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Detailed Structural and Stratigraphic Analysis of the Salt-Sediment Interactions on Top of the Wheeler Dome Salt Tongue, Mississippi Canyon Area, Gulf of Mexico

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Detailed Structural and Stratigraphic Analysis of the Salt-Sediment Interactions on Top of the Wheeler Dome Salt Tongue, Mississippi Canyon Area, Gulf of Mexico

By

Ryan Michael Jaska, Bachelor of Science

Presented to the Faculty of the Graduate School of
Stephen F. Austin State University
In Partial Fulfillment
Of the Requirements

For the Degree of
Master of Science

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Detailed Structural and Stratigraphic Analysis of the Salt-Sediment Interactions on Top of the Wheeler Dome Salt Tongue, Mississippi Canyon Area, Gulf of Mexico

By

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Abstract

The Mississippi Canyon is in the northeastern part of the Gulf of Mexico, south of the state of Mississippi. In this area, there are many different salt structures present including salt canopies, diapirs, and salt pillows. The Callovian aged Louann Salt covers this area and is the cause of many of the salt structures and structures of the overlying formations seen in Gulf of Mexico today. Salt is mobile when subjected to stress from overlying sediment and gravity. Stress will force the salt to not only move upward, but to also move down slope deeper into adjacent basins through the process of halokenesis. Salt movement may commence as early as when deposition has been completed and may trigger the formation of structural features such as faults, rafts, and displacement of the overlying formations.

By careful analysis of 3-D seismic data in combination with available sea floor imaging, these subsurface structures were mapped and interpreted. This study involves the mapping of salt structures and surrounding features affected by salt movement to detail the tops of the Louann Salt using structure maps created within the study area. These maps were used along with other structural data to reconstruct the salt canopy through time. A detailed reconstruction of the study area has produced a model that demonstrated salt migration over time and showed how gravity and the overlying formations were affected by it over time. As the salt moved downslope into adjacent

basins, the formations on top of the salt faulted and moved due to the additional stress. The salt movement also caused nearby formations to separate and attach to the salt moving down dip into the basin, thus separating it from the rest of the formation. These faults also caused some rotation of the layers along the fault.

Acknowledgements

I would like to thank my family for their constant support during the process of this project. Without them this project may have never been completed. I would also like to thank them for helping with the trip back to the campus in order to continue the work on this project.

I would also like to thank Dr. Brown for taking the time to help me write this out. He kept this project from being sloppy as well as kept the project on track. The meetings were always helpful in filling in the gaps.

To Jim Ferry for being able to aid in the direction that the project should be going and what should be looked at. His advice and expertise on the area was a great help in starting and finishing this project.

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Chapter 1: Introduction

The Northern Gulf of Mexico (GOM) is home to large deposits of salts called the Louann Salt which over time caused formation of structures within the area to allow for the trapping of economic materials. The Mississippi Canyon contains a large allochthonous salt structure which is in the Gulf of Mexico in Figure 1 off the coast of Mississippi. The Louann Salt is a large evaporite body of halite that, like all sedimentary rocks, was originally deposited horizontally across that area in Callovian time, Mid-Jurassic period. The salt had begun to move into the basin over time altering the shallow subsurface. In present time the salt is in the form of a canopy where it was pushed up to a shallower point in the subsurface and then slowly crept into the basin creating the canopy. The 3-D seismic data was acquired from Tomlinson Geophysical Services Inc. (TGS) which covers a section of the Mississippi Canyon area.

Seismic data are obtained by using artificial energy sources to cause vibrations near the surface or on the surface and then collecting the arrival times of the vibrations at the surface as they reflect off the different lithologies in the subsurface. 3-D seismic data can be manipulated to produce a visual representation of structural and stratigraphic subsurface features. Each reflector represents a change in basic lithology of the rock and not what formations are present. This makes seismic data suitable for analyzing the structures between two very different lithologies such as a mudstone and salt contact.

A detailed examination at the toe of the salt as well as the channels in the area revealed structural information about this canyon. With the seismic interpretation these attributes can be seen on the seafloor using pictures of deep-sea bathymetry. Using images of the sea floor with the interpretated data it has been determined what types of structures can be observed on the surface.

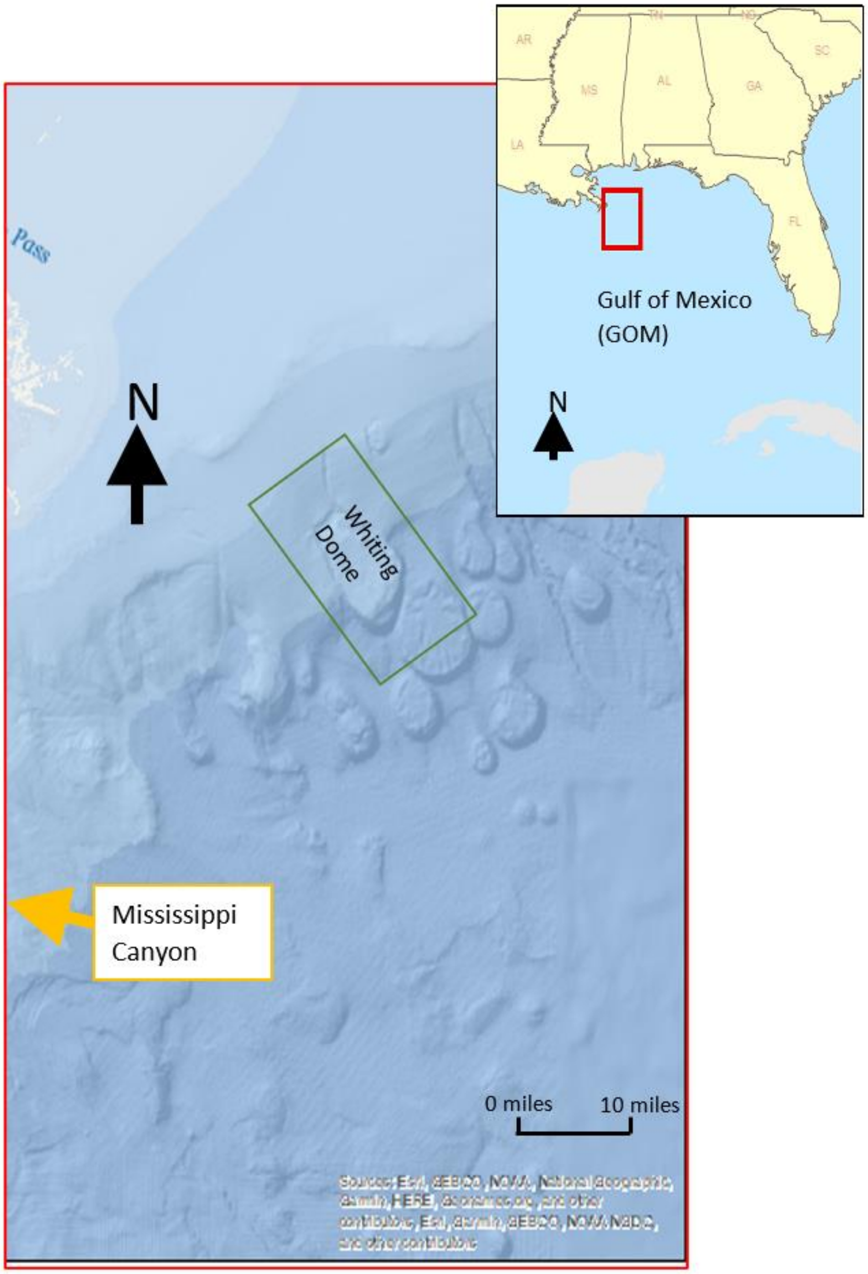


Figure 1 The green box represents the extent of the 3D-seismic data that was used in this study that is surrounding the Whiting Dome. The red box is the location of the study area with perspective to the south-eastern US.

1.1 Study Area

The Gulf of Mexico is a widely observed area for the purpose of both economic and academic studies. The Callovian Louann Salt that is present over much of the GOM and its coast is the main cause for the formation of the geologic structures present in the GOM. The Whiting Dome is located 40 miles off the coast of Louisiana. In Figure 1 the green rectangle is the extent of the study area as well as the extent of the seismic data that was provided by TGS. The study area is 10 miles wide and 15 miles long following the same trend of the Whiting Dome itself.

To the east of the study area there is the Mississippi Canyon which is the very dominant feature in the north central GOM according to the U.S. Geologic Survey. Within the study area and around the GOM the dome structures that are visible in Figure 1 are caused by halokinesis or the movement of salt. The Louann Salt's movement is down slope into the basin which follows the trend of the dome and study area in Figure 1. Halokinesis has caused structures such as the round raised sea floor that is visible in the Figure 1 sea floor map inside the green study area box and other form of structures like rafting and rotating beds that are present in the subsurface.

1.2 Objectives

1. To identify the key salt structures within the Mississippi Canyon in the Gulf of Mexico using 3-D seismic data.

2. Relate the structures found in the seismic data to the sea floor of the Mississippi Canyon using deep sea bathymetry images.
    a. See which of the structures can be identified from the sea floor alone.
    b. Check for any other identifying sea floor structures that can aid in the interpretation of the salt's movement.
3. Create a reconstruction of the salts movement to show the order and impact of the structures on the sea floor.

1.3 Significance

The salt structures being studied in the Gulf of Mexico are currently active sites for petroleum exploration which are of economic importance. The salt creates anticlinal structures which forms traps for the accumulation and storage of economic resources. The value of these resources promotes the study of the structures that allow for the accumulation of these resources. Finding the important structures present in the Whiting Dome can aid in the interpretation of other salt canopies in the future.

The comparison of salt induced structures along with their impact on the surface or sea floor allows for the general interpretation of salt structures without geophysical tools or surveys. A detailed analysis of the structure can reveal its history and how it migrated over time after its deposition. Being able to analyze subsurface structures by investigating a deep-sea bathymetry map can give some assumptions before the subsurface data is taken.

1.4 Limitations

The data that was acquired from TGS was limited to the seismic data and the bathymetry images were used from Google Maps satellite view of the Gulf of Mexico area (Figure 2). While geophysical data gives a large amount of information it is best paired with physical data to ensure that the data is as accurate as possible. Deep-sea bathymetry images were being used for the ground truthing of what can be seen on the sea floor in the study area.

Geophysical data is based on the idea that there is a change or contrast in a physical property between the units or strata that are being observed. For seismic data to be effective there needs to be an acoustic impedance contrast between different rock strata that are being studied. Acoustic impedance is equal to the density times the acoustic velocity. Salt has the unusual property of having a low density at 2.2 g/cc and a high velocity at 10,000 ft/s. The greater the velocity contrast, the stronger the reflectors become in the data. If adjoining rock strata have the same or very similar wave velocities, the change in lithologic units might not show up in the seismic data. This means that the focused units need to differ in this wave velocity. The Louann Salt has a very high seismic wave velocity compared to the overlying beds

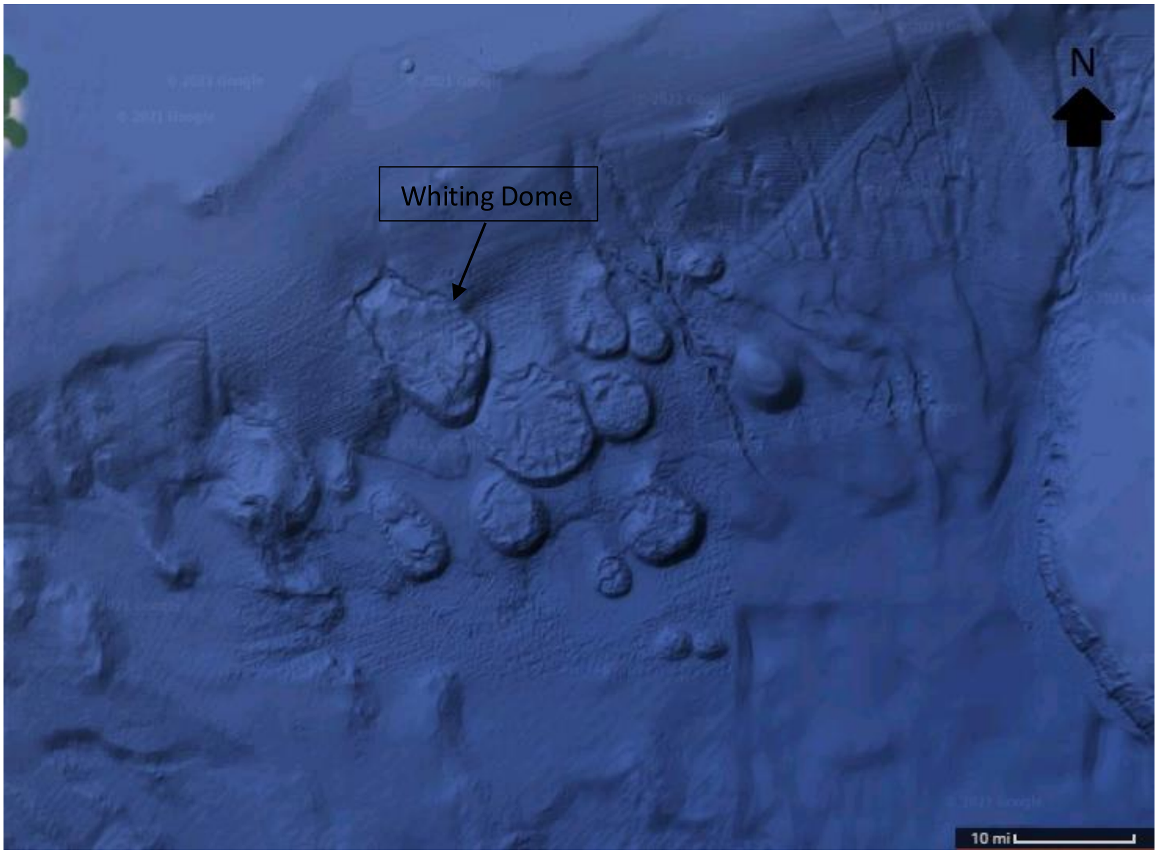


Figure 2 A satellite view of the Gulf of Mexico Mississippi Canyon area. Shows the many different salt structures that trend in south-eastern direction. The direction of the salt structures movement shows the direction that leads into the basin.

Chapter 2 Literature Review

2.1 Geologic History

"The Gulf of Mexico (GOM) originated as a small ocean basin created by seafloor spreading in the Middle Jurassic through Early Cretaceous." (Galloway et al. 2011) The Gulf of Mexico Basin commenced formation in the Triassic age as rifting occurred between the North American plate and the Yucatan plate. "Pennsylvanian to Triassic deposits derived from erosion of the Ouachita tectogene" (Wilhelm and Ewing 1972). This basin began relatively small but grew due to the rifting process. Rifting continued through the early Cretaceous period creating a deep basin. During the Jurassic period, the largest amount of crustal extension occurred within the basin. This thinning also extended the basin more allowing for the deposition of large amounts of Jurassic salt deposits.

"Pre-Oxfordian Louann salt and post-Oxfordian Buckner anhydrite and salt were deposited in the earlier periods of the Jurassic transgression" (Wilhelm and Ewing 1972). As with all sedimentary rocks this evaporite "was deposited in a single broad basin, which eventually split in two as the gulf widened" (Hudec et al. 2013). The Gulf of Mexico was creating from rifting in the GOM plate during the Late Jurassic time and split the large basin into two smaller basins. The splitting of the basin caused some deformation within the allochthonous salt with the most notable be the faulting. During the extension of the Gulf of Mexico the “salt stretched and thinned, allowing the top of the salt to subside well below the sea level” allowing the salt to be buried by sediment (Hudec et al. 2013).

