Salt interpretation for velocity model building using long offset multi-WAZ data – improving the subsalt image in eastern Mississippi Canyon, Gulf of Mexico.

Dan Chaikin, Henrik Roende and Jason Kegel, TGS*

Summary

A new long-offset multi-WAZ (M-WAZ) dataset provides insight, enhancement and redefinition of critical geologic features in the Miocene, Mesozoic and presalt sections of eastern Mississippi Canyon in the Gulf of Mexico (Figure 1). Miocene sand reservoirs are imaged in unprecedented detail. These Miocene units can be mapped further and more accurately under salt and along salt flanks. The structure of the Mesozoic section in areas never previously imaged is revealed. The deep base-salt image at the Louann level is enhanced. Finally, the image provides a new 'first look' at the presalt section of the region in 3D.

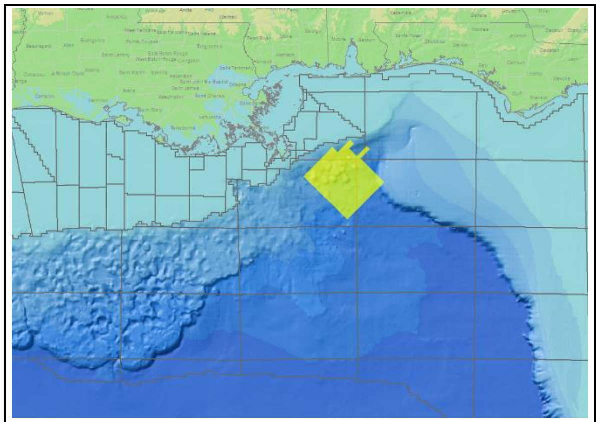

Figure 1: Eastern Mississippi Canyon dataset indicated by yellow-shaded polygon.

Several factors contribute to this uplift, including M-WAZ acquisition with long offsets up to 16 km, as well as processing enhancements and improvements in the salt interpretation strategy. This paper will outline the strategy with examples where reinterpretation of the salt led to improvements that ranged from refinement to complete redefinition of the salt tectonic structural framework. The resulting model, combined with the benefits from long offset M-WAZ, have a direct positive impact on the migrated image.

Velocity model building with salt interpretation requires conceptual guidelines that become more important as the geologic structures become more complicated and the seismic image less clear. It is critical that the concepts are tested and proven successful in the resulting migrated image. The shapes of salt structures can be complicated but, once they are built, can simplify the geologic model.

Certain types of improvements stand out. Refinement of the shallow salt shape, and especially of shallow overhangs, uplifts the local subsalt image. Salt-stock geometries are addressed and in some cases shapes are simplified. Salt wings and early Miocene canopy structures are reevaluated. The common hourglass shape of vertical stocks is simplified, widening the "waist", vastly improving the base-salt image at the Louann level and permitting presalt imaging. Finally, in some cases where the salt tectonic framework was poorly understood, the salt model is reinterpreted with different geologic concepts and confirmed with migration testing. This essentially involved a reworking of the salt tectonic structures and results in an enhanced image, particularly in the Mesozoic section.

Introduction

Salt structures in eastern Mississippi Canyon are characterized by three main elements: the original Jurassic Louann salt formation, a younger suite of shallow salt canopies, and narrow salt stocks that connect the original mother salt to the canopies. (Figure 2). Shallow canopies have the most significant impact on the subsalt image. These are typically well-imaged, and modeling generally depends on correct placement of interpreted top- and base-salt horizons.

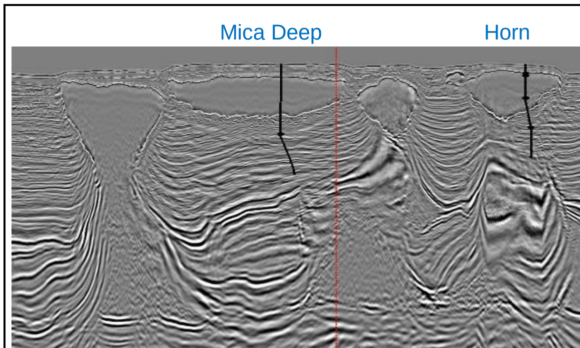

Figure 2: Arbitrary depth line through eastern Mississippi Canyon showing salt-stock and canopy structures.

The salt stocks may have complex structures, but are typically well imaged when they lie adjacent to Miocene or younger sedimentary sandstone and shales. These units have seismic velocities significantly slower than salt, and the velocity contrast typically results in strong seismic reflectors. However, the Oligocene through Mesozoic depositional section is characterized by faster seismic velocities, especially in carbonates. Velocities approach and exceed salt. Due to the lack of velocity contrast, detail and form of salt within these sections is not always well imaged or understood.

