging. 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. In this case, we build a high-resolution velocity model in the Gulf of Mexico, facilitated by an accurate high-performance wave equation migration that allowed multiple iterations of wave-equation migration and angle common image gathers (ACIG) to be quickly and efficiently delivered for interpretive evaluation and update. We show how in certain instances picking in depth slices in tandem with vertical perspectives can build more detail into the velocity model, and how well log information and other geological information were integrated into the velocity model in collaboration with the Company interpreter team, to produce an optimal depth migrated image and to more effectively evaluate the continuing economic potential of the property.

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 a velocity model precisely defining local velocity details.
- Integrating the velocity modeling methodology within a complete wave equation imaging system 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 rapidly declining in acceptability by 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 where necessary for accurate spatial positioning.

The bottom line is that an accurate velocity model determines the success of seismic imaging. Hence, the emphasis in this discussion is on the definition of the salt body and its velocity environment. First, however, let's review some other criteria for success.

Wave-equation imaging improvements and steep dips

The selection of a wave equation imaging method rather than a ray-based scheme was based on the observation that wave equation created less artifacting and effectively handled any possible multi-pathing present in this complex subsurface. Additionally, Source Receiver wave-equation migration (SRM) allows many more fine grained velocity iterations than Shot Profile migration (SPM) for equivalent computational cost. SRM 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 SRM an essential tool for iterative migration velocity 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 provide angle gathers without aliasing due to data decimation or shot aliasing (Popovici, 2000) for use in the velocity modeling and updating process. 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.

Until recently, criticism of wave equation PSDM methods was that they did not seem to image steep dips as well as Kirchhoff. With several of the alternative wave equation methods, economics constrained the aperture invoked and it was not uncommon to see apertures restricted to half of the radius used in a Kirchhoff solution. The computational performance of SRM now allows full aperture to be used resulting in equivalent steep dip performance to Kirchhoff as seen in the following figures. The reflected energy from deep, steeply dipping 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 these events.

Figure 2 was obtained in an earlier iteration when the radial aperture was only 3 km. Figure 3 shows the presence of much steeper dips for a radial aperture of 10 km. In this case, the imaging of the steepest dips played a central role in the definition of the salt body shape.

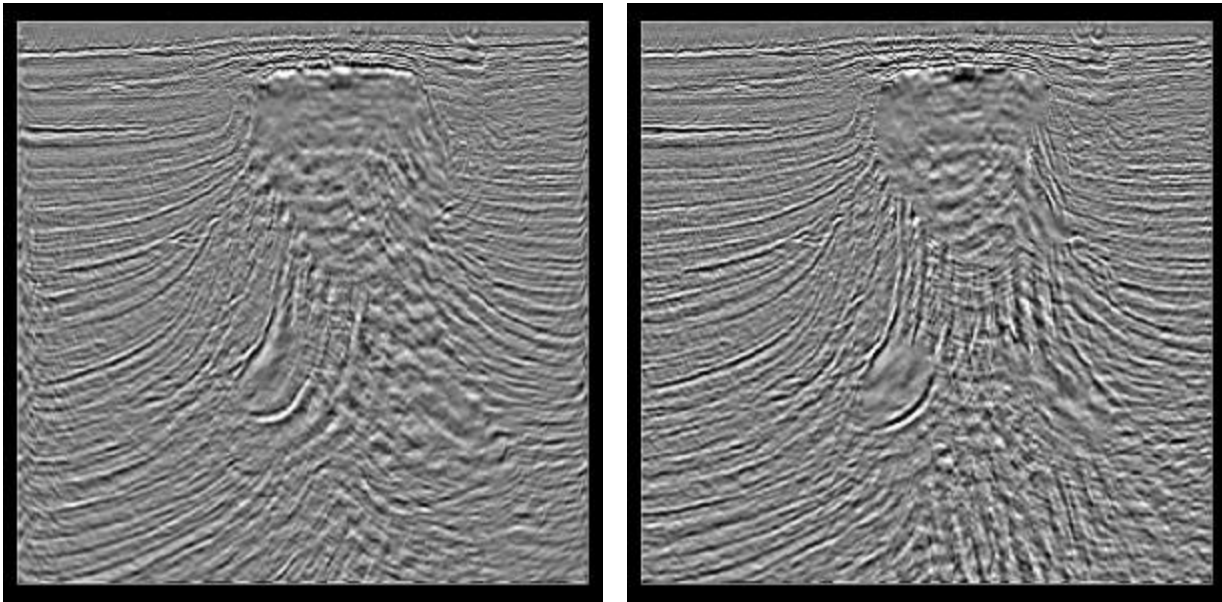


Figure 2: Wave equation imaging with 3km aperture. **Figure 3:** Wave equation imaging with 10 km aperture. Note improved imaging of steepest dips

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.

