Salt interpretation validated by salt tectonic study in the offshore Gulf of Mexico

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Summary

To identify and define a complex salt body with rugose top and base is essential in building an accurate velocity model for premium quality depth imaging. We present a few real data examples from shelf to deepwater to demonstrate the complicated salt geometries and their interpretation. The salt interpretation is finalized and validated to fit the regional geological setting, e.g. the Gulf of Mexico and is supported by the theories and hypotheses proposed by the industrial salt tectonics and physical model studies.

Introduction

Since the 1990s, salt related hydrocarbon traps in the offshore Gulf of Mexico (GOM) have drawn a lot of attention from the oil and gas industry. The objective of depth migration is to correctly position the oil and gas traps on the salt flanks and sub-salt structures due to strong velocity contrast between salt and the surrounding sediments. Decades of fast computer hardware advancement, migration technology development in pre-stack depth domain, and the geological research in salt tectonics, have helped image steep salt flanks and sub-salt structures. However, the complex geometry of salt bodies still present challenges to depth imaging. How to delineate the salt bodies and assess its relationship to the surrounding sediments is what the salt model building and depth image team are facing routinely.

In the regular Pre-stack Depth Migration (PSDM) velocity model building workflow in the GOM, a smooth starting sediment velocity between water bottom and top of salt is derived by tomographic updates and calibrated by check-shots when available. The data is migrated with this updated sediment velocity. The first top of salt is interpreted using this volume. In the second iteration, the entire volume below the top of salt is flooded using a constant salt velocity (usually 4500m/s in the GOM), and then the first base of salt is interpreted on this saltflood volume. Two or more iterations will be required to define salt overhangs. This interpretation of the overhang is normally more challenging and time-consuming. Knowledge of the regional salt tectonics at this stage is very critical.

Current salt interpretation in the offshore GOM basin is guided by one of the most popular salt tectonic views: the original autochthonous Louann salt is believed to have been deposited and formed in the Jurassic. The salt was later deformed in response to rapid sedimentation in the Tertiary and extension and compression throughout the tectonic history. The displaced allochthonous sheets overlying younger strata have partially or completely coalesced into salt canopies (Jackson et al., 1994). The allochthonous salt deformation is characterized by 1) downdip compression and salt thickening, where individual salt sheets and tongues were sutured into massive salt canopies; 2) updip extension and salt withdrawal concurrent with Tertiary sediment loading, which can lead to dramatic change in salt thickness, and feed the seaward-dipping allochthonous salt. Eventually, withdrawal remnants and salt welds become common in the landward or updip direction.

In the following real data examples, we will discuss the presence of different salt structures in varying water depths from shelf to deepwater areas. We derive a reasonable salt interpretation that is supported and explained by salt tectonics, such as salt evolution hypothesis and theory and laboratory observations by physical modeling.

Interpretation of salt structures in the offshore GOM

Upon completion of several 3D seismic interpretation projects in the GOM, we have observed salt structures different from the shelf to the slope and then to the deepwater areas.

The first example (Figure 1) is a north-south section taken from the northwestern Mississippian Canyon. Water depth is less than 1000 meters. The second example (Figure 2) is from Stanley project located in the ultra deepwater of over 2000 meters, in the southern Walker Ridge area of the GOM.

First, we discuss two interesting salt features on the shelf-slope after much of salt had been evacuated and covered by thick overburden.

Salt horn: This type of salt feature is found near the top of salt along faults as seen in Figure 1. The narrow horn-like features are relics of former salt diapirs that were later stretched and fell. Salt horns are aligning with the regional normal faults, of which the hanging walls move seaward and leave relic structures in the footwalls. The salt horn implies that the salt source doesn't have enough salt supply to keep the diapir rising during regional extension. The bulges above the salt horn indicate that the diapirs were once higher than the present salt. Recognizing the salt horns along the faults led us to better define the salt body.

Salt keel: This is a root-like structure below the main salt body or a concave-shaped structural low. The presence of the root-like salt keel could be the seal for the updip sub-salt sediments and form potential hydrocarbon traps if other factors in the petroleum system are favorable.

Unlike the salt structures on the shelf, we see a lot greater percentage of salt along the section in the second example (Figure 2). The salt canopy is closer to the water bottom and more massive. These huge canopies or walls are commonly observed in the deepwater in the GOM. The overlying deep-water suspension sediments are thin because this area is starved of sediments compared with the shelf. The gentle regional dip also helps the salt stability and its gradual piling-up in this area.

As seen in the lower left side of Figure 2, the Kirchhoff image shows sub-salt events with opposite dips and an apparent 'pull-up' event at deeper depth. This observation suggests that adding a new interpretation of a detached tear-drop shaped feeder/stock (highlighted in white) provides us the chance to further improve the imaging of the subsalt section. The raw result of the new model testing shows that the deep 'pull-up' event is pushed down and aligns with deep regional unconformity.