“By the middle Oxfordian, intra-continental extension in the Gulf of Mexico had reached a point (constrained South America divergence rate) where it had opened enough to accommodate the entire extent of the Louann and Campeche evaporite basin, but salt deposition may have been in the Callovian or earlier” (Pindell 1994) Figure 3 displays the diverging of the North and South American plates enlarging the basin for the evaporite deposits. During this time the African plate was also diverging from the American plates starting the opening of the Atlantic Ocean along the Mid-Atlantic ridge.

Starting in the Late Aptian in Figure 4 the basin has widened to a very large extent. This is the start of the Proto-Caribbean with the GOM now split between north and south based on the divergent boundary between the Americas.

Figure 5 shows the GOM in the Middle Campanian is a calm period where most of the action was the continued expansion of the GOM Basin. Due to the expansion of the Farallon the Proto-Caribbean is also beginning to be overtaken.

During the Late Paleocene the Proto-Caribbean had been completely taken over and is now covered by what is now seen as the Caribbean as shown in Figure 6. The expansion of the GOM Basin has also slowed to a halt during this time. “Collision between the Greater Antilles and the Bahamas began in the Paleocene, although subduction accretion packages occur onshore Cuba which formed during the late Cretaceous and included late Cretaceous orogenic sediments probably derived from Yucatan, confusing the definition of the exact age of the onset of the Cuba-Bahamas collision." (Pindell 1994)

Figure 7 shows the GOM in the Late Eocene beginning to take shape to resemble what it looks like in present day with the Caribbean plate moved closer to its present-day position. The boundary that separates the American plates in the GOM has stopped diverging and is now a transform fault.

The Early Miocene in Figure 8 has the less active movement of the plates, and the action is focused on the splitting point along the center of the GOM basin.

During the Cenozoic period, the accumulation of sediment into the basin was almost constant. This post-Laramide sediment varied in composition depending on its origin. The sediment varied in location from southern Louisiana to northern Mexico following the coast. This heavy influx of sediment put a lot of pressure on the Louann salt and as such caused more movement in this unit. There are "25 principal depositional systems that constitute the bulk of the sand-bearing Northern GOM Cenozoic basin fill" (Galloway et al. 2000). These 25 different depositional systems each vary in duration and location of the sediment influx. Figure 9 shows the position of the plates as they are in the present day.

Over time, the Gulf of Mexico received a large amount of sediment, adding more and more weight over the Louann Salt. The pressure of the sediment on top of the salt caused the salt flow deeper and deeper into the Gulf of Mexico basin, as well as initiating the structures that are observed in the salt today. These two segments of the gulf suggest that there is a transform fault that offset the basins. This fault was named that Brazos transfer fault and is a “northwest- trending structure” (Simmons 1992). The Brazos Transfer fault was formed during the rifting of the gulf and marks the cut off between the inner and outer parts of the basin. However, “the Cretaceous and earlier Tertiary times, was the period of construction of the Florida and Yucatan platforms” (Wilhelm and Ewing 1972). During the late Cretaceous time the large-scale Laramide orogeny began to alter the Gulf of Mexico basin. This large event shaped how and what kinds of sediment would be accumulating in the basin as well as eroding away some of the structures and sediment that was present at the time.

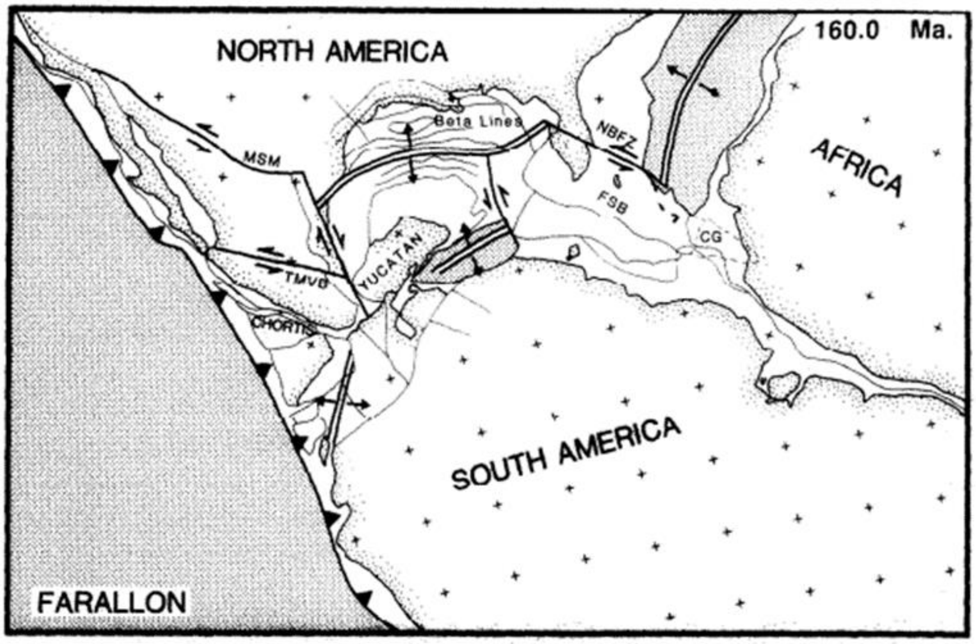


Figure 3 Gulf of Mexico (GOM) tectonic plates during the Oxfordian, 160 Ma. (Ross and Scotese 1987)

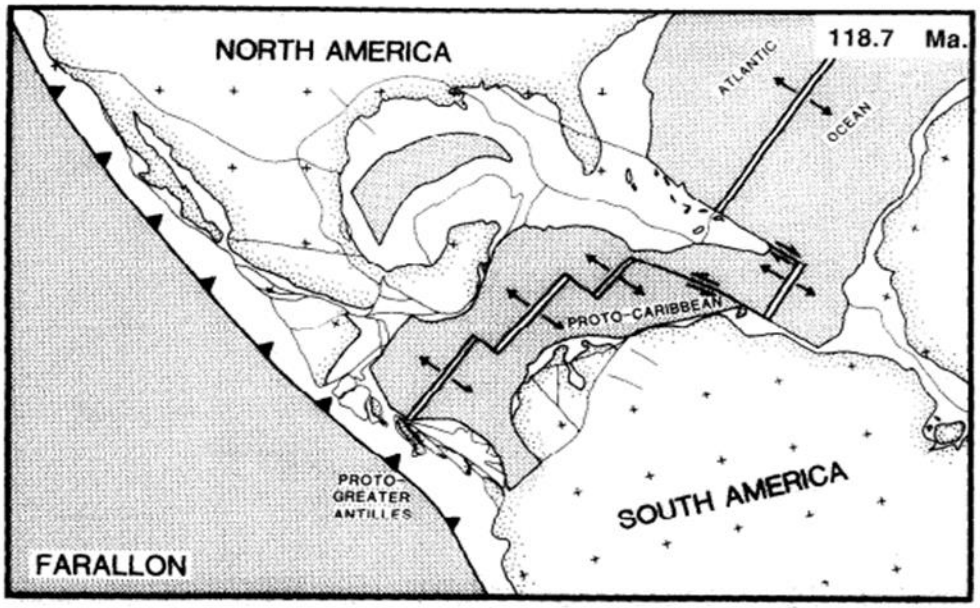


Figure 4 GOM tectonic plates during the Late Aptian, 118.7 Ma. (Ross and Scotese 1987)

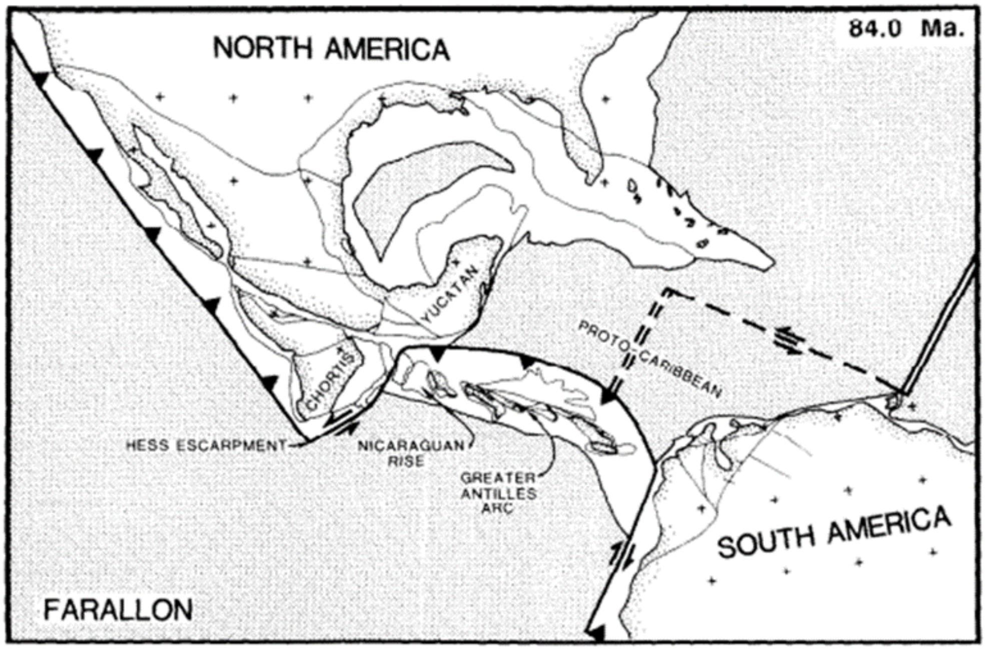


Figure 5 GOM tectonic plates during the Middle Campanian, 84 Ma. (Ross and Scotese 1987)

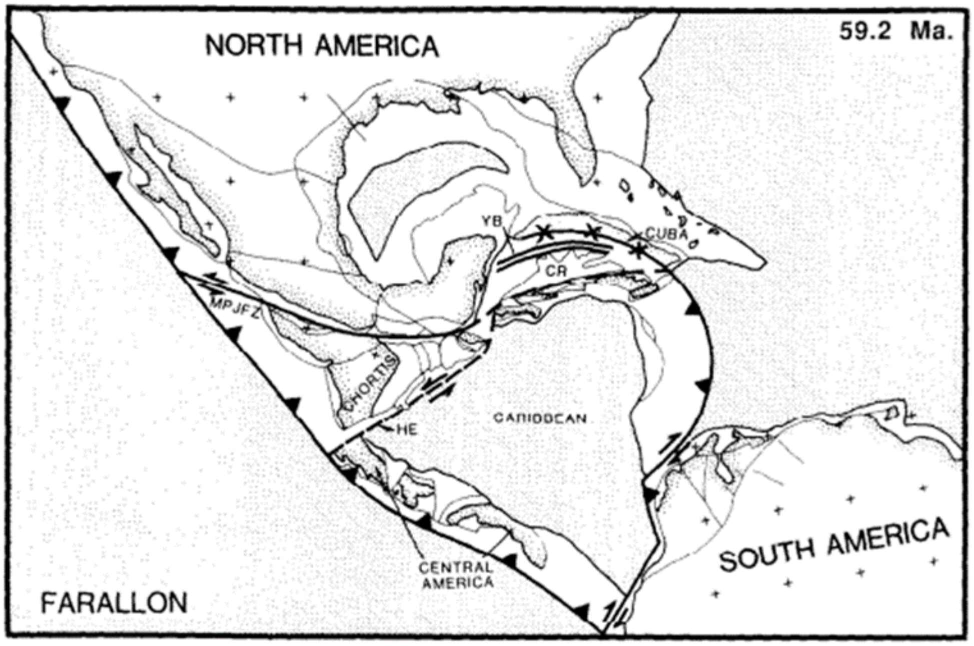


Figure 6 GOM tectonic plates during the Late Paleocene, 59.2 Ma. (Ross and Scotese 1987)

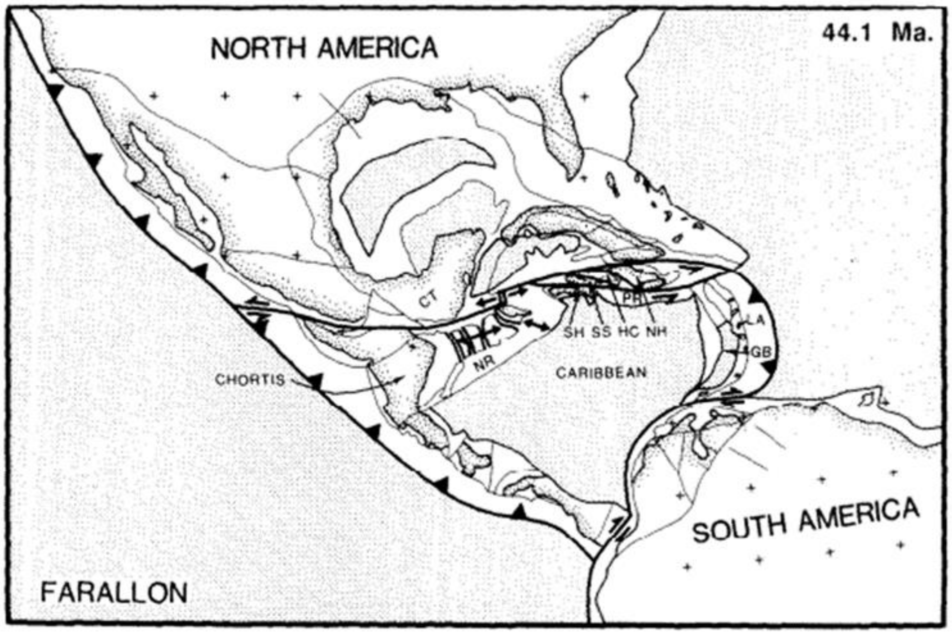


Figure 7 GOM tectonic plates during the Late Eocene, 44.1 Ma. (Ross and Scotese 1987)

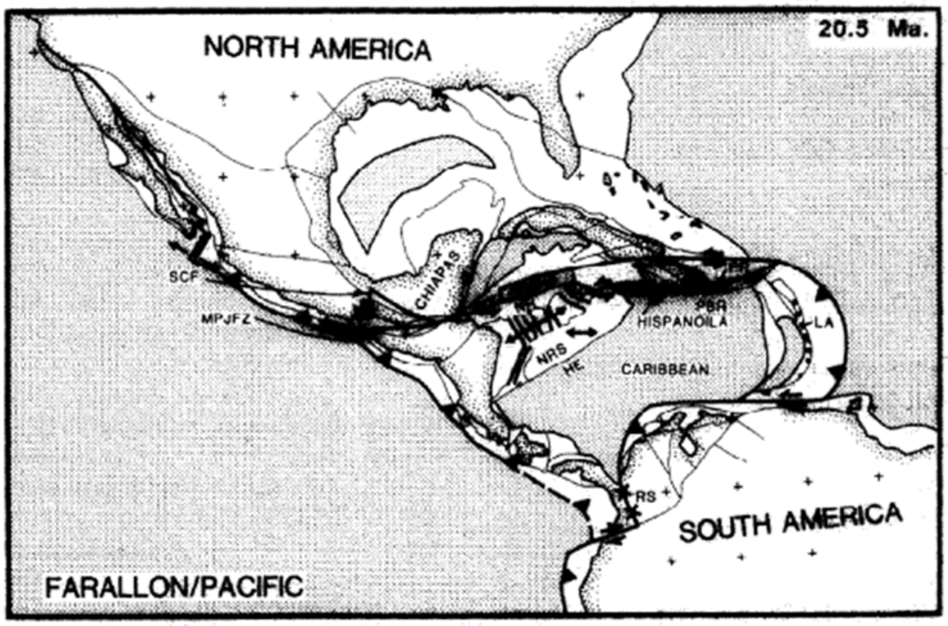


Figure 8 GOM tectonic plates during the Early Miocene, 20.5 Ma. (Ross and Scotese 1987)