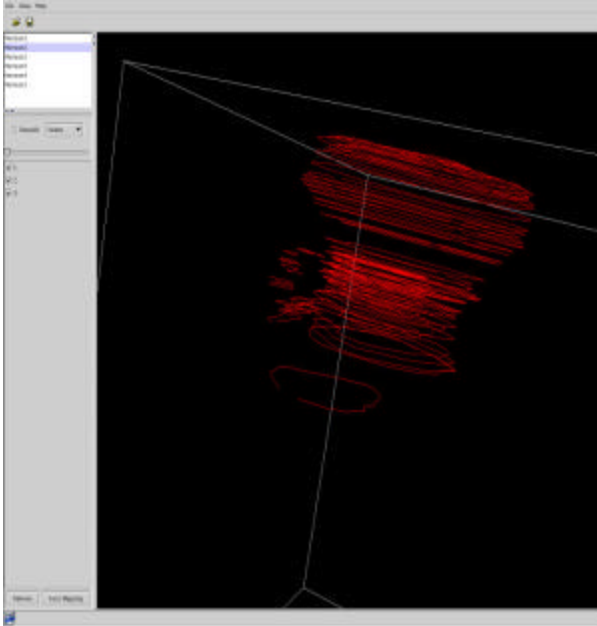


Figure 4: Depth slice picks for the salt body.

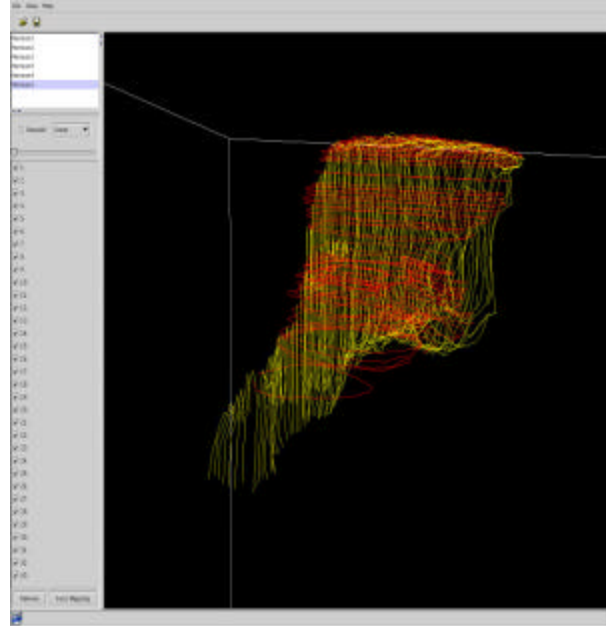


Figure 5: Inline and depth slice picks for better constraint

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. Above, Figure 4 shows salt boundary picks in depth slices, Figure 5 shows inline picks together with depth slices picks. Figure 6 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 7 shows how well log or any other geological and stratigraphic information can be incorporated in the salt velocity model.

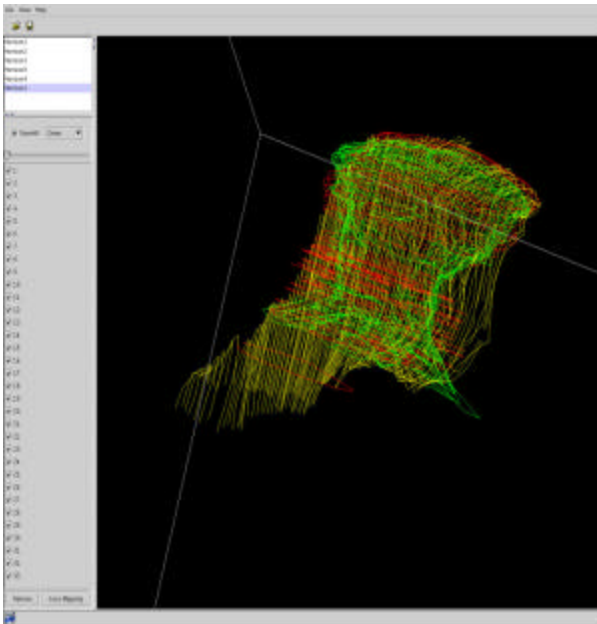


Figure 6: Integrated inline, xline and depth picks.