M-WAZ acquisition and processing

The data used for this survey is an underlying WAZ with 7200 m offset acquired in 2010 and a new orthogonal WAZ survey with 16,000 m offset with staggered boat acquisition pattern completed in 2016. The processing sequence is state of the art. Some of the highlights are deghosting (Zhang et al. 2016), image guided tomography (Hilburn et al. 2014) and orthorhombic migration (Tiwari et al. 2015). Combined with the long-offset M-WAZ improved illumination, all of these factors significantly enhance imaging in this project (Figure 3).

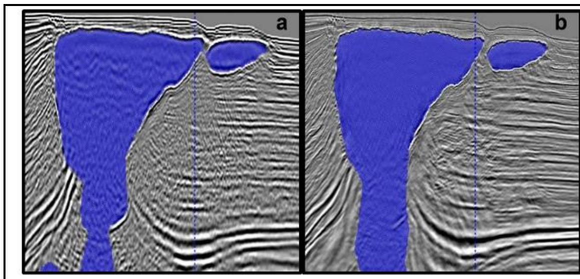

Figure 3: Subsalt illumination improvements. (a) WAZ image. (b) Long offset M-WAZ image with similar model

Salt interpretation process

Modeling follows a top-down approach, consistent with the seismic ray path. Shallowest salt boundary, or the top of salt, is interpreted first. A salt flood velocity model is created and used for a migration. Next the shallowest salt exit event, or base of salt, is interpreted, providing a single salt body model. Subsalt sediment velocities are updated with image guided residual curvature tomography. Afterward, the process is repeated, until a second salt body is defined. This approach continues until the original salt layer, the Louann salt, is reached.

There are several challenges to successfully manage the top-down approach. Assumptions must be made about the salt model at the beginning of the process and pursued before their accuracy is confirmed. Errors early in process can corrupt the entire interpretation. Complex shapes that don't naturally fit into the top-down approach need special attention. Two factors are critical to success of this method. First interpretation needs conceptual guidance, and, second, these concepts need confirmation within the resulting seismic image. One lesson from this project is that a complex approach to interpretation can result in a simpler and more successful geological model.

Shallow salt overhangs

During the early stages of interpretation many shallow complicated salt structures were identified (Figure 4). These structures are often overlooked because the shapes may be complicated and they are not expected to impact the image significantly. However, incorporating them often provides a model that is geologically more sensible and structurally more simple. And, critically, the subsalt image can be radically improved. Figures 4a and 4b show a previously existing model that tries to over-simplify a salt wing in the middle of a salt canopy. The resulting model is somewhat awkward and there is an image gap in the subsalt. Figures 4c and 4d show the same lines in the new M-WAZ data. The structure is remodeled by more closely honoring the events in the seismic image. The resulting model adds a shallow overhang, yet provides a simpler geologic picture. The subsalt image is healed and now imaged through over 5 km of subsalt section.

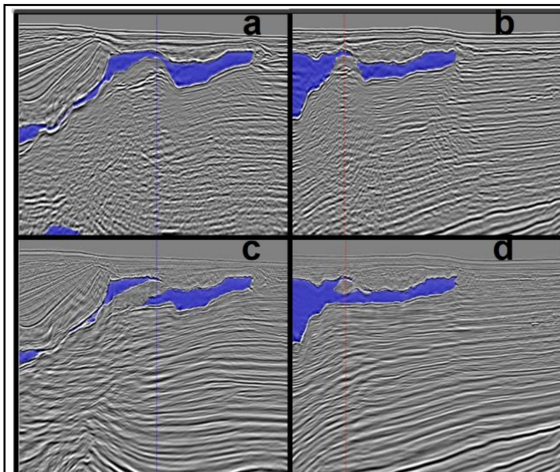

Figure 4: Shallow overhangs. (a) & (b) are orthogonal lines showing a simplified salt model. Note the image gap under the salt. (c) & (d) show the corresponding lines with the new interpretation. Salt shape is more complicated, but geologically simpler. The subsalt image is significantly improved.