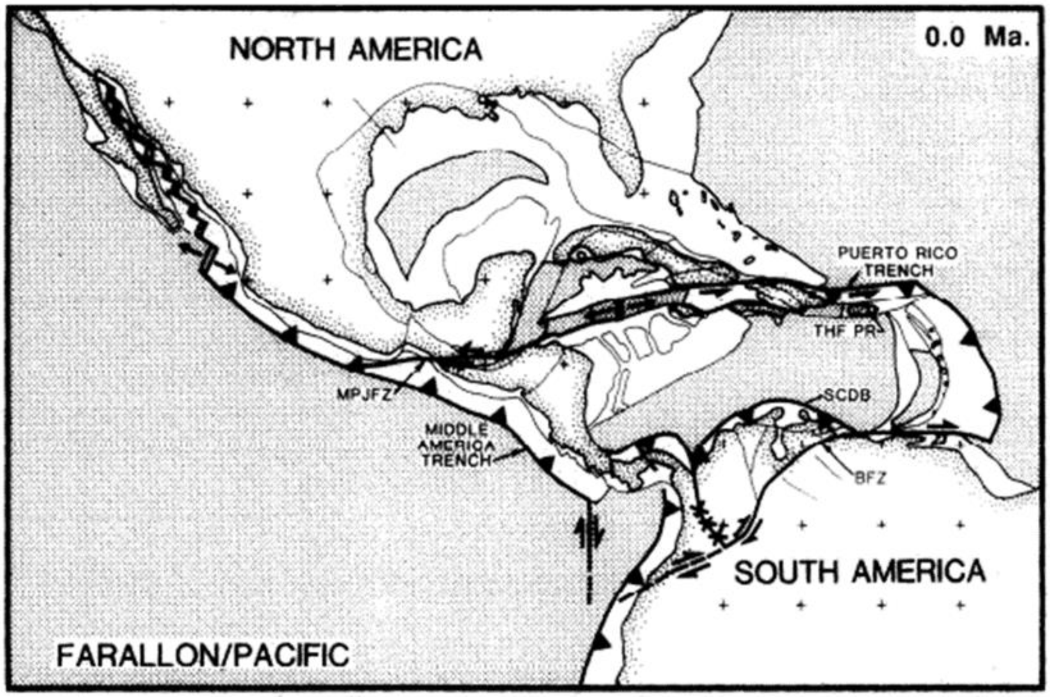


Figure 9 GOM tectonic plates during the present day, 0 Ma. (Ross and Scotese 1987)

2.2 Salt Structures

“Salt is the type example of a rock flowing in the solid state by gravity alone, because it has such low density and negligible yield strength.” (Jackson and Talbot 1986) “Salt structures can be triggered by a variety of mechanisms” (Ge et al. 1997). With all three factors “gravity is the main driving force” for the salt structures as it impacts the overbearing rock (Wu et al. 1990). Within the study area the main styles are a “result of extensional and gravitational deformations” (Wu et al. 1990). Like other sedimentary rocks salt is initially deposited horizontally, but over time the salt will begin to in response to the overbearing weight of the rock. The salt will move laterally and begin to concentrate in adjacent areas over time while leaving other areas to contain only a thin layer after the movement. Once accumulated the salt will begin to move upwards if more pressure is applied causing salt structures such as seen in east Texas or the Gulf of Mexico. These are called either salt diapirs or salt pillows with the latter being a larger area with less uplift and the diapirs being relatively narrow uplifts of salt. “Salt pillows are broad, plano-convex domes of salt that represent a less mature, more primitive stage of salt-dome growth. Salt diapirs consist of a core of intrusive salt— the salt stock— surrounded in most instances by an aureole of domed sediments.” (Jackson 1984) In the Gulf of Mexico, the slope is dipping down into the basin and so over time the salt structures begin to move down slope into the basin. The horizontal movement gives these canopy structures to the salt in the area. These canopy structures are the sloped fan-like structures in the Gulf of Mexico such as in Figure 10.

As with all sedimentary rocks, the rock that overlies the salt was originally deposited horizontally but as it adds pressure on the salt the salt will move and accumulate in areas of reduced pressure. The rock layers above the concentrated areas will then begin to fold around the salt. These structures have a strong impact on the surrounding rock formations in the area due to the uplifting of the concentrated areas and the down dropping of the areas of salt withdrawal. The salts uplift creates anticlinal structures over the top of the salt. These anticlinal structures formed in the overlying rock layers will also cause fracturing and faulting. With a proper seal in place, these additional structures can provide reliable traps for economic resources such as oil or gas. These structures can also reveal genesis and migrational history of the salt.

These structures are usually located deep in the subsurface and, in of the Gulf of Mexico, visualizing these structures without any geophysical aid is impossible. Due to the difficulty associated with observing these subsurface structures they are commonly imaged using 2-D or 3-D seismic data as it allows for an overall view of these large structures and lithologic changes in the subsurface. The use of seismic allows the imaging of these subsurface structures, as well as their structural impact on the surrounding rock layers.

Within the GOM basin “the size and type of salt-related structures seem to be directly controlled by the thickness of the underlying salt.” (McGowen 1984) With the thickness of the Louann Salt changing across the basin means that the structures that are found can be different from area to area.

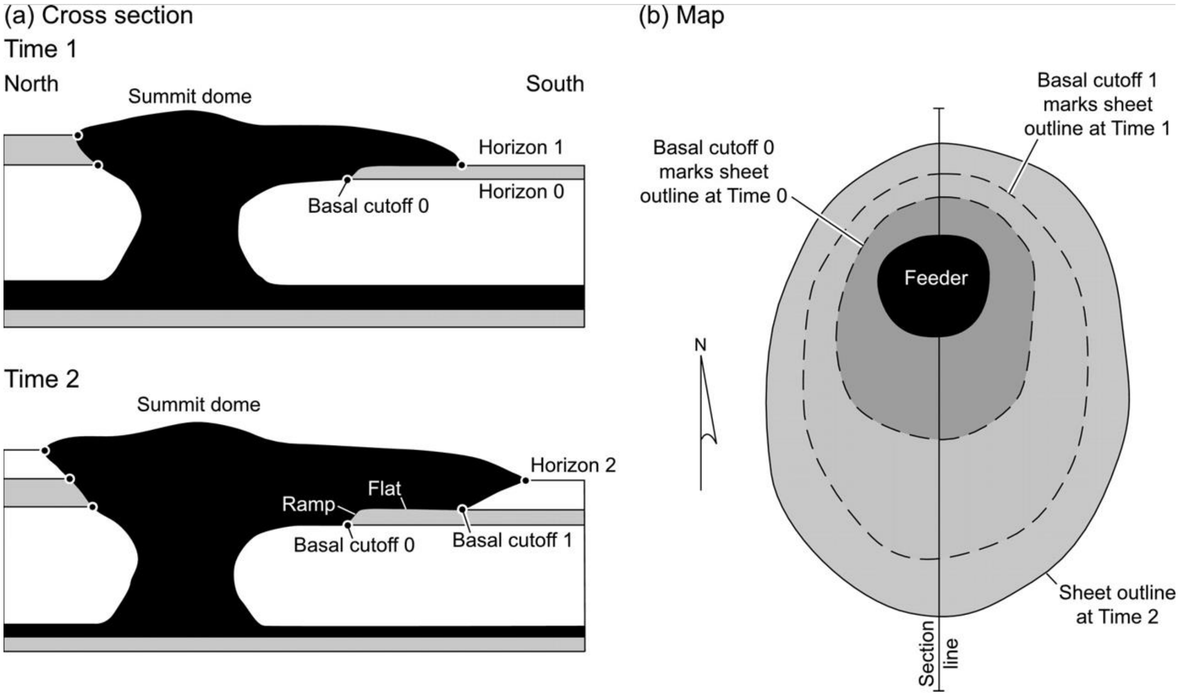


Figure 10 Shows the parts of a salt canopy as well as how the canopy can move over time. In section (a) the two-time images show the parts of a salt canopy in a cross-sectional view. Section (b) shows the same salt canopy structures, but as a top-down view. (Jackson and Hudec 2017)

2.3 Depositional Systems

In order to identify the different kinds of depositional systems found in deep sea subsurface rocks the use of 2-D and 3-D seismic data is a valuable tool. Turbidity channels can be found within slope and basin floor environments and may have levees present. “At the base of a channel complex, most leveed channels are characterized by inclusion into the immediately underlying substrate” which can be seen in the slices in the seismic data (Posamentier and Venkatarathnan 2003). The fills of channels can be seen within the seismic data and can be determined as passive fills or active fills. In general, the passive fills will sit on top of the active fills and fill in the area that the active fill could not. These channel fills “are characterized primarily by high-amplitude seismic reflections and are interpreted to be sand-rich” for the most part (Posamentier and Venkatarathnan 2003). The size of these deposits is dependent on the degree of the meander loops of the system.

Overbank and levee deposits are where the sediments are deposited over the floor plain outside of turbidite channel due to overflow of the channel. These sedimentary deposits can form what are called sediment waves in flood plains where the sediment will form wave-like structures as it is deposited. These sediment waves can vary in size and wavelength depending on the amount of energy in the system at the time with a higher energy giving a longer wavelength. As the overbank flows farther away from the system there is an increase in the volume of sand when compared to the volume of mud. These "deposits have been documented to contain reservoir-quality thin-bedded sandstones" and as such provide potential for trapping an economic resource.

"The transition from leveed channel to splay complex is associated with a marked reduction in channel width, channel depth, channel sinuosity, and levee height" (Posamentier and Venkatarathnan 2003). The splays are fed by the leveed channels and is more of the system out flowing into unconfined areas. These areas can possess high reservoir qualities depending on the quality and volume of sand present. These unconfined sections can also be very widespread allowing for many resources to be present.

Debris-flows are when large amounts of sediment begin to flow down a slope like a liquid. These "deposits take a variety of forms, ranging from sheets to lobate tongues to channel fill" (Posamentier and Venkatarathnan 2003). These flows are generally not widespread but instead are condensed to a smaller area. No matter which of the types of depositions that occur with the debris flow there will always be grooves present. These grooves are great identifying factors for the presence of a debris flow.

There are many factors that determine the type of deposition that will occur within a deep-water environment. Each of these factors determines different properties of the deposition and so various mixes may cause very different results. The amount of sand compared to the amount of mud can determine whether there is one channel, or a network and the gradient of the floor can determine the shape of the network or levee. When analyzing the deposits in the seismic data all the properties can be linked back to the initial determining factors of the depositional system.

2.4 Seismic Data

“Geophysical inversion involves mapping the physical structure and properties of the subsurface of the earth using measurements made on the surface of the earth.” (Russell 1988) Seismic method focuses on the collection of the arrival times of the various seismic waves that are created during the process. Seismic surveys can be done on both land and sea using slightly different processes to get the data. Each seismic survey has two major parts which are the source and the receivers.

“A disturbance propagates outward as a series of wave fronts quite analogous to the ripples on the lake.” (Burger et al. 2006) A seismic source is used to create the initial seismic waves that are reflected off interfaces between geologic strata with different seismic properties. This is a singular location that creates a wave and for small land surveys a hammer hitting a metal plate will work to create an initial wave. “The passage of the wave fronts by each point on the surface is marked by the motion of that surface, which can be measured and recorded by sufficiently sensitive detecting equipment and recording instruments.” (Burger et al. 2006) For larger seismic surveys, the most common source that is used is a thumper truck or controlled source explosives. For marine surveys, air guns or water cannons attached to the back of the boat are used as sources. The type of source is mainly determined by costs and environmental considerations.

In addition to a source, exploration seismologists need to record seismic travel times from source to geological interfaces and back to receivers. For a 2-D survey these receivers are strategically placed around the source to produce optimum levels of geometric coverage. For a 3-D survey a grid of receivers is set up instead of just one line. For the 3-D surveys receivers, there is a difference between the way the receivers are arranged. On a land survey, geophones are staked into the ground and for a marine survey the geophones are often floating very close to the surface of the water.

There are three different ways that the waves from the source can travel. The first is the simplest wave and is called the direct wave. This wave travels just parallel to the ground surface or water surface. Since it only travels on one surface the velocity of this wave is consistent as it is traveling only on one surface.

Refracted waves travel down into the subsurface and when they hit rock layers of varying velocities, they will experience a chance in direction as they travel across that boundary. Waves will also begin to create new waves as they travel so as the wave travels across the contact surface it creates new waves that return to the surface. These waves are then timed by the receivers at the surface. These are generally only used in shallow surveys with only one or two changes in wave velocity.

The third wave type is the reflected waves which are the most common wave type used in deep surveys which can have numerous amounts of impedance boundaries. “When a compressional seismic wave travels through a material—whether solid, liquid, or gas—part of the wave reflects wherever a change in acoustic impedance occurs” (Dragoset 2005). In other words, these waves will hit a velocity change and bounce off it and return to the surface at the same angle that it hit the boundary. The wave will also bend and continue down as well reflecting off deeper velocity boundaries. Each boundary will have a recorded two-way time at the receivers and can then be processed into a full seismic section.

The interpretation of processed seismic data is mostly done through the reflected waves. Post-processed seismic data shows different reflectors which are the visual representation of the velocity changes in the subsurface. These reflectors are typically seen using black and white in Figure 11 however “Color-encoded displays of attribute values aid in interpretation of seismic data relevant to stratigraphy.” (Taner 1979) Figure 12 shows various colors patterns that can be used to make some kinds of reflectors more visible than others.

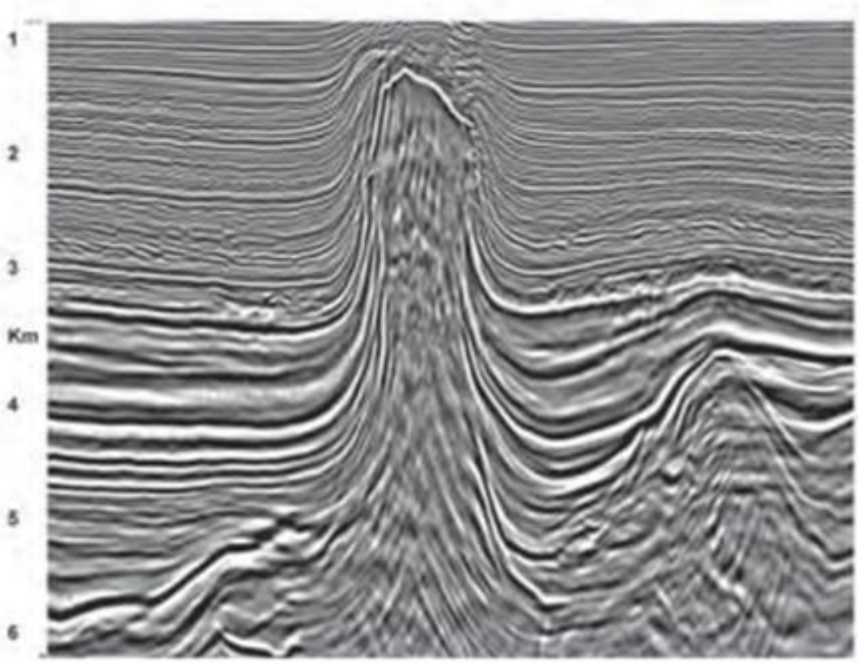


Figure 11 Black and white seismic reflectors being used to show salt structures. (Jones and Davison 2014)