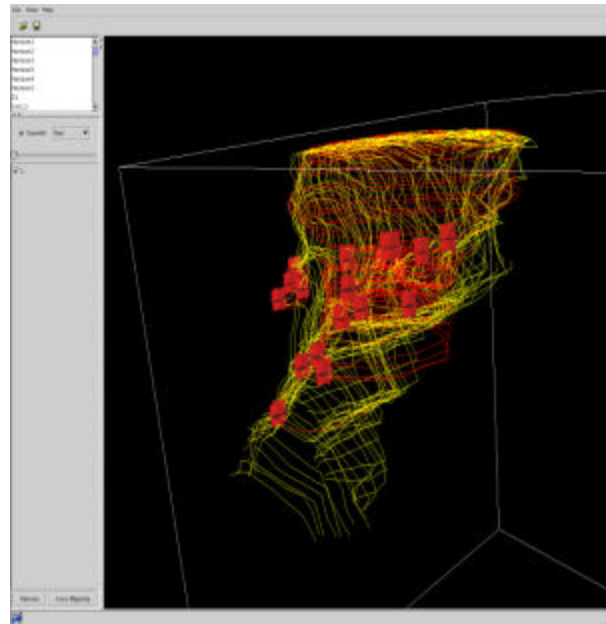


Figure 7: Wells integrated into model definition

Figure 8 shows representative inline, crossline and depth slices extracted from the final PSDM iteration volume indicating the resolution obtained to provide the definition of salt and sediment interfaces. These data have provided a volume capable of making improved economic decisions regarding placement and continuing potential of the remaining reserves in this piercement salt dome environment.

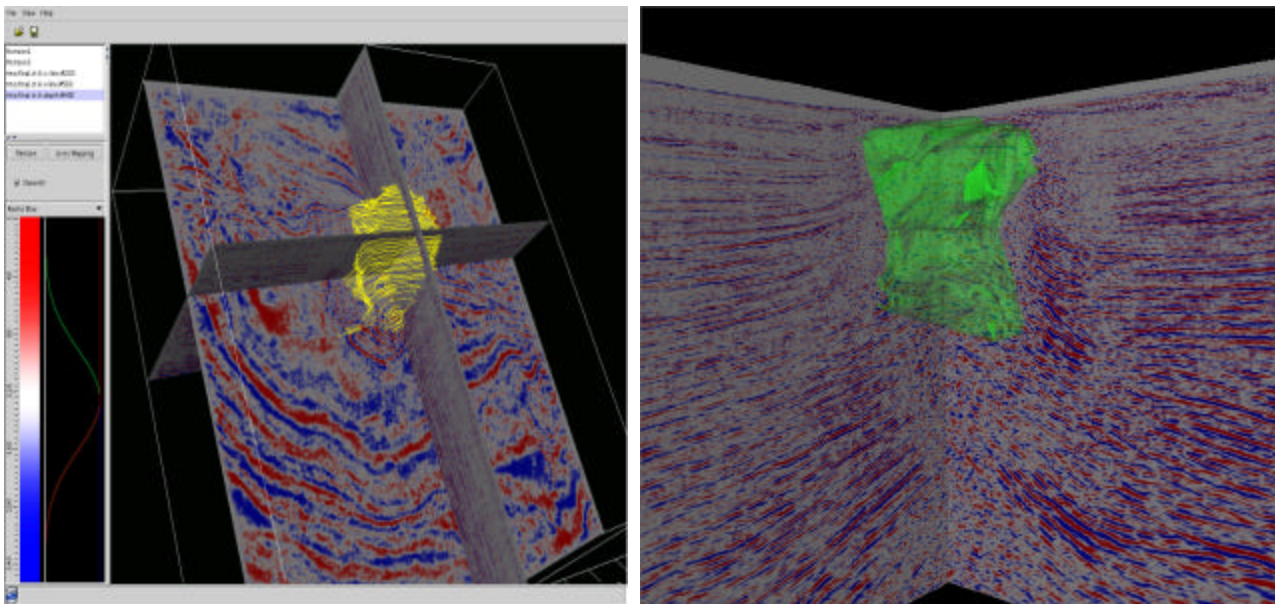


Figure 8: Inline, crossline and depth slices through the final image and the salt body.

Conclusions

We have presented a case history of building a high-resolution velocity model in a piercement salt dome environment on the Gulf of Mexico Shelf, 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, crossline, depth) to carefully build the detailed definition of very complex salt bodies for insertion into 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 successful state-of-the art wave-equation velocity model building.

Acknowledgments

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