Megaflap along the flank of a salt stock

A danger of the top-down approach to interpretation is that mistakes inserted in the model at a shallower level corrupt the deeper image, preventing accurate interpretation. Figure 5a shows the results of such a problem. When a ray exits salt, it typically moves into sediments with much slower velocity. The resulting seismic event is a strong trough, and this trough event is used to key the base-salt interpretation. This method is successful in Figure 5a from roughly 2 to 3 km depth. However, the trough at ~5000 m depth is suspect. It appears to be a typical base-salt event, but could also represent a sediment event misplaced in the migration by the salt velocity in the model. The resulting salt model implies that there was a salt canopy in the early Miocene. (The strong peak event at ~5000 m depth is the base of the Miocene section.) Reevaluation of the structures imaged with the new acquisition leads to a simplified model, confirmed through testing. The result is shown in Figure 5b. The early Miocene canopy structure is removed, and Mesozoic events are now imaged in their place revealing a large Mesozoic-to-Oligocene megaflap along the salt flank. The result is a substantially different, less complex structure that is more seismically convincing.

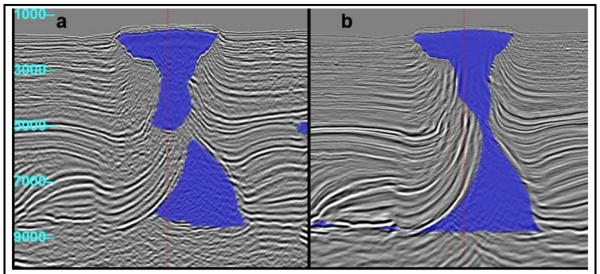

Figure 5: (a) Earlier model with early Miocene canopy included interpretation at 5200m. (b) Removing the canopy simplifies the model and helps in imaging of a megaflap along the salt flank.

Salt flanks hidden within fast velocity sediment sections

Steep salt flanks, while challenging, can be mapped with fair accuracy when they are represented by strong events in the seismic. However, when the salt flanks are poorly imaged, determination of the salt-sediment boundary can be difficult and uncertain. In the M-WAZ survey extremes of both styles are evident. Miocene and younger sandstones and shales have seismic velocities substantially slower than salt and provide a strong reflector at salt boundaries. Oligocene and Mesozoic carbonates have much faster seismic velocities, exceeding salt velocities in some cases. The salt-sediment boundary within this section is often very subtle or missing entirely. It is difficult to interpret salt boundaries with confidence, yet the interpretation has a significant impact on the image. These salt structures can usually be worked out with some confidence by careful observation and interpretation of the imaged sediment structures and then confirmed by testing.

Figure 6a shows both types of steep salt flanks. Along the flanks of the shallow salt diapir a strong peak can be clearly observed where Miocene and younger events lie against the salt, from roughly 2400 m to 5600 m. Below top-Oligocene, salt flanks essentially disappear. General salt structure is implied by sedimentary events and can be roughly determined. However, the uncertainty has resulted in complicated shapes. The salt within the Mesozoic section is interpreted to have an hour glass shape with a thin waist. The result is that the deep base-salt (here the base-Louann at roughly 8800 m) is not flat as generally assumed. Instead, it warps down where salt is thick and warps up where salt is thin. These structures confound an already weak presalt image.

Figure 6b shows the reworked interpretation using long offset M-WAZ data. Salt flood testing revealed a strong base-Louann event, indicating a more uniform salt diapir width with depth within the Mesozoic-Oligocene section. This thicker waist concept is matched with the imaged sediments. The result shows two striking improvements to the image. First, the base-Louann event is generally flatter and the apparent base-Louann structure is independent of the salt shape. Second, the presalt section is tremendously improved; permitted partially because of the simplified base-Louann.

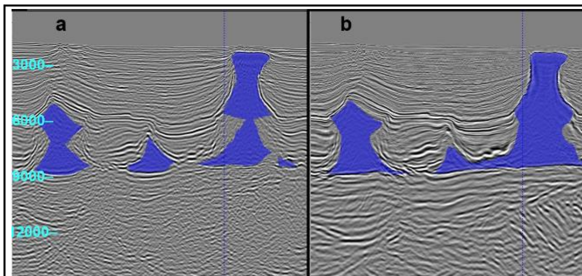

Figure 6: (a) Salt model with thin waist within the Mesozoic section, where the salt flank is not well imaged. (b) Newer model with thicker waist within the Mesozoic section. The main base of salt is flatter and the presalt geology image is substantially improved.

Complex salt in poorly imaged sections

Salt interpretation and image quality have a rough correlation that varies with geology and complexity. In areas of substantial salt-tectonic complexity, the interpretation of the salt is less certain. And the more incorrect the salt model, the worse the image is likely to be. In such areas, salt interpretation requires some conceptual guidelines and testing.

