Salt tectonic styles in the spreading basin: Yucatan, Offshore Mexico

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Summary

The TGS Gigante project is comprised of 188,497 km of 2D seismic data acquired in 2016 and primarily covering the offshore Mexican side of the Gulf of Mexico (Figure 1). Within the survey, 180 seismic lines with 5 km average spacing are in the increasingly important Yucatan area, where active hydrocarbon exploration is taking place. The data was acquired with a 12 km streamer length and a 2 ms sample interval. Both Kirchhoff and Reverse Time Migration significantly improve the seismic image quality in the structurally complex offshore Yucatan area.

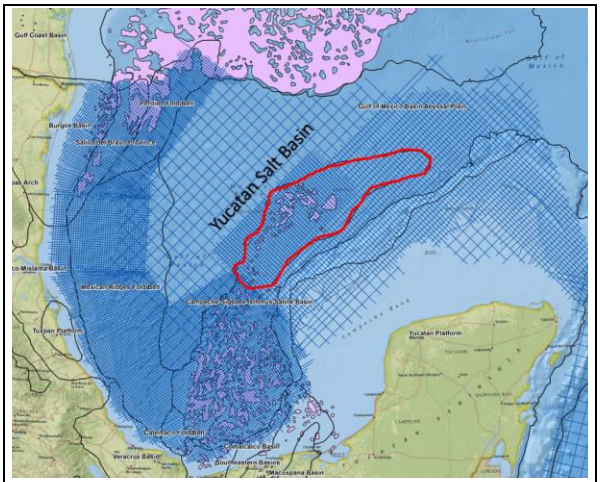

Figure 1: 2D Gigante survey in offshore Mexico.

The Yucatan in offshore Mexico is a relatively underexplored area, where a better understanding of the regional geology is still in progress. Due to lack of well control, a clear conceptual geologic model is required before starting seismic interpretation work. Detailed salt interpretation improves image quality in presalt sediments, resulting in a better definition of potential plays. In this case study, we present salt interpretations, based on regional tectonic knowledge, towards the improvement of image quality. With high resolution imaging and seismically constrained interpretation, the deeper Mesozoic section stands out for the presalt plays in Yucatan, offshore Mexico.

Understanding the structural orientation of the basin, and salt flow directions with reference to 2D line acquisition geometry, is a necessity for seismic interpretation. The existing 2D lines follow the strike and dip orientation of the basin. Large salt diapirs with wide pedestals and shallow steep overhangs are the most common structures in the area. However, small rollover autochthonous salts and reactive diapirs, attached to the extensional growth fault systems, are also identified in the Yucatan salt basin.

Introduction

The survey area covers the spreading basin, where North America separated from the Yucatan peninsula. Yucatan separating from North America is from northwest to southeast. The basin is confined to the west (Mexico) and east (Florida). The Gulf of Mexico started to open through rifting during early to mid phase of the Jurassic Period (Pindell and Kennan, 2007). Salt tectonic styles are synkinematically related with the spreading history of the basin. Salt began to form complex structural styles as the basin continued spreading. Salt structures started to vary throughout mid to late Jurassic time (CNH 2015).

The seismic image connects the salt depositional history with a valid 3D consistent geological model integrated into the 2D salt interpretation. Our interactive detailed salt interpretation methods help to build an accurate velocity model. The model is subsequently validated with a migrated seismic image. Complex salt geometries are interpreted into an iterative top down PSDM model building process approach. This detailed salt interpretation method significantly improves the image quality, both in the presalt and in the postsalt level (Figure 2).

Spreading basin

Salt deposition in a spreading basin has been extensively researched to understand the associated petroleum systems. Among these types of basins, major salt deposits are observed in three regions: 1) Offshore Brazil, 2) Offshore Angola, and 3) the Gulf of Mexico.

The first two regions were divided during the spreading of the South American and African plates in the Early Cretaceous (Montaron and Tapponnier, 2009). As a result, the Santos and Kwanza basins were created in the Brazilian and Angolan side, respectively.

The third region, the Gulf of Mexico, is one of the most studied basins in terms of oil exploitation. It began to open in the late Triassic, by rifting between the North America plate and the Yucatan microplate (Pindell and Dewey, 1982; Hudec et al., 2013). In this split-up, the Yucatan carried away a portion of the salt mass. During the early Cretaceous, the Yucatan microplate rotated counterclockwise, and moved southward, until it reached

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the northern South American plate (Dribus et al., 2008). Because of this spreading, the original continuous Callovian salt split into the Central Louann (US side) and the Isthmian (Mexico side) basins. There are two subbasins within the Isthmian salt basin separated by a basement ridge: Campeche and Yucatan (Hudec et al., 2013) (Figure 1).