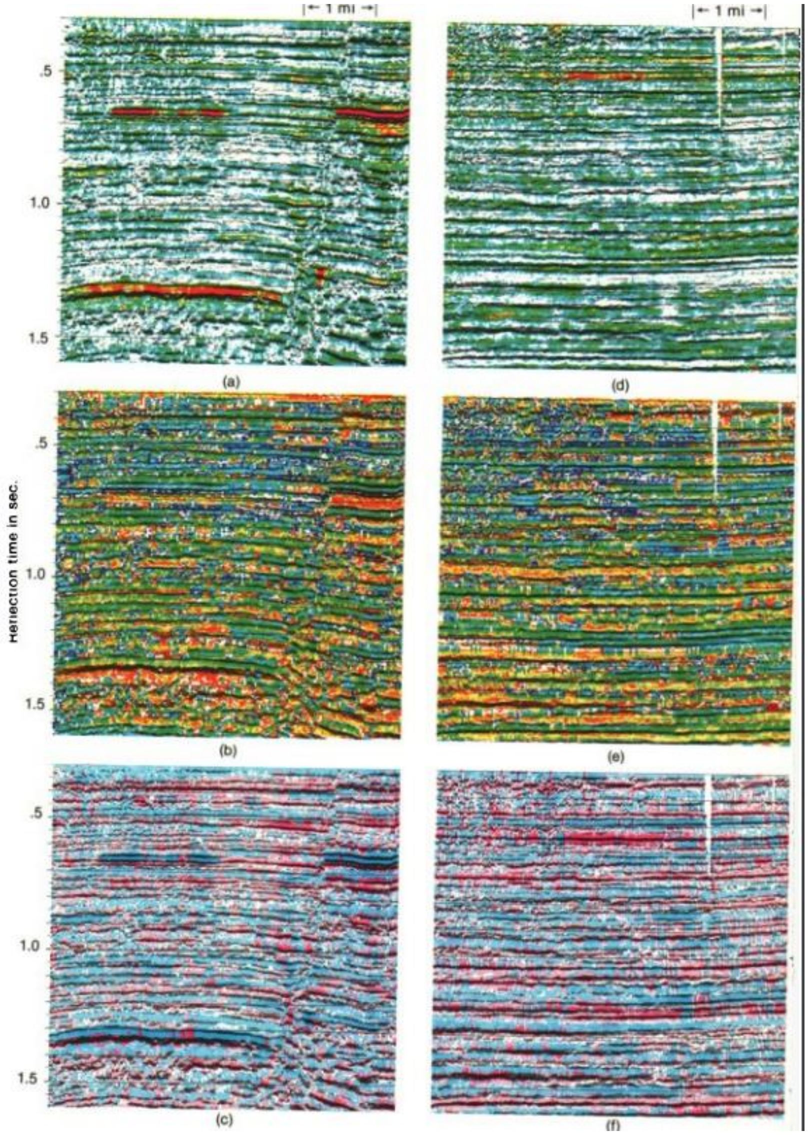


Figure 12 Examples of different color patterns that can be used to make various structures easier to see. (Taner et al. 1979)

2.5 Analog

Salt is commonly found in various parts of the world. In addition to being found in the Gulf of Mexico, salt strata are similarly located in the Kwanza Basin off the west African coast which is seen in Figure 13. “Outboard of the escarpment lies a region of salt-detached raft blocks, which are closely analogous to type examples in the Kwanza Basin, Angola, in terms of structural style, scale, and amount of extension.” (Pilcher et al. 2014) Due to the many similarities, this basin was used as a good reference as to what should be seen when analyzing the Gulf of Mexico.

Rafting is one of the lesser-known structures caused salt movement but is a very impactful structure. Rafting is the movement of the overlying rock by the horizontal movement of the salt into the basin. The overlying rock will ride on top of the salt as it moves into the basin. The Kwanza Basin has this occur in multiple stages and the units will continue to move if there is a constant supply of salt moving deeper and deeper into the basin. The various structures of the Kwanza Basin that were influenced by rafting are depicted in Figure 13. Figure 14 shows the rafting caused by the salt is shown in both a diagram and in the uninterpreted seismic data.

The Kwanza Basin when compared to the Gulf of Mexico basin tends to have thicker salt strata included in it. This means that the salt structures in the Kwanza Basin can be fed for a longer period. In the Gulf of Mexico Basin much of the salt structures have already started to spread themselves a little bit thinner due to being cut off from the salt or not having enough salt. A good example of this is how in the study area the canopy is cut off from the source of salt. Along with the Kwanza Basin offshore Israel also shares the extensional domain of salt-basin margins are normal faults associated with the salt pinch-out. (Gradmann et al. 2005)

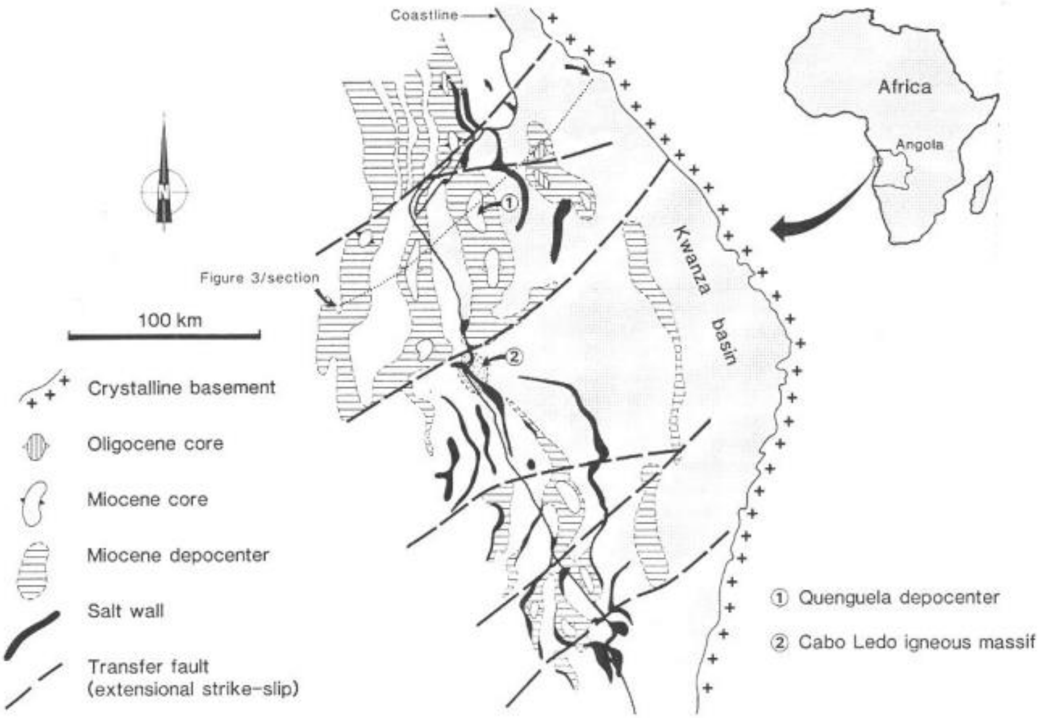


Figure 13 A structural map showing the geographical location of the Kwanza Basin in Africa. The Kwanza Basin is off the coast of Angola, Africa containing many extensional strike-slip faults that run south-west to north-east. This map focuses on the major salt and faulting structures that are found in this basin. The salt walls above are rafts that were moved down into the basin by the underlying salt layers. Duval (1992)

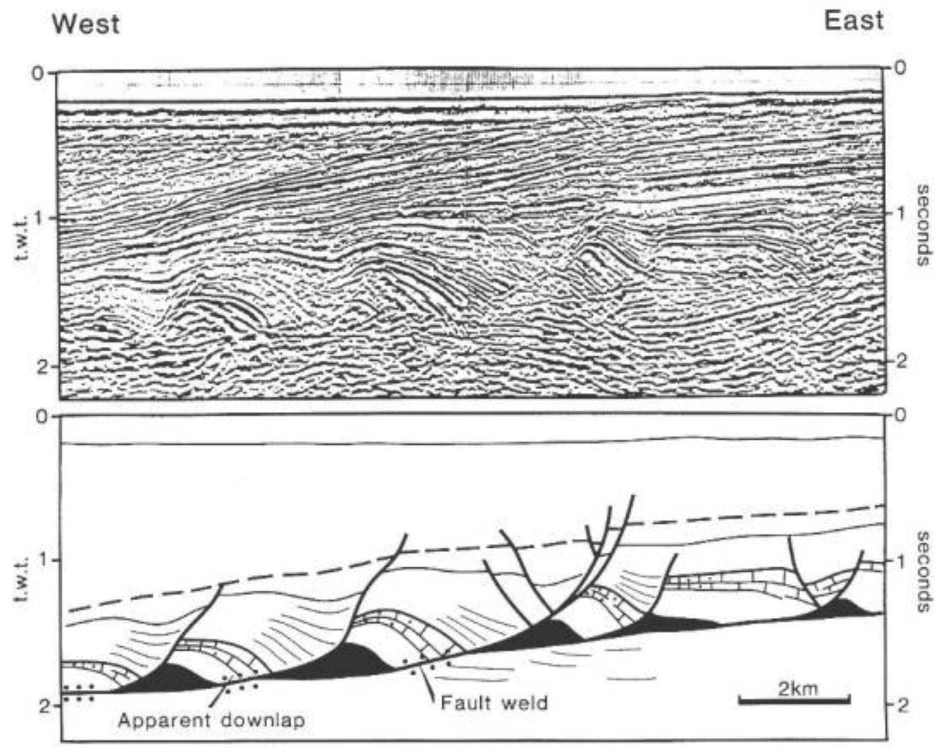


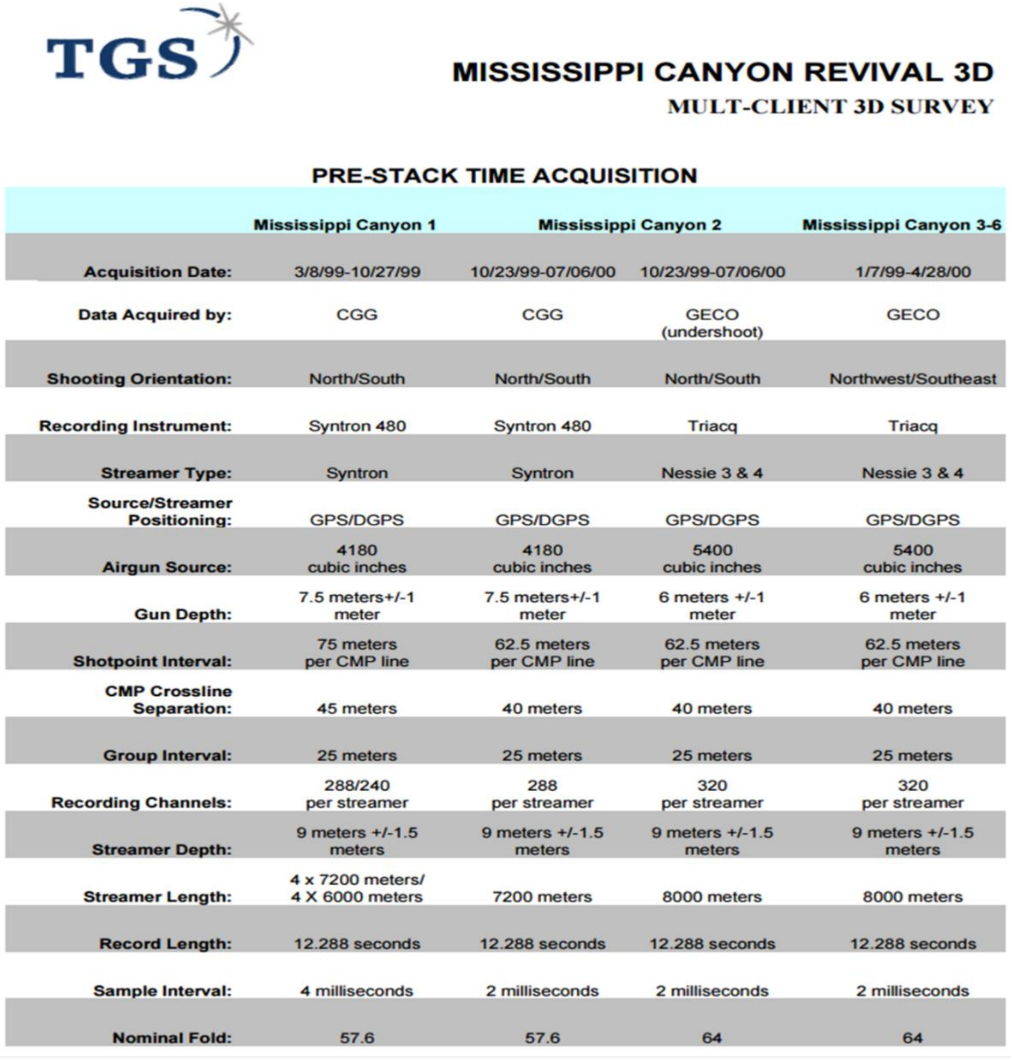
Figure 14 The upper image shows the uninterpreted seismic data that was seen in the Kwanza Basin. Between the 1 and 2 second two-way times small triangles can be seen that are the rafted units. The bottom image shows the interpretation of the section above including the rafts and faults. Duval (1992)

Chapter 3 Methodology

3.1 Data Acquired

The data is presented in the form of 3-D seismic data from the Mississippi Canyon area covering the Whiting Dome. This seismic data was acquired from Tomlinson Geophysical Services, Inc (TGS). over the study area. The 3-D seismic survey was conducted over the Whiting Dome and used the parameters shown in the tables Figure 15 and Figure 16 shown below. These Figures include the acquisition time, crossline distance separation, and survey orientation that were used. This seismic data allowed for the mapping and analyzing of the Louann Salt and the structures that are created by its movement within the study area. This seismic data was provided in two-way time format from 0-3 seconds in time depth. The seismic data was used for all the data interpretation of the Whiting Dome and the associated structures, which will be compared to the sea floor map in Figure 2.

The deep-sea bathymetry data was acquired in two ways for the purpose of this study. The first is an image of the sea floor that is used from Google Maps. The second image is a seismic interpretation of the sea floor horizon from the seismic data provided by TGS. The seismic data interpretation can give more detailed information on the subsurface structures than what can be viewed on general sea floor images. Both were used to not only round out the data, but also ground truth the seismic sea floor to that of the sea floor imaging.



TGS

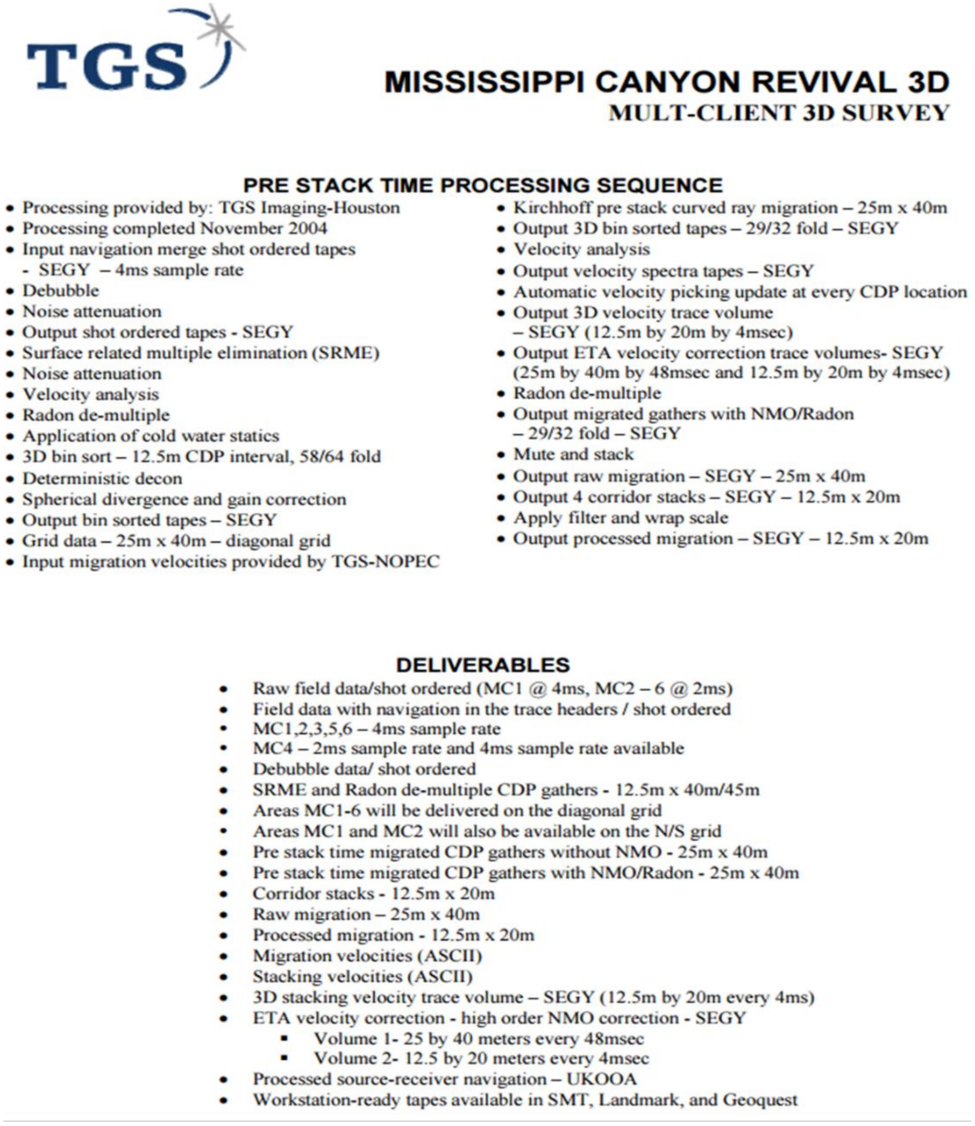
MISSISSIPPI CANYON REVIVAL 3D

MULT-CLIENT 3D SURVEY

PRE-STACK TIME ACQUISITION

	Mississippi Canyon 1	Mississippi Canyon 2		Mississippi Canyon 3-6
Acquisition Date:	3/8/99-10/27/99	10/23/99-07/06/00	10/23/99-07/06/00	1/7/99-4/28/00
Data Acquired by:	CGG	CGG	GECO (undershoot)	GECO
Shooting Orientation:	North/South	North/South	North/South	Northwest/Southeast
Recording Instrument:	Syntron 480	Syntron 480	Triacq	Triacq
Streamer Type:	Syntron	Syntron	Nessie 3 & 4	Nessie 3 & 4
Source/Streamer Positioning:	GPS/DGPS	GPS/DGPS	GPS/DGPS	GPS/DGPS
Airgun Source:	4180 cubic inches	4180 cubic inches	5400 cubic inches	5400 cubic inches
Gun Depth:	7.5 meters+/-1 meter	7.5 meters+/-1 meter	6 meters +/-1 meter	6 meters +/-1 meter
Shotpoint Interval:	75 meters per CMP line	62.5 meters per CMP line	62.5 meters per CMP line	62.5 meters per CMP line
CMP Crossline Separation:	45 meters	40 meters	40 meters	40 meters
Group Interval:	25 meters	25 meters	25 meters	25 meters
Recording Channels:	288/240 per streamer	288 per streamer	320 per streamer	320 per streamer
Streamer Depth:	9 meters +/-1.5 meters	9 meters +/-1.5 meters	9 meters +/-1.5 meters	9 meters +/-1.5 meters
Streamer Length:	4 x 7200 meters/ 4 X 6000 meters	7200 meters	8000 meters	8000 meters
Record Length:	12.288 seconds	12.288 seconds	12.288 seconds	12.288 seconds
Sample Interval:	4 milliseconds	2 milliseconds	2 milliseconds	2 milliseconds
Nominal Fold:	57.6	57.6	64	64

Figure 15 The table shows numerical values that were used by TGS in order to take the seismic data in the Mississippi Canyon. This includes information about the types of instruments that were used to record the data and how they were positioned.



TGS

MISSISSIPPI CANYON REVIVAL 3D

MULT-CLIENT 3D SURVEY

PRE STACK TIME PROCESSING SEQUENCE

- Processing provided by: TGS Imaging-Houston
- Processing completed November 2004
- Input navigation merge shot ordered tapes
  - SEGY – 4ms sample rate
- Debubble
- Noise attenuation
- Output shot ordered tapes - SEGY
- Surface related multiple elimination (SRME)
- Noise attenuation
- Velocity analysis
- Radon de-multiple
- Application of cold water statics
- 3D bin sort – 12.5m CDP interval, 58/64 fold
- Deterministic decon
- Spherical divergence and gain correction
- Output bin sorted tapes – SEGY
- Grid data – 25m x 40m – diagonal grid
- Input migration velocities provided by TGS-NOPEC
- Kirchhoff pre stack curved ray migration – 25m x 40m
- Output 3D bin sorted tapes – 29/32 fold – SEGY
- Velocity analysis
- Output velocity spectra tapes – SEGY
- Automatic velocity picking update at every CDP location
- Output 3D velocity trace volume
  – SEGY (12.5m by 20m by 4msec)
- Output ETA velocity correction trace volumes- SEGY
  (25m by 40m by 48msec and 12.5m by 20m by 4msec)
- Radon de-multiple
- Output migrated gathers with NMO/Radon
  – 29/32 fold – SEGY
- Mute and stack
- Output raw migration – SEGY – 25m x 40m
- Output 4 corridor stacks – SEGY – 12.5m x 20m
- Apply filter and wrap scale
- Output processed migration – SEGY – 12.5m x 20m

DELIVERABLES

- Raw field data/shot ordered (MC1 @ 4ms, MC2 – 6 @ 2ms)
- Field data with navigation in the trace headers / shot ordered
- MC1,2,3,5,6 – 4ms sample rate
- MC4 – 2ms sample rate and 4ms sample rate available
- Debubble data/ shot ordered
- SRME and Radon de-multiple CDP gathers - 12.5m x 40m/45m
- Areas MC1-6 will be delivered on the diagonal grid
- Areas MC1 and MC2 will also be available on the N/S grid
- Pre stack time migrated CDP gathers without NMO - 25m x 40m
- Pre stack time migrated CDP gathers with NMO/Radon - 25m x 40m
- Corridor stacks - 12.5m x 20m
- Raw migration – 25m x 40m
- Processed migration - 12.5m x 20m
- Migration velocities (ASCII)
- Stacking velocities (ASCII)
- 3D stacking velocity trace volume – SEGY (12.5m by 20m every 4ms)
- ETA velocity correction - high order NMO correction - SEGY
  - Volume 1- 25 by 40 meters every 48msec
  - Volume 2- 12.5 by 20 meters every 4msec
- Processed source-receiver navigation – UKOOA
- Workstation-ready tapes available in SMT, Landmark, and Geoquest

Figure 16 This table lists what was done in order, for processing the raw seismic data that was acquired by TGS. The deliverables section is what comes with the data that was processed.

3.2 Data Interpretation

The Kingdom Software (TKS) by IHS was used to interpret the 3-D seismic dataset. The TKS allowed for the viewing and manipulation of the seismic inlines and crosslines as well as the ability to map horizons over the study area through their respective reflectors. "A horizon is a generic term for a picked surface within the seismic data." (Worrell 2017) The bulk of the study was based on observing at the structures that are directly caused by the Louann Salt's movement into the basin.

"Louann salt that is at least Oxfordian but more likely Callovian in age." (Bartok 1993) The top of the Louann Salt provides a very strong reflector in the seismic section as it spans most of the study area and is the major factor in the creation of the structures that are found in the study area. The strength of the reflector makes it differentiable from the other reflectors in the seismic data. The sea floor was also mapped using the seismic data as a secondary resource to use alongside the sea floor imaging. The use of both were used to verify the accuracy of the data and information interpretation.

The major unit that is being mapped throughout the study area is the top of Allochthonous Louann Salt Canopy. The age of the depositional units that are located on top of the Whiting Dome salt are deposited in the Pliocene epoch (Worrell 2017). Though these unit's tops will not be individually mapped from not having well log data these are the units that are present in the study area. The units that are listed above are in order from the oldest to the youngest in geologic age. The structures in the study area are heavily influenced by the halokinesis of the Louann Salt.

The faults have also been mapped across the area and then split into sections based on how the faults formed and where the faults had formed in the study area. The faults were split up into four different sections that cover the study area in Figure 18. The head of the salt is located right above the neck of the salt canopy. The next section is the toe of the salt which is located at the farthest point of the canopy from the head of the salt. The center of the salt canopy and the sides of the salt canopy are the remaining two sections where faults were observed.

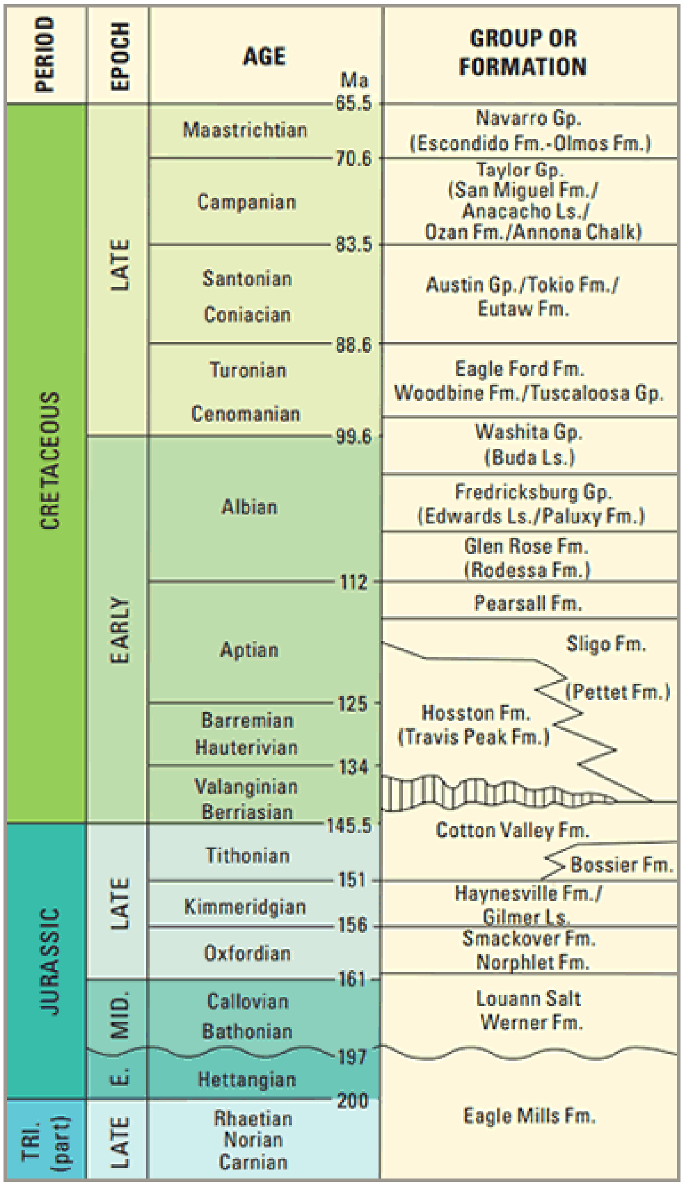


Figure 17 A stratigraphic section of the Gulf of Mexico area from the late Triassic to the late Cretaceous. The Callovian Louann Salt is the major unit that is being studied. Above the Louann Salt is the Norphlet, Smackover, Haynesville, and Cotton Valley which were deposited just after. (King 2019) At Whiting Dome the salt canopy is allochthonous and has been remobilized downdip and up section from its original location of deposition. During the remobilization, the original roof rock is often not preserved and today the age of the sediments on top of Whiting dome are Pliocene (Worrell, 2017)

Figure 18 The salt canopy was split into 4 different sections. The neck is the section where the salt is being fed into the canopy. The toe is the furthest section into the basin. The edge are the sides of the salt canopy where the salt had moved perpendicular to the direction of the basin. The center is the area where the previous four sections meet.

Chapter 4 Interpretations

4.1 Canyon Infills

A canyon occurs where a deep gorge is present in the surface rock through a period of erosion in the area. A canyon infill is where these deep gorges are filled in entirely with sediment. Canyon infills are visible in seismic sections where the reflector makes a U-shaped dip. These infills are present across the major unconformity in the study area.

Figure 19 shows five different canyon infills that were present in inline 17840. In Figure 19 the canyon infills are centered around crosslines 15540, 15480, 15360, 15240, and 15080. The canyon infills cover between 1.5 and 1.6 seconds deep on the two-way time. These are located across the Upper Pliocene horizon and a representative of the change between the rafted units that are present below this horizon and the flat lying unit present above this horizon.

The canyon infills are not found throughout the study area and are focused on the northeastern part of the study area in areas where the salt is present below in Figure 19. The southwestern part of the study area is void of the canyon infills, but still containing the Upper Pliocene horizon and is still an unconformity.

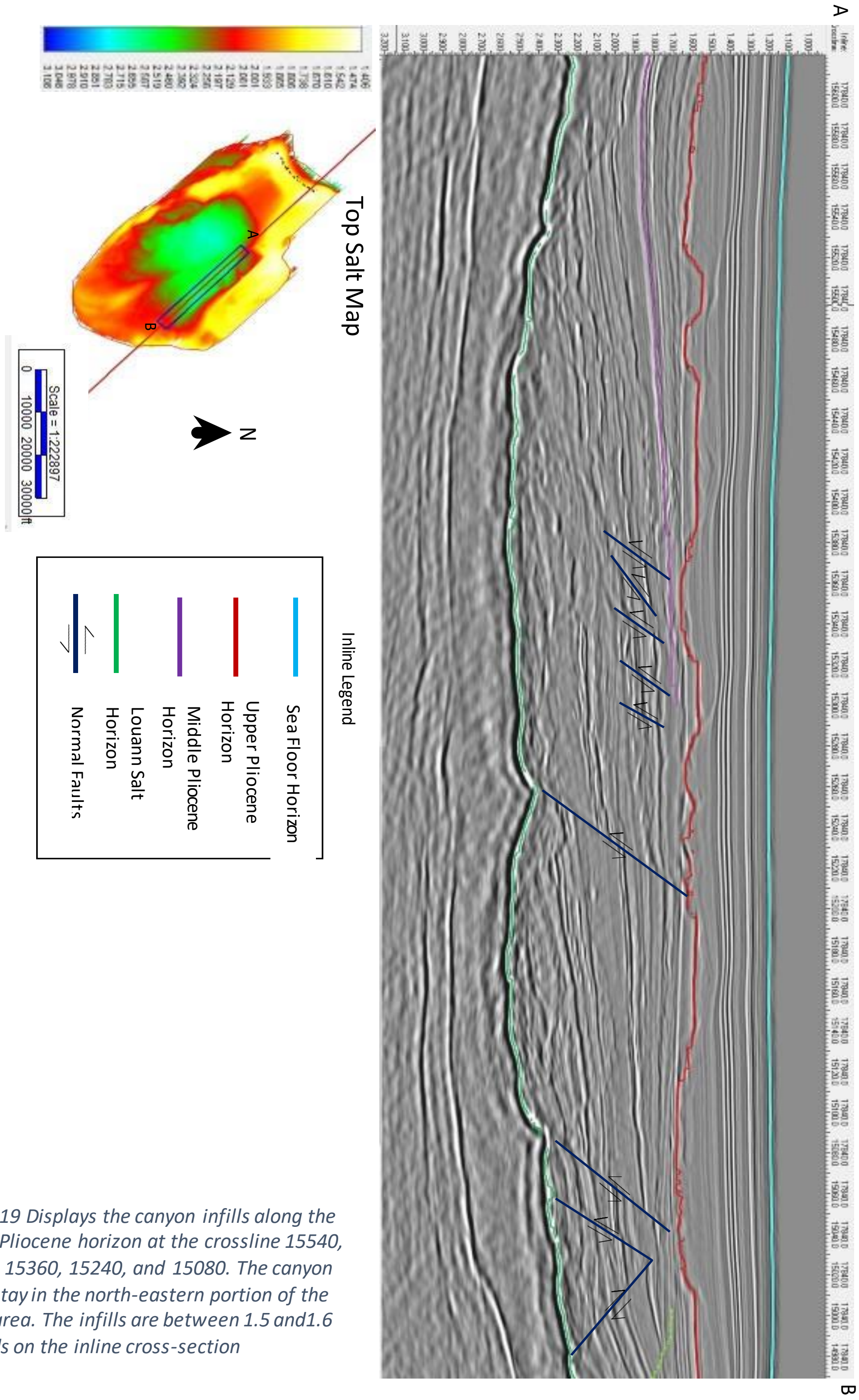


Figure 19 Displays the canyon infills along the Upper Pliocene horizon at the crossline 15540, 15480, 15360, 15240, and 15080. The canyon infills stay in the north-eastern portion of the study area. The infills are between 1.5 and1.6 seconds on the inline cross-section

4.2 Faulting

Faults located in the study area are consistent with faulting that would be expected in areas associated with salt movement. The movement of the salt mostly vertically in the process of creating newer diapirs will cause many normal faults to be formed around and above the new diapir. Faulting observed in the study area was determined to be normal faulting, which is typical for salt structures to create during their movement. The study area has been split into four sections for the identification of the faults. These sections are the neck, toe, sides, and the center of the salt canopy.