Figures 7a and 7b show seismic depth lines through a complex area. The shallow salt and shallow structures can be interpreted without much difficulty. However, below roughly 5 km the image is unclear and any interpretation is uncertain. The resulting deep-salt model is unconvincing.

Salt interpretation for velocity model building using long offset multi-WAZ data

Working out this structure requires conceptual guidelines and testing for confirmation. The structure of observable Mesozoic events identify the general location of salt feeders. A critical step is the recognition of a thick salt body between 4200 and 7000 m (Figure 7c), mapped to be consistent with salt feeders at 3-to-4 km depth. Testing reveals steeper events within an adjacent pre-Miocene minibasin (to the left of this intermediate salt body, between 5000 and 7500 m depth, Figure 7c) that conform geologically to this salt body. Further subsalt velocity enhancement is necessary to improve the deeper Mesozoic section (to the right of this salt body, Figure 7c). The complete model is built on the basis of these test results.

Figures 7c and 7d show substantial improvement. While there is some uncertainty, the general salt tectonic framework can be deciphered, and the Mesozoic to Oligocene section (roughly below 5 km) can be observed and mapped.

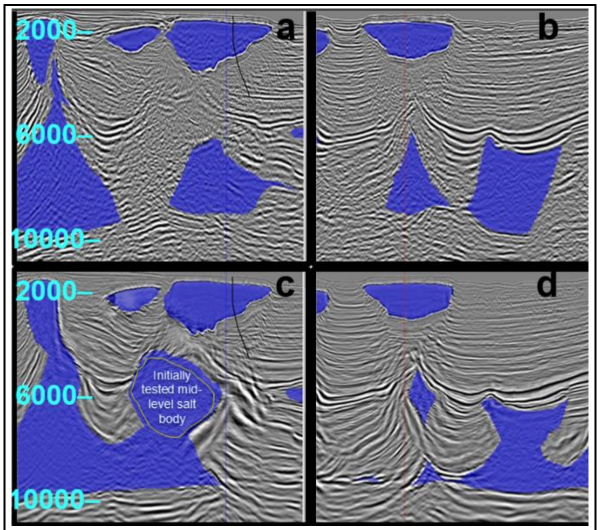

Figure 7: (a) & (b) are orthogonal lines with an earlier interpretation and resulting image. (c) & (d) show the corresponding lines with the new interpretation and improved imaging of the deeper section. Critical to the new interpretation is the addition of the mid-level salt body, labeled in (c).

Conclusions

Shallow overhangs, steep salt flanks and fast sediment velocities in older units create image and interpretation challenges in the salt stock and canopy structures in eastern Mississippi Canyon. Acquisition with M-Waz and 16 km offset improve the illumination, enabling a chance to rework structures with a state of the art dataset. Successful modeling of these salt structures is critical to the imaging.

Interpreters must manage several factors when building a salt model. They must honor observable detail, make use of observable sedimentary events and the structures they imply, and follow general salt tectonic concepts. Also interpreters need conceptual guideline, and must confirm these models with testing. Complicated modeling approaches can simplify and clarify the geologic structure.

The improved data quality and this interpretation approach led to many improvements to salt model. As a result, the image is enhanced and provides insight to the redefinition of critical geologic features in the Miocene, Mesozoic and presalt sections of the eastern Gulf of Mexico.

Acknowledgements

Thanks to Connie VanSchuyver for careful edits, to Susan Williams and Mike Hudec for detailed review, and to my TGS colleagues and management for enabling this paper.

EDITED REFERENCES

Note: This reference list is a copyedited version of the reference list submitted by the author. Reference lists for the 2017 SEG Technical Program Expanded Abstracts have been copyedited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

REFERENCES

Hilburn, G., Y. He, Z. Yan, and F. Sherrill, 2014, High-resolution tomographic inversion with image-guided preconditioning and offset-dependent picking: 84th Annual International Meeting, SEG, Expanded Abstracts, 4768–4772, http://doi.org/10.1190/segam2014-1219.1.

Tiwari, D., G. Hilburn, Y. He, Y. Li, F. Sherrill, and Z. Guo, 2015, High resolution tilted-orthorhombic tomographic inversion to improve velocity modeling and imaging: A case study of its impact on subsalt: 85th Annual International Meeting, SEG, Expanded Abstracts, 361–365, https://doi.org/10.1190/segam2015-5922279.1.

Zhang, Z., Z. Wu, B. Wang, and J. Ji, 2016, Adaptive Windowed Deghosting—Applications to FAZ Acquisition: 78th Annual International Conference and Exhibition, EAGE, Extended Abstracts, Th STZ1 01, https://doi.org/10.3997/2214-4609.201601582.