Yucatan salt basin

The Mexican and US salts were deposited into a single basin until mid Jurassic (Callovian) time. Salt deposition ended before the separation between Yucatan and North America started (Hudec et al., 2013).

Evaporites, specifically halite, are the predominant lithology which filled the accommodation space created by crustal extension (Pindell, 2002). The arid, dry mid Jurassic climate was not favorable for other types of sediment deposition in the Gulf of Mexico. Thus, salt deposition in the Yucatan area was a syndepositional extension.

In the offshore Yucatan, seismic data shows a salt-detached extension in Jurassic strata over a large extended area. The extensional growth faults are of late Jurassic (Oxfordian - Kimmeridgian) age. There are seaward dipping salt diapirs resulting from salt-detached shortening. The magnitude of downdip shortening is minimal compared to updip extension. Shortening happened after extension, and is not kinematically related (Hudec et al., 2013). The Yucatan salt basin has undergone three stages of salt deposition:

1) Mid Jurassic Callovian (165-161 Ma): Continuous supply of seawater, and a warm and arid climate, provided layered salt deposits. Salt deposition began at mid Jurassic Callovian time. Salt was deposited into one continuous salt basin in the Gulf of Mexico.

2) Mid-Late Jurassic Callovian-Oxfordian (161 – 154 Ma): As the basin started opening, in the early Oxfordian, there was a separation between continental and oceanic crust. The continued rifting between the two crusts created an outer marginal trough. Salt in the Yucatan province began to flow seaward. Salts got stretched over the outer marginal trough as the basin continued widening (Hudec et al., 2013)

3) Late Jurassic Oxfordian-Kimmeridgian (154-151 Ma): Unconfined seaward salt flows advanced huge, stretched, overburden deposits onto parautochthonous salts (salt lies outside the autochthonous salt basin). With increasing overburden pressure, salts at the outer marginal trough got squeezed. Salt began to form diapirs without much down dip shortening. There are allochthonous salt diapirs trending towards down dip transitional crust and autochthonous Louann/Isthmian salts trending towards up dip continental crust.

After late Jurassic/early Cretaceous, the Yucatan reached its stable present day position. Salt tectonic activity ceased in the Yucatan salt basin.

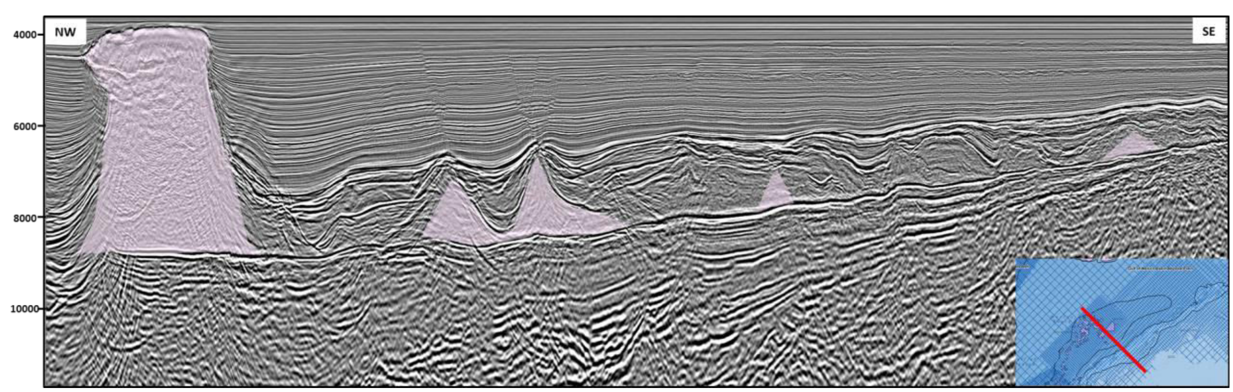

Figure 2: RTM depth stack shows improved image in presalt and postsalt sediments, salt diapir observed in west central Yucatan basin.