Salt interpretation validated by salt tectonics theories

However, in many real cases, seismic images are not clear enough for a definite salt interpretation; we need to try two or more possible interpretations and compare migration results (Mosher et al., 2007). The final salt model will be validated through the image quality and salt tectonic theories to see if it fits the overall environment. In the GOM, how salt interacts with sediments is believed to be controlled by several variables. Besides sediment density, more evidence suggests that regional extension is a more effective way to drive the tabular salt through the thinned overburden roof and form diapiric salt domes (Jackson et al., 1994).

In the following example, the pointed shallow salt crest indicates the salt is reactively growing and responding to the late Tertiary regional extension. Figure 3a is a sediment flood section, in which the character of shallow salt is obscure and the tabular salt geometry is complex. In this situation, two different salt model trials are tested. Figure 3b is the final migration result using the original salt interpretation. The result did not show a correctly imaged deep base of salt without the proper interpretation of shallow piercing salt. Figure 3c shows an updated salt model with a defined diapiric shallow salt. This result shows a more accurately imaged shallow overhang. The sediments are well imaged inside the overhang area.

The correctly positioned sediments below the shallow overhang, as shown in Figure 3c, have improved the overall image quality. In this shallow water section, the small rising diapiric salt implies the salt is most likely reactively moved upward by the sediment loading during late Tertiary regional extension. The vertical salt stem shows up in the improved image. It is linking the shallow and deep salt and is nearly parallel to the seaward dipping of regional faults, which may indicate the direction of salt emplacement.

Conclusions

The examples illustrate the methods and processes used to derive viable salt interpretation and models for quality depth migration products in various geological settings in the offshore GOM. Equipped with knowledge of salt tectonics, the interpreters can start identifying apparent reflectors and characteristic structural features that are related to the salt on the seismic images. Then they can interpret them, map their extents, and finally derive a sound salt interpretation and velocity model in a geologically very complex area.

Acknowledgments

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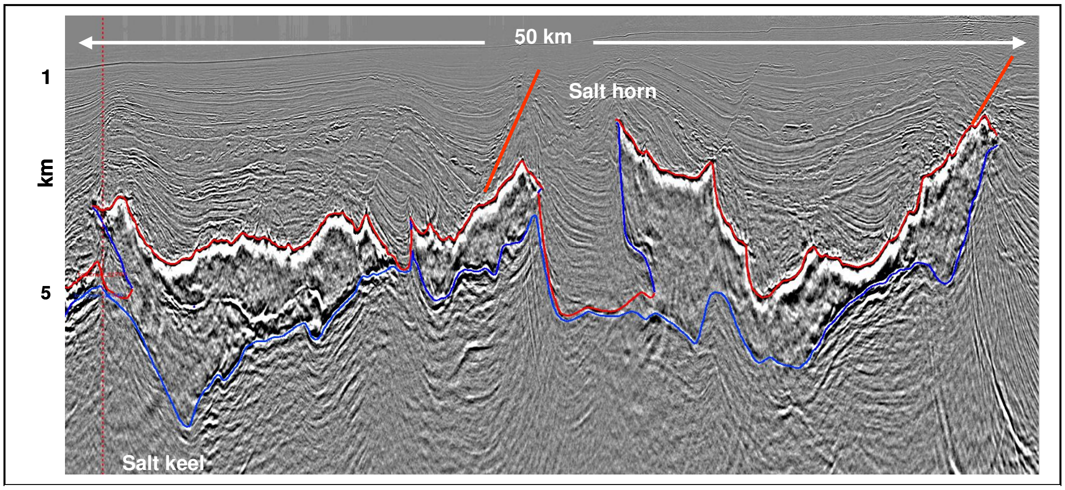

Figure 1: A north (left)-south (right) seismic section in western Mississippi Canyon area (water depth < 1km) shows two interesting features, salt horns on top of salt and salt keels in the base of salt level, which are most likely under regional structural control. Upthrown strata against the base of salt can be of economic potentials.