The neck of a salt diapir is the area where the canopy or diapir was being fed more salt from the source. This can be connected to the source presently or be cut off from the source creating a detached diapir or canopy. This section of the study area is the oldest area as this is where the salt first moved vertically and before the salt diapir had moved horizontally. These faults above the neck of the salt canopy are normal faults they extend upward all the way to the sea floor in the study area. In Figure 20 the faults created a depression in the sea floor horizon. A fault created depression is visible on the sea floor which gives an idea of where the neck of the salt canopy is located if looking at just the sea floor.

The center of the salt canopy is a large area where the salt seems to dip downward creating a bowl-shaped horizon such as that shown in Figure 24. This area has a limited number of faults present. In Figure 21 there a very few faults present in the area, but there are other structures that were created by the movement of the salt such as the rafting of the units and uplift of the sea floor that is caused by the vertical movement of the salt canopy.

The toe of a salt canopy is the point that has moved the furthest into the basin through the halokinesis process. In Figure 22, the toe is the point furthest southeast in the study area. The toe of the canopy has risen to be a structurally high point relative to the center of the salt canopy. There is also the presence of new salt diapirs that are being formed in this area. Above the newly created salt diapir and in various parts of the toe, there are normal faults. The faults that can be found above the new salt diapir create a depression that is visible in Figure 24. The uplifted salt at the toe it expressed as a salt high and a sea-floor high. There could be trust faulting at the edge of uplifted salt seen in figure 22 on the SW edge, but most of the uplift/thrusting appears to have taken place within the salt and not clearly visible as thrust faults in the section above the salt.

The remaining area of the salt canopy is the north-eastern and south-western areas, sides or edges of the study area. These areas are very similar to the toe of the salt canopy as they are high points in respect to the canopy. This leads to the creation of normal faults above these sections in Figure 21. These faults are also visible from the sea floor as depressions. With these depressions present in Figure 24, there is a circle of depressions that wrap around the area in which the salt is present.

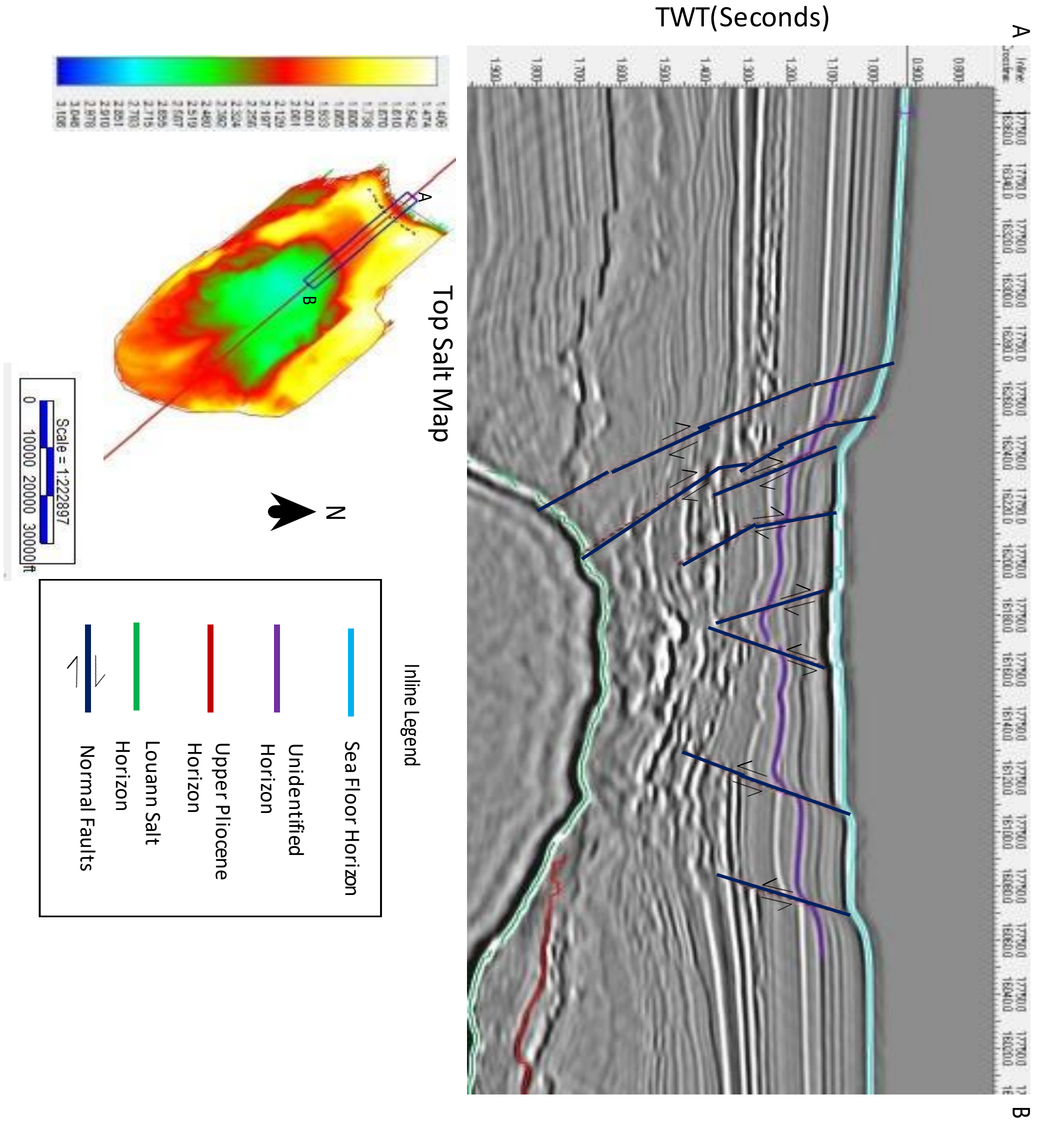


Figure 20 Located above the neck of the salt diapir there are the first normal faults that were formed from the original creation of the salt diapir. These normal faults dip towards the center of the salt neck and also cause a depression in the sea floor.

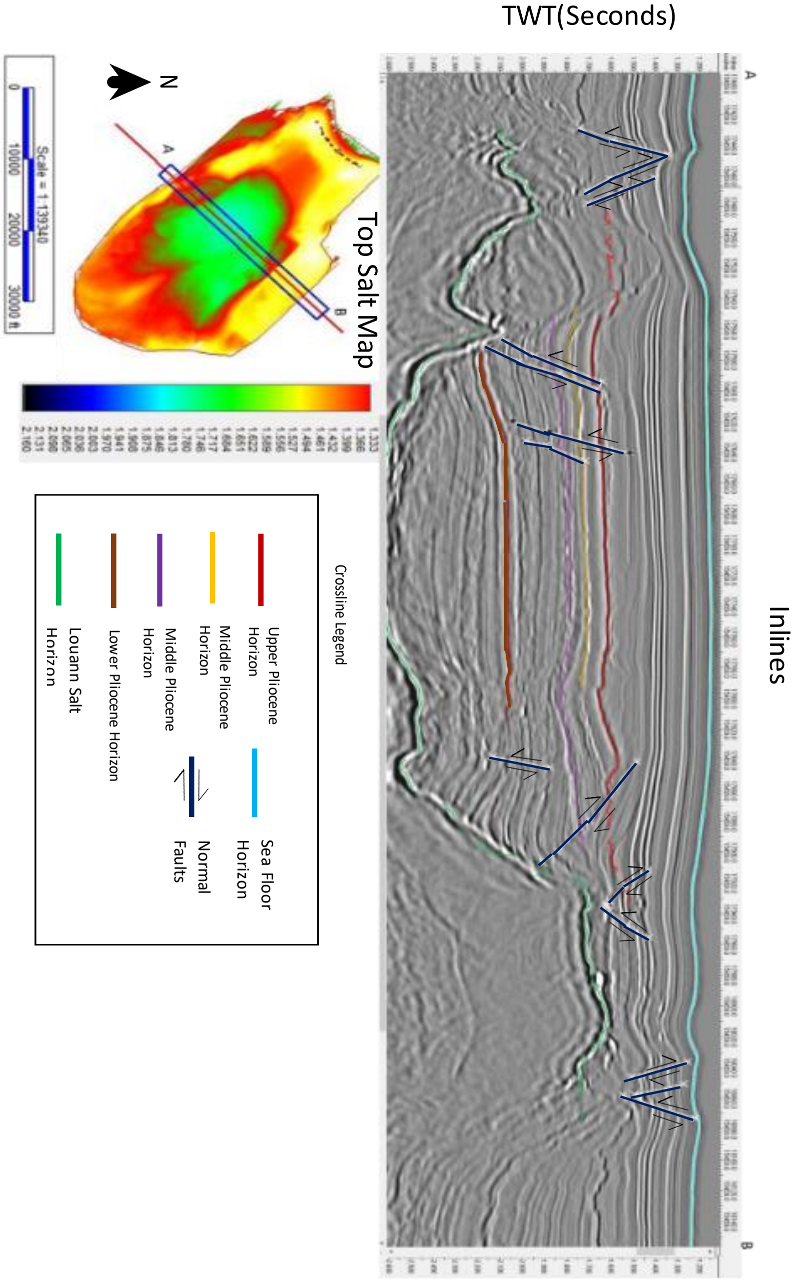


Figure 21 Faults tend to not be located in the center of the salt canopy, but instead tend to be on the edges of the boundaries.

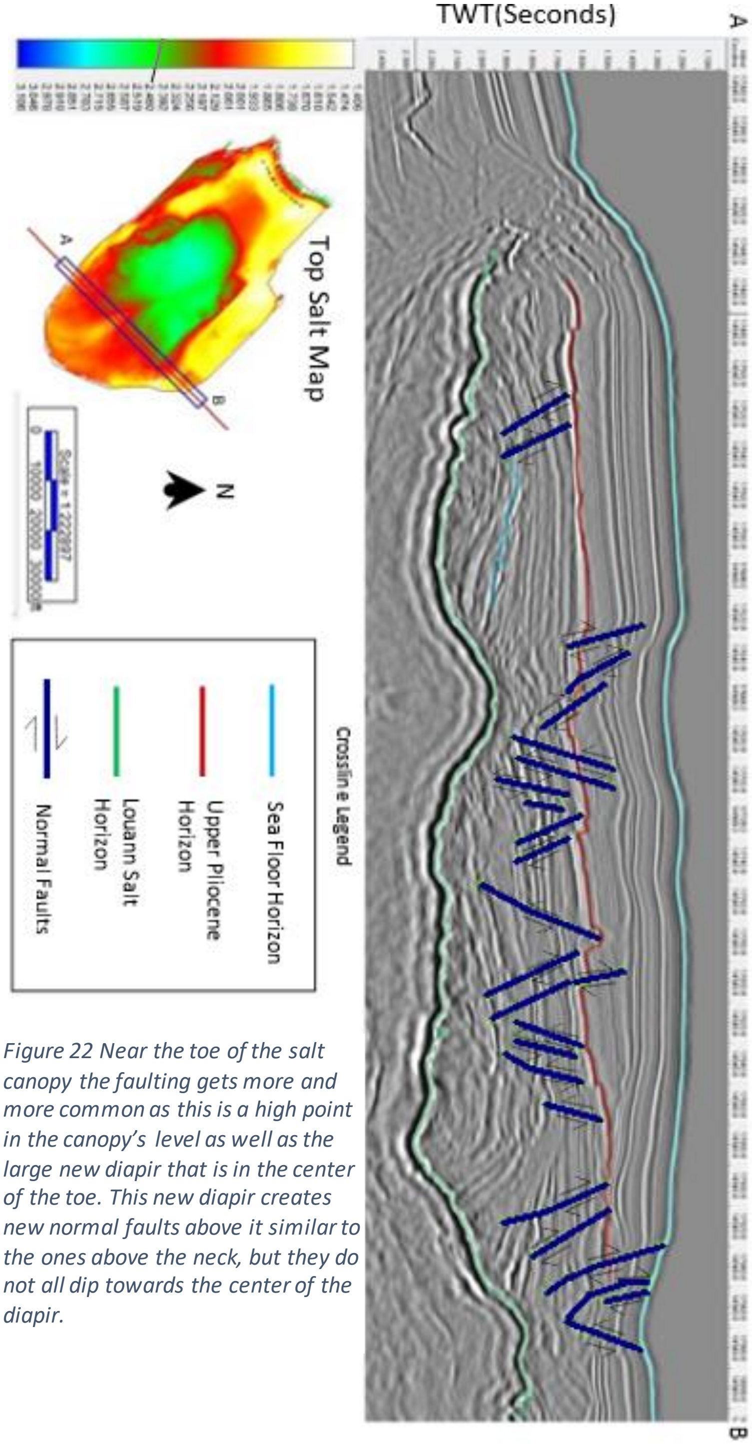


Figure 22 Near the toe of the salt canopy the faulting gets more and more common as this is a high point in the canopy's level as well as the large new diapir that is in the center of the toe. This new diapir creates new normal faults above it similar to the ones above the neck, but they do not all dip towards the center of the diapir.

4.3 Rafting

"Raft tectonics is an extreme form of thin-skinned extension" (Duval and Cramez 1992) and "occurs where the pressure gets so extreme that the blocks separate and no longer share a mutual contact." This pressure is usually due to the movement of the underlying halokinesis and is common in areas where there is a lot of salt movement such as the Kwanza Basin and the Gulf of Mexico Basin. This type of lateral extension requires horizontal space unlike the rest of the structures that are discussed which require the vertical space to move.

The Pliocene units in Figure 23 have all been moved from their originally deposited positions and deeper into the basin while riding on the Louann Salt. Since the movement occurs on the salt the north-western side of the units that is in contact, the salt will begin to fold the unit slightly due to the pressure from halokinesis. This folding of the units is more extreme the older the units is as the Pliocene horizons can be seen deviating more from the original horizontal deposition than the younger Pliocene units.