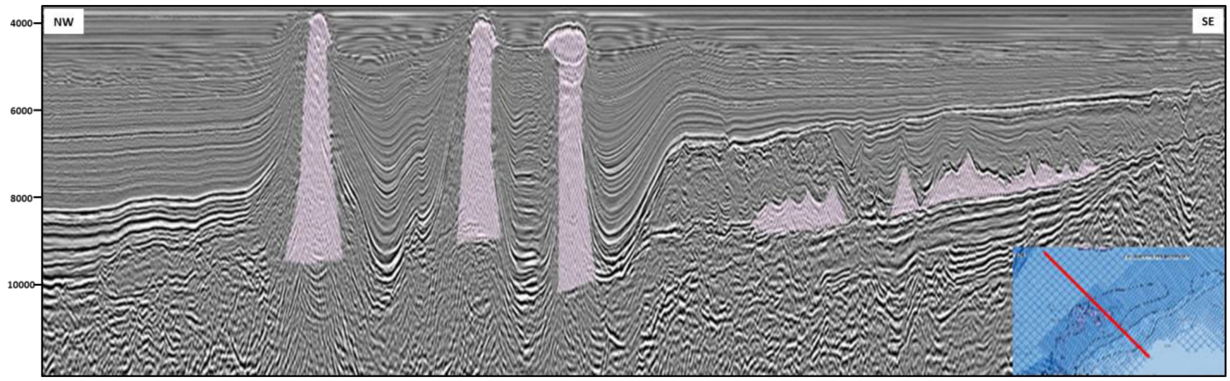

Figure 3: SE-NW line in central Yucatan basin shows salt diapirs in seaward dipping transitional crust and smaller Isthmian salts in extensional continental crust.

Salt tectonic styles

Two major salt tectonic styles are observed in the Yucatan salt basin:

1) Allochthonous salt diapirs on downdip contraction: Large allochthonous salt diapirs are observed in the west-central part of the basin (Figure 2, 3). These salt bodies lie on the transitional crust formed by downdip contraction. Towards the southwest, salt diapirism dies out near the nose of the Yucatan basin. The seismic images (Figure 2, 3) show variable stages of salt diapirs towards the seaward dipping basin with alternating small-large-small salt diapirs as we move from southwest to northeast in the west central part of the basin.

2) Autochthonous salts on up dip extension: As we move further east of the Yucatan salt basin, in the updip platform area, the tectonic style changes to an extensional regime where small, autochthonous Jurassic Isthmian salts are located on the continental crust. These salts are associated with an extensional fault system. An extensional fault system is formed by basinward translation, and by subsidence into salt. These are the growth faults rooted with salts formed in the landward margin of the basin. This linked extensional fault system is related to different salt structural styles (Rowan et al., 1999). Salt pinch out, salt roller and salt welds are observed (Figure 4).

Figure 5 clearly shows two different salt tectonic styles along the basin in the strike direction. The northeast side is on extensional zone where small autochthonous Isthmian salts with extensional growth fault system are identified. In the southcentral side of the basin, larger shallow salt diapirs are observed. These two tectonic styles are separated by a paleo high.

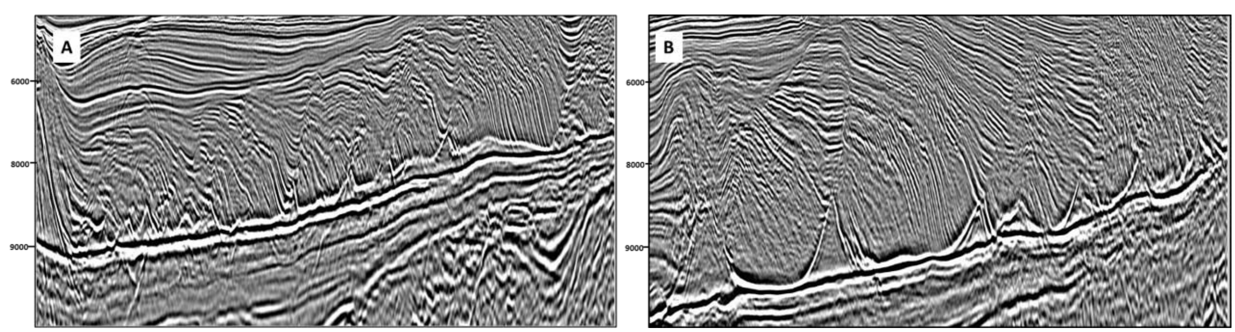

Figure 4: A) Extensional autochthonous salt pinch out, salt roller. B) Extensional autochthonous salt welds, reactive diapirs.