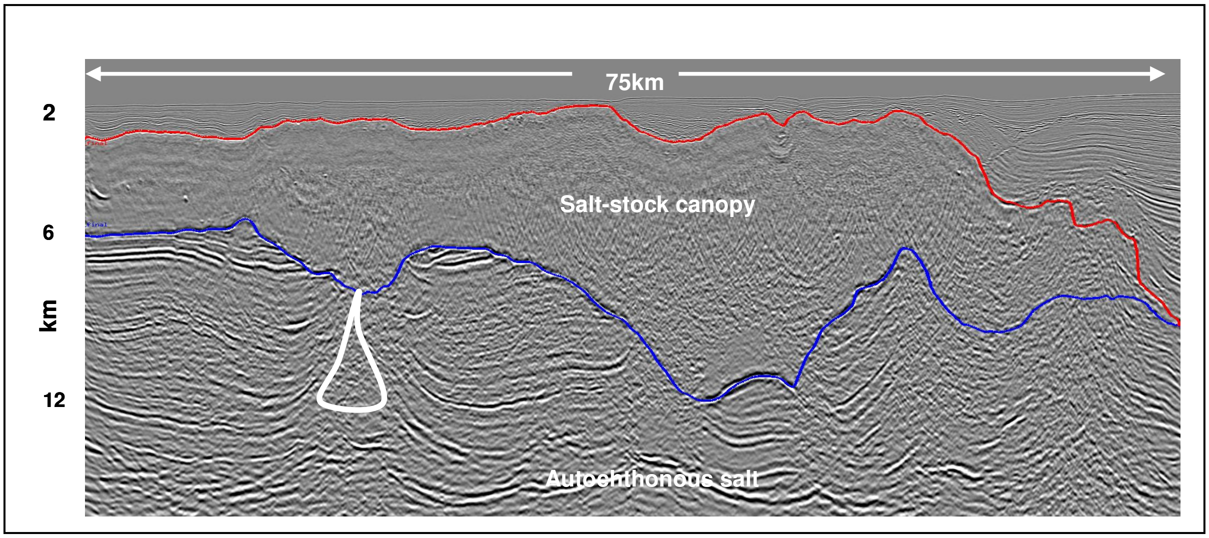

Figure 2: A north (left)-south (right) seismic section in deep water Walker Ridge area (water depth > 2km) shows a massive salt-stock canopy overlaid by thin suspension sediments. Opposite dipping events below the base of salt suggests a possible salt feeder/stock (highlighted in white).

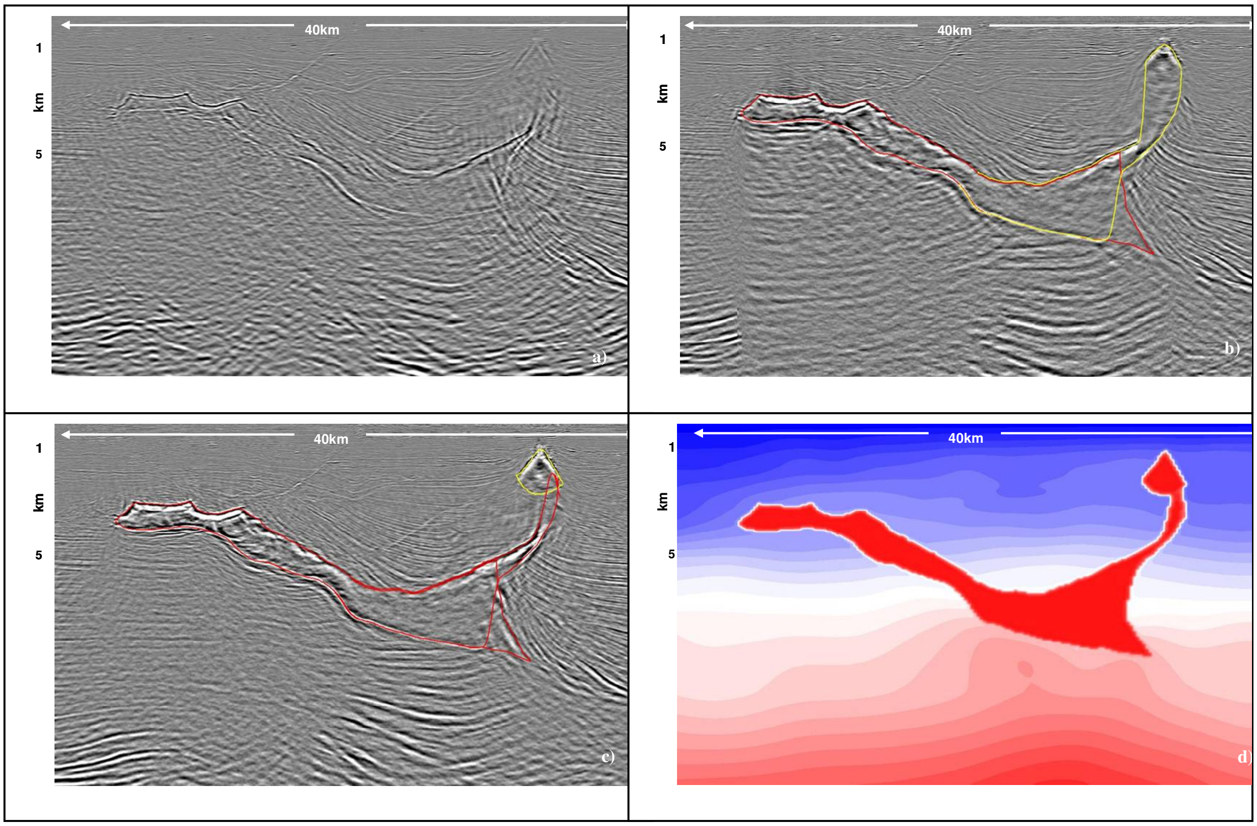

Figure 3: a) A north (left) –south (right) section in the offshore central GOM with sediment velocity migration shows an obscure but complex salt structure. b) The wider shallow diapric salt model has no clear salt flanks. The first salt model is in yellow. c) Vertical salt link is clearly imaged in the final image. A pointed diapir with a little overhange is used to preserve the sediments below the salt in the new salt model. d) The smoothed velocity model with salt velocity 4500 m/s is used for the final migration in c. Salt is highlighted in red.

EDITED REFERENCES

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