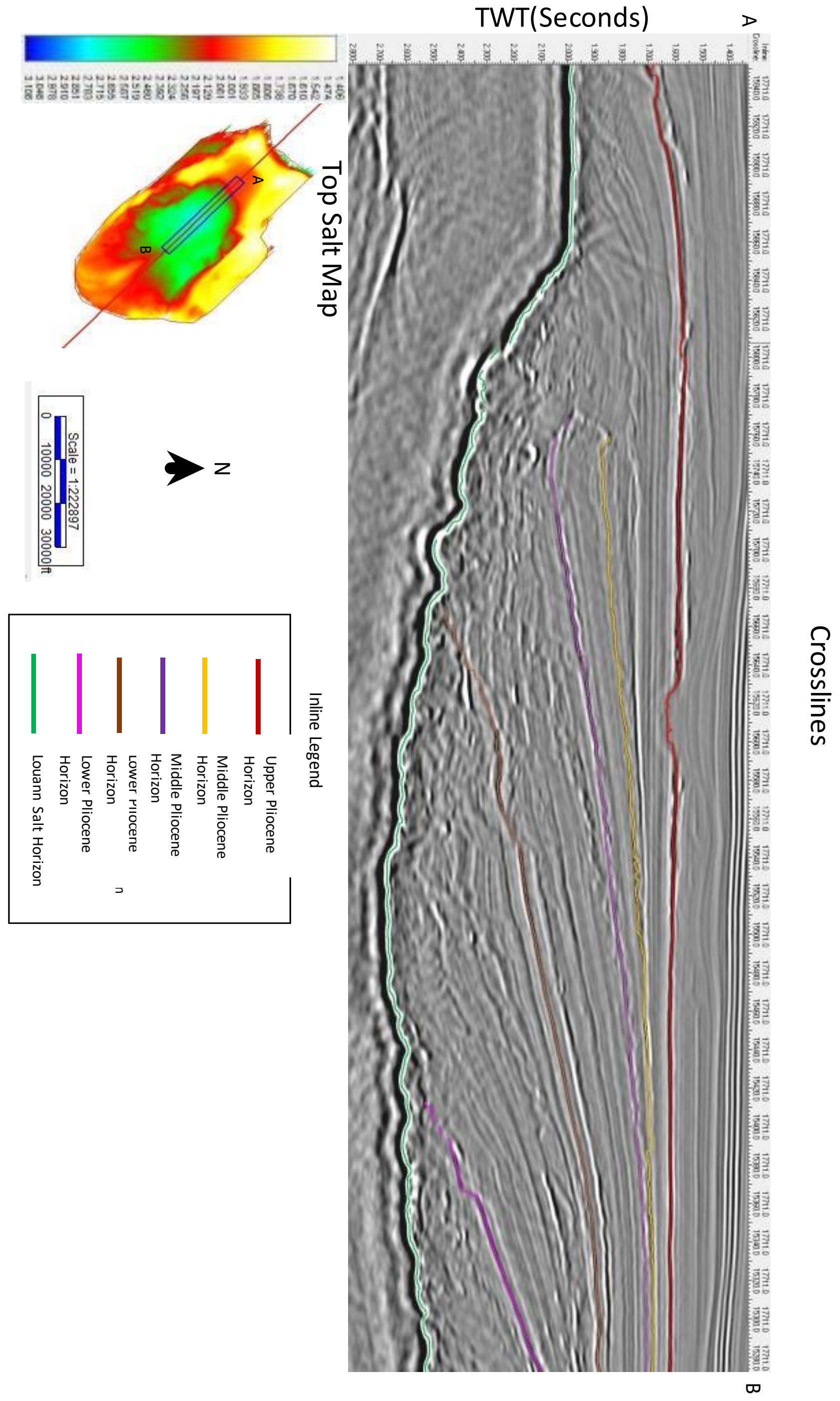


Figure 23 The units that are located over the salt canopy have been moved deeper into the basin at inline 177110. The Pliocene units were all moved from their original location in the above. As the units are moved into the basin the side of the units that are closer to the neck tend to fold down towards the salt.

4.4 Rotated Beds

A unit or bed is considered rotated when the originally horizontally deposited unit begins to rotate in the direction that it is being pulled. This may be due to pressure from the surrounding units in the area and is generally associated with compression in the area. The compression within the study area is also associated with the faulting that surrounds the rotated bed, Figure 24. The reflectors in the Figure shown are at an angle relative to the surrounding flatter units showing that the units have been rotated due to compression.

The extensional force that caused these units to be rotated was caused by the movement of the underlying salt. The movement of the salt rafts the sediment pods down dip and there is accommodation space up dip where there are thicker sediments filling the accommodation space. The thicker sedimentation up dip may also push the underlying salt downdip due to differential loading. There is a newly created diapir on the canopy centered around crossline 15400 in Figure 25. The new diaper may be the result of extension, perpendicular to the toe due to the spreading outward of the salt canopy. The newly formed diapir has surrounded the rotated beds creating a room like structure that can be seen in Figure 25. The room can be used to see the extent at which the beds were rotated as well as to why the rotated beds are not seen throughout the study area and are instead localized to a small area.

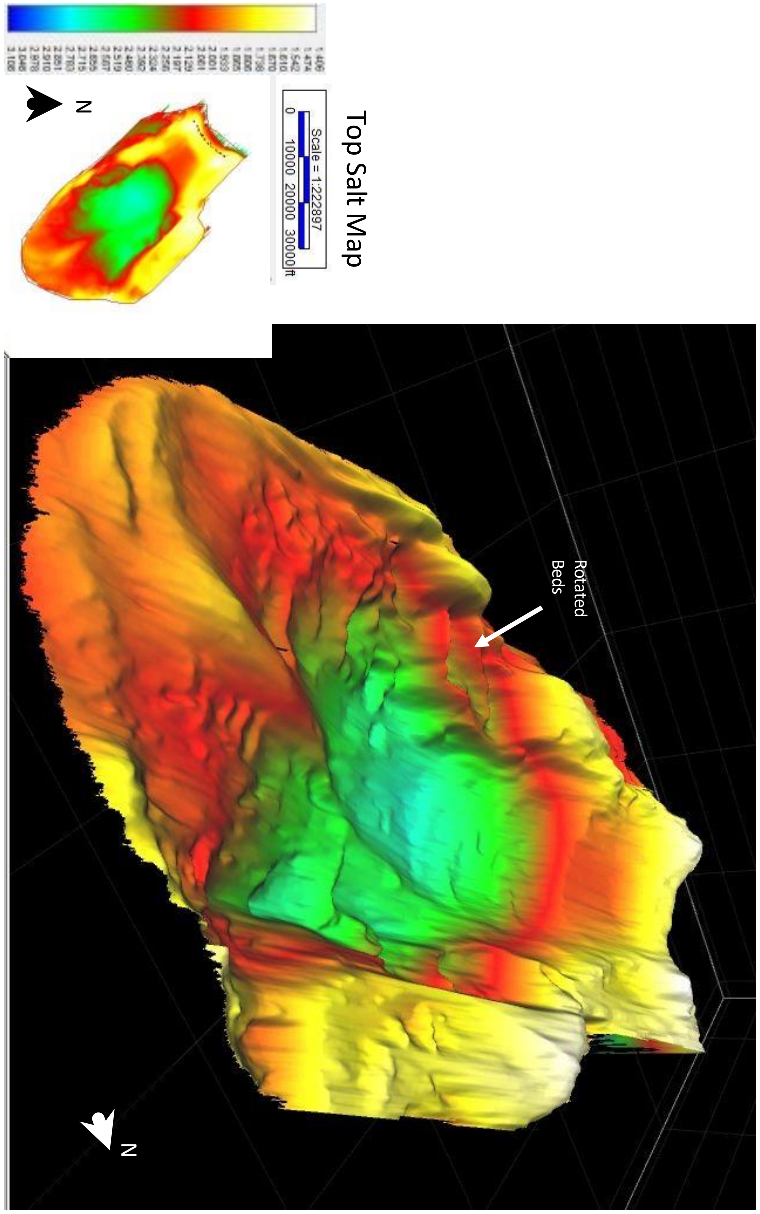


Figure 24 Above is a 3-D image of the salt canopy created from the horizon picks. The arrow points to the location that the creation of a smaller salt diapir has created a room that contains the rotated bed.

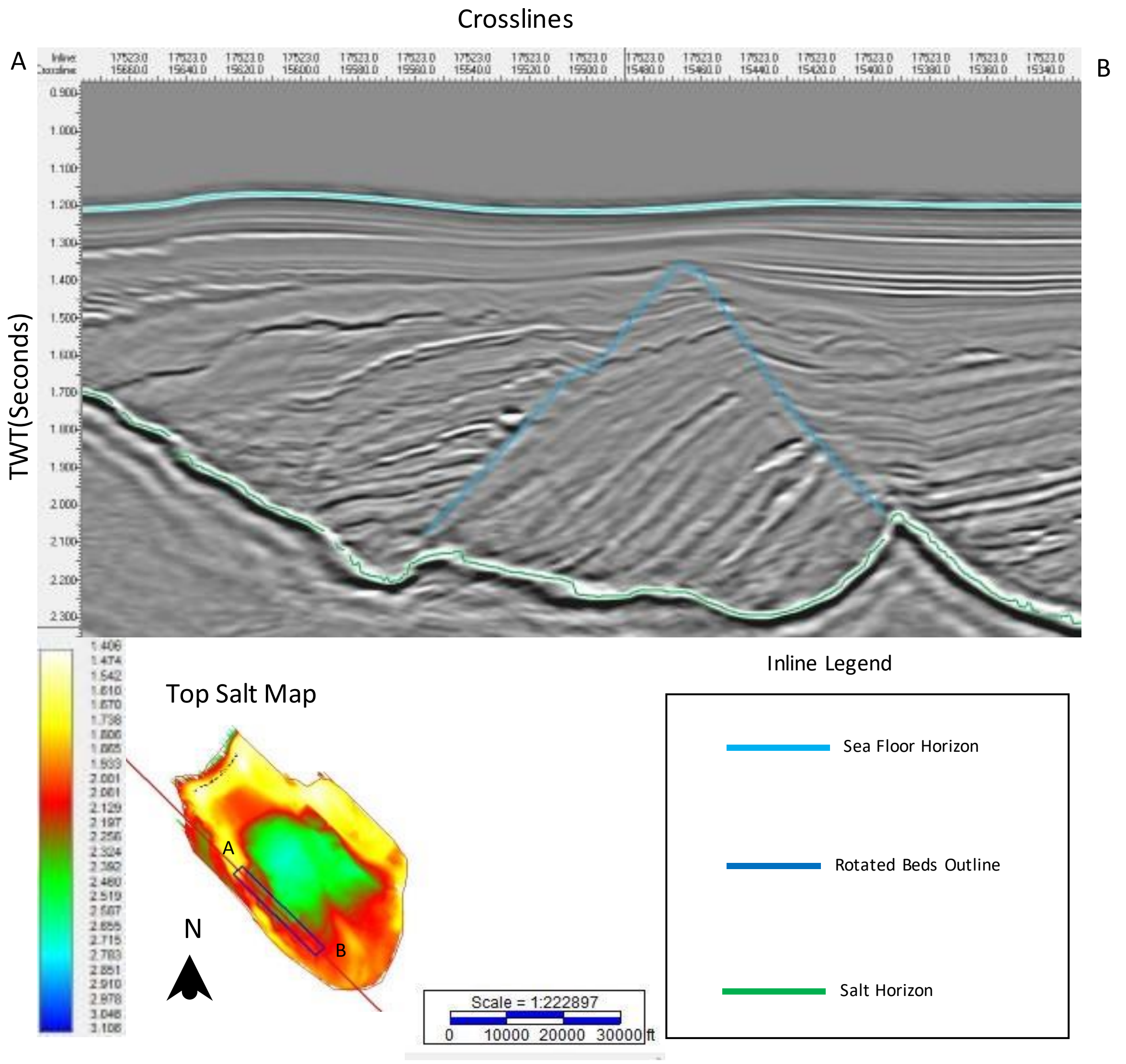


Figure 25 Cross-sectional image of the rotated bed using the inline on the seismic data. The rotated beds are outlined in the above image with the small salt diapir that they are pressed against being shown on the right-hand area of the cross-section.

4.5 New Diapirism

Salt migration will follow the path of least resistance during the process of halokinesis by finding points of weakness in the areas as it moves down into the basin or upward through overlying formations. While the canopy in the study area is moving horizontally into the basin if it finds vertical weaknesses in the overlying units, the canopy will create new vertical diapirs using the canopy as a source.

Figure 26 shows a diapir that spans over a large area of the canopy's toe. This new diapir will ultimately cause the faulting of the overlying units that was mentioned previously. This indicates that this area had some form of weakness vertically that incentivized the vertical movement of the salt over the given area. While this is the largest example of new diapirism in the study area there are many smaller areas such as the area where the rotated beds are located at; however, the diapir located at the toe appears to be the diapir that has had a major impact on the sea floor, as the faults above it caused a depression oriented perpendicular to the toe front which is generally an area of uplift.

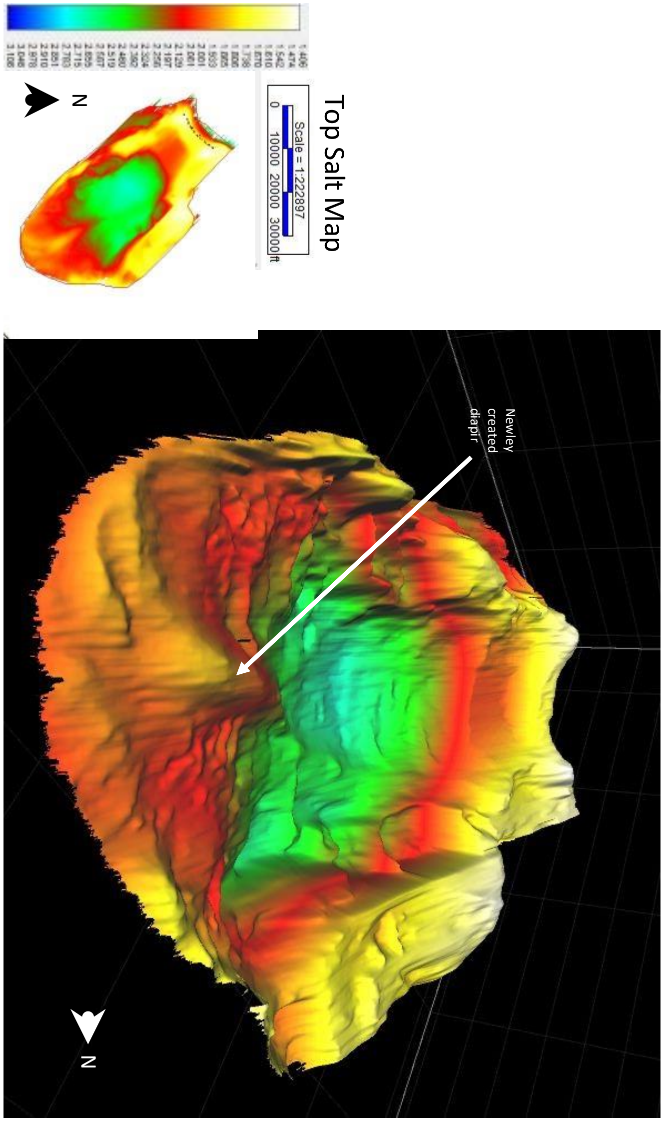


Figure 26 Shows the creation of the new salt diapir at the toe of the salt canopy using the 3-D image of the salt.

4.6 Unconformity

An unconformity is a surface separating two rock boundaries showing a gap in time that was created by a period of nondeposition or erosion of previously deposited strata. Unconformities show a period where the strata that were deposited were exposed to the surface for natural processes to erode the units away. These unconformities can be used to track changes in sea level during the time of the unconformity. The upper portion of the units that was studied ends at an unconformity which is represented as the Upper Pliocene Horizon in Figures 22 and 23. The unconformity stays at a TWT depth of 1.6 to 1.7 seconds in the Figures.

Above this unconformity surface, the units are deposited and had minor changes by the process of the salt. These units are relatively horizontal in orientation and have very little structures caused by the salt besides the area above the neck of the salt canopy. However, below this line the units are very heavily influenced by the movement of the salt. They begin to show heavy faulting and rafting over their existence. Based on this, it is assumed that the salt supply may have been cut-off at that time.

4.7 Sea Floor

Parts of salt movement can be traced by examining the seafloor as it will cause a change in the shape of the sea floor. Using this idea, other salt canopies can have a general interpretation of their subsurface structures before any major data is collected. This will allow for a more accurate placement of wells and seismic data areas.

Canyon infills and the rafting of the units on top of the salt are not easily observable when examining the seafloor data in the study area, as their structural impact on the overlying units dissipates very quickly. Rafting is not visible at the sea-floor, but the canyon infills do affect some of the overlying units.

The diapirs that are created during the process of halokinesis leave very large imprints on the seafloor in the form of faults and related depressions. These faults are typically normal faults and, depressions will normally be observed on the seafloor. Since there are faults present completely around the perimeter of the salt canopy, the size of the canopy can be estimated by extending a little past the stop of the depressions. The last section of the area that shows the faults is the new diapir that is near the toe but runs in a north-western direction in Figure 26 which is perpendicular to the salt-toe uplift. This area does have the same depression as caused by the faults around the parameter of the canopy.

A seafloor study is an ideal way to get a general idea of how the salt might be moving vertically and horizontally over the area. They tend to radiate out and move downdip from a feeder. They are usually covered by a relatively thin veneer of sediments that show the general shape but do not show the detailed faulting that can be seen on seismic. The thin veneer of sediment on top of a salt canopy near the sea-surface may be related to the low density of salt relative to all but the shallowest sediments. These observations can be used to identify diapirs regarding other salt canopies in the Gulf of Mexico as well as any other canopies around the world.

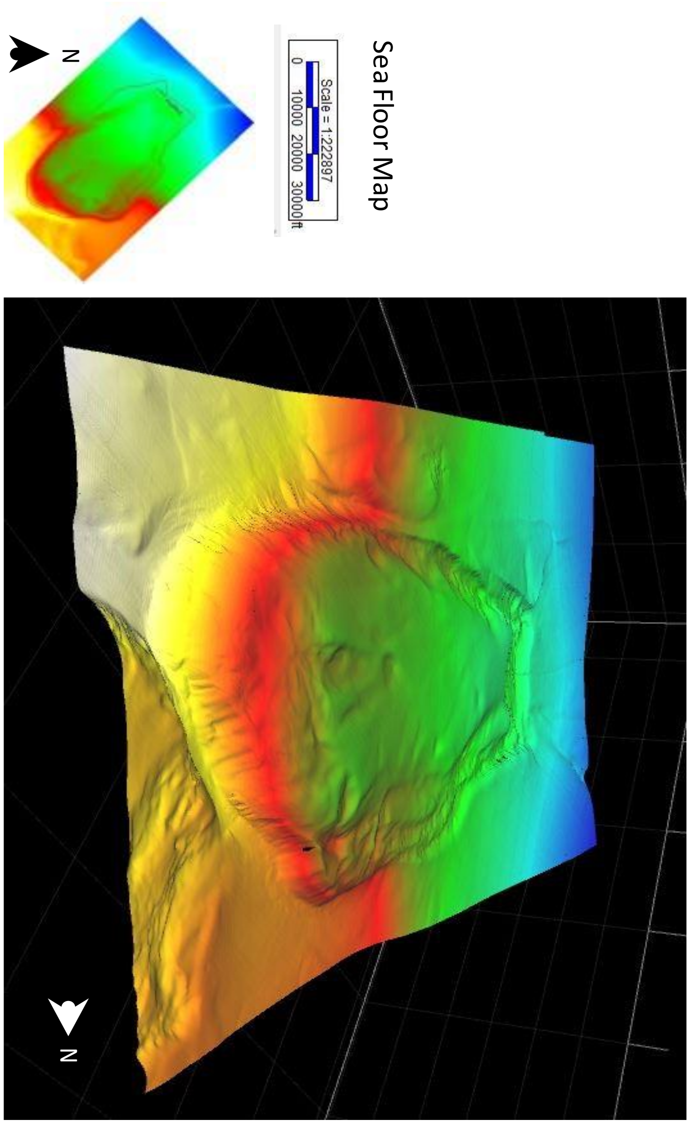


Figure 27 A 3-D image of the sea floor that was created from mapping the sea floor reflector in the seismic data. The large hill present is where the salt canopy is located and the various dips on top of and surrounding the hill are cause by the subsurface structures.

Chapter 5 Conclusions

The allochthonous salt domes present in the Gulf of Mexico have a complex history that can be tracked by the structures that are formed during its movement over time. These structures were anywhere from simple normal faulting that appears above almost all the salt diapirs to rafting of units down slope on top of the salt. A convenient way to analyze how the structures were influenced by the salt is through carful analyses of 3-D seismic data, which could be used to propose the mechanism of the salt migration over time. Figures 28 through 36 provides a possible mechanism for the evolution of the salt canopy over time.

Stage 1 is representing the original deposition of the evaporite in its original position in Figure 28. This will follow the normal rules of the deposition of salt for a horizontal layer of it is placed down. At this point in time there is no movement of the salt as there is no overlying pressure to drive halokinesis.

Stage 2 once the salt was deposited there was sections of sediment that were placed on top of the salt in Figure 29. The deposition of the new sediment on top of the salt layer will add overlying pressure to initiate salt migration. The overlying pressure is gravity driven and as it increases the salt will become mobilized and flow towards areas of reduced pressure, usually upwards. Buoyancy of the relatively low-density salt also contributes to its up-section movement over time.

Stage 3 When that Louann Salt finally has enough pressure from gravity and the overlying sediments, the salt will begin to migrate vertically creating a salt diapir in the location in Figure 30. This is the first major structure that is created through this process. The salt diapir will fracture overlying to create normal faults, similar to those located directly above the diapir. These normal faults will also cause visible depressions in the sea floor. These depressions will allow for a quicker identification of the major diapirs locations. The creation of the diapir will also cause the units to its side to bend upward with it. These two sections are both very good traps for various kinds of liquids and gasses that might be present in the subsurface.

Stage 4 after the creation of the diapir the slope that leads into the basin will begin to affect the diapir and force it to start moving down slope shown in Figure 31. This means that there is a change in the direction that the salt is moving from vertical to a horizontal movement. This is the creation of the salt canopy and is also where most of the deformation of the overlying units happens. The salt in this study formed a bowl-shaped canopy trapping the units inside of itself and moving them down slope with it in a process called rafting. These units are cut off from the rest of their unit and moved away from their location by riding on the horizontal salt movement.

Stage 5 the salt continues to move deeper and deeper into the basin forming the canopy in Figure 32. As the salt moves into the basin it carry of rafts some of the overlying units along with it. The oldest rafted unit is the smallest as there was less salt moving the surface area grew allowing for more and more of the overlying units to be moved deeper into the basin.

Stage 6 is a period of little to no deposition at the top of the Pliocene units. The period of little to no deposition will represent a gap in geologic time at the top of the Pliocene units. There has been some erosion present at the top of this section which will become more defined in stage 7.

Stage 7 with the period of little to no deposition happening on top of the Pliocene units the natural erosion would dig deeper in some areas than others in Figure 34. These canyons created at the end of the Pliocene are areas where there was a heavy amount of erosion. With the aid of faults currents were able to cut canyons into the sea floor.

Stage 8 The previously exposed units continued to have new deposition on top of them in Figure 35. This gap between deposition periods is what section of time that is missing in the study area. This will also finish the creation of the canyon infills as the overlying units fill in the previously created canyons.

Stage 9 is the last section where the salt could be fed and is cut off from the original section of salt below shown in Figure 36. The lack of more salt will slow or stop the creation of new salt structures in the present area until the presence of more pressure is put on the salt.

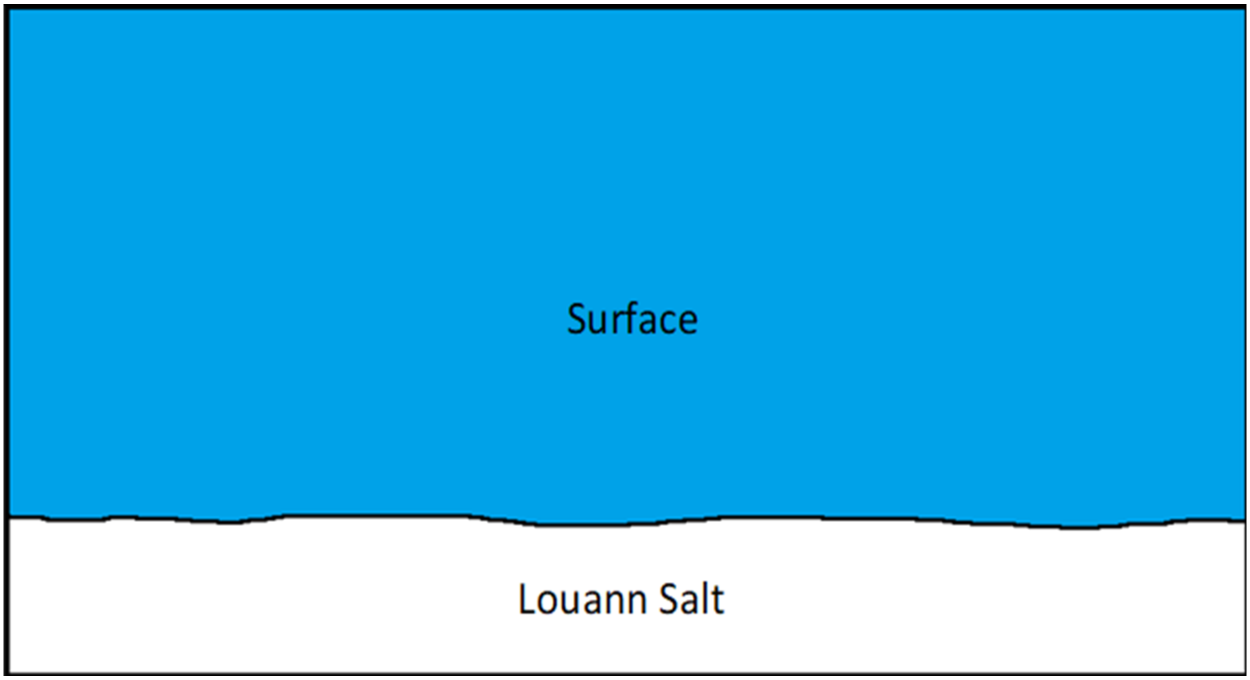


Figure 28 Stage 1 Initial deposition of the Louann salt in the Gulf of Mexico. The evaporation of the water here leaving behind salt in order to start the first steps of evaporite deposition.

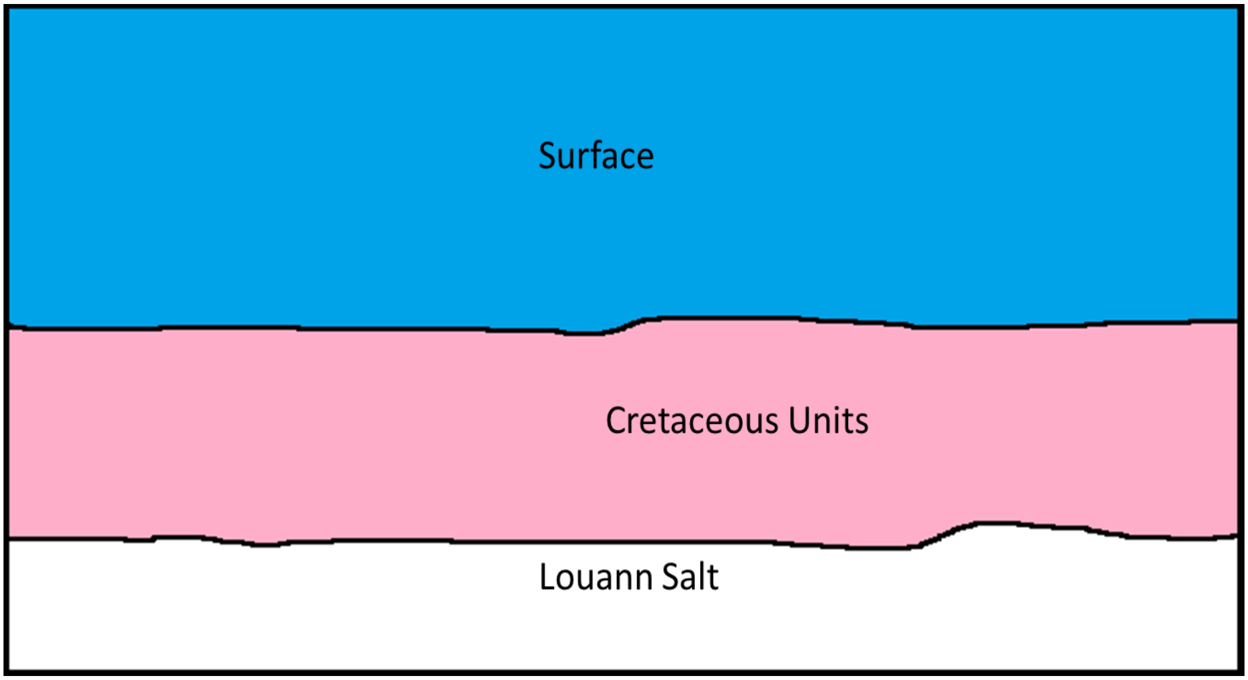


Figure 29 Stage 2 Deposition of the initial units on top of the salt horizontally. These are the first units that put pressure on the salt and will begin its movement.

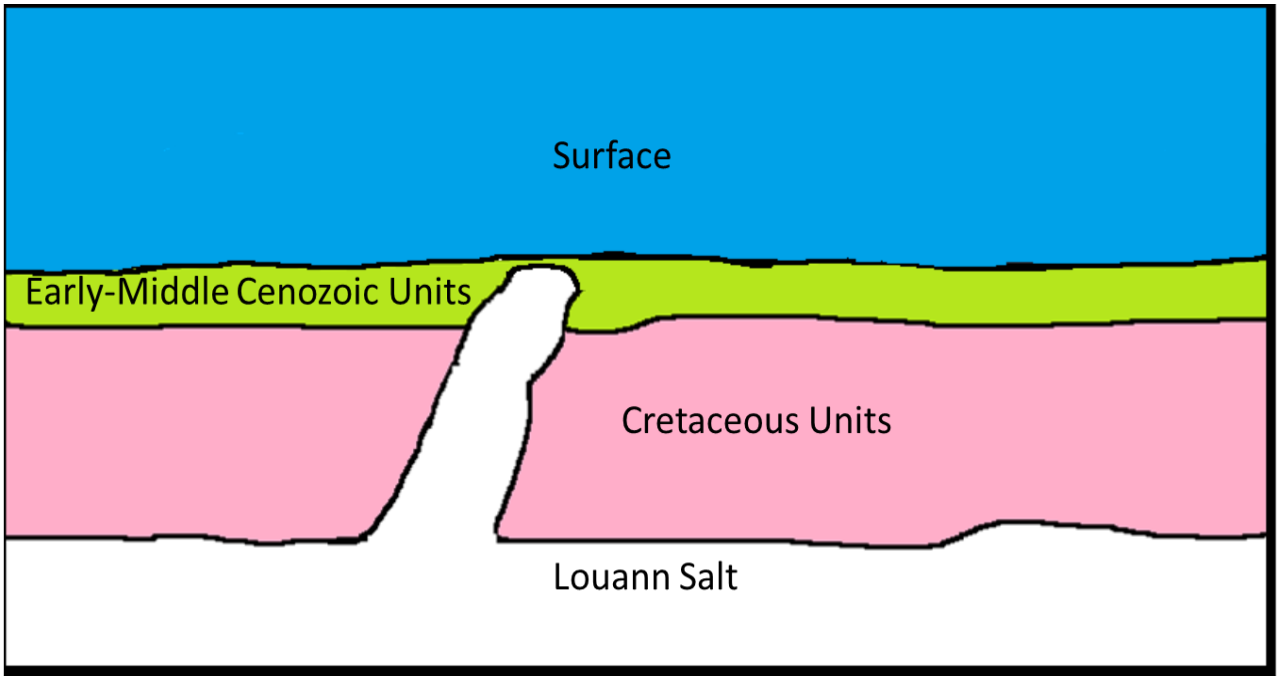


Figure 30 Stage 3 The salt begins to move vertically due to the pressure that the overlying unit caused. This is the first creation of the salt diapir which caused the normal faults that are located above the neck of the salt canopy.