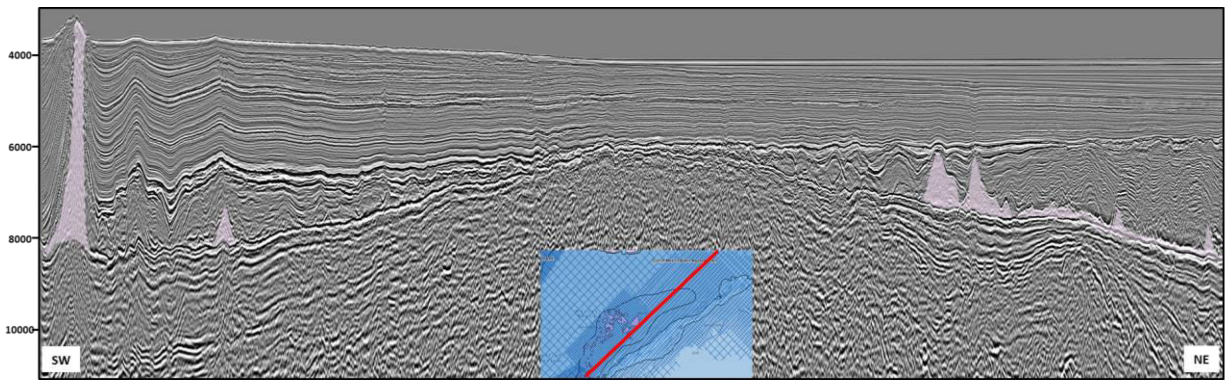

Figure 5: NE-SW strike line shows two evident salt tectonic styles separated by a basement high.

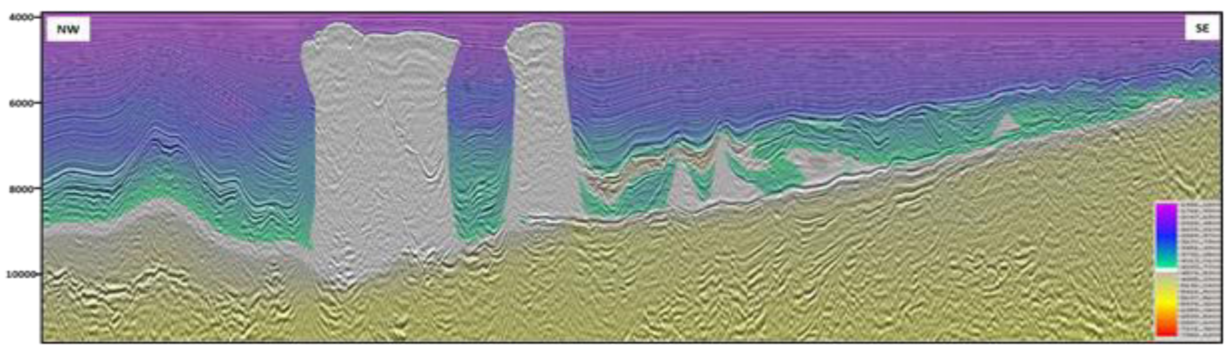

Figure 6: The final velocity model created by PSDM iterative seismic interpretation method.

Salt interpretation methods

A 3D-consistent model is a necessity for a modern-day 2D interpretation. This provides a geologically reliable salt body model with consistent thickness at intersecting 2D lines. Salt interpretation begins with a top-down approach. A migration is then performed, reinstating the expected sediment velocities into the salt volume (except where the top and base of the salt is picked). This process is repeated with as many salt bodies as necessary. Overhang tomography is performed in between the salt body iterations with an accurate velocity model.

A quick migration can be performed on a whole or partial line, with alternative salt models representing the top and base of salt, to test the model interactively. This approach is useful in determining if too much or too little salt is being modelled, by examining the subsalt and surrounding sediment image. Adjustable salt models are tested for the best imaging, while keeping in mind the expected geologic salt model as a constraint (Figure 6).

Conclusions

The relationship between salt deposition and basin spreading history is clearly established with seismic interpretation. The geological concept has been verified with an accurate velocity model and prestack depth migrated seismic images. Understanding the regional geology is imperative before commencing a seismic interpretation-driven model building, in a structurally complex, less explored area, like the Yucatan salt province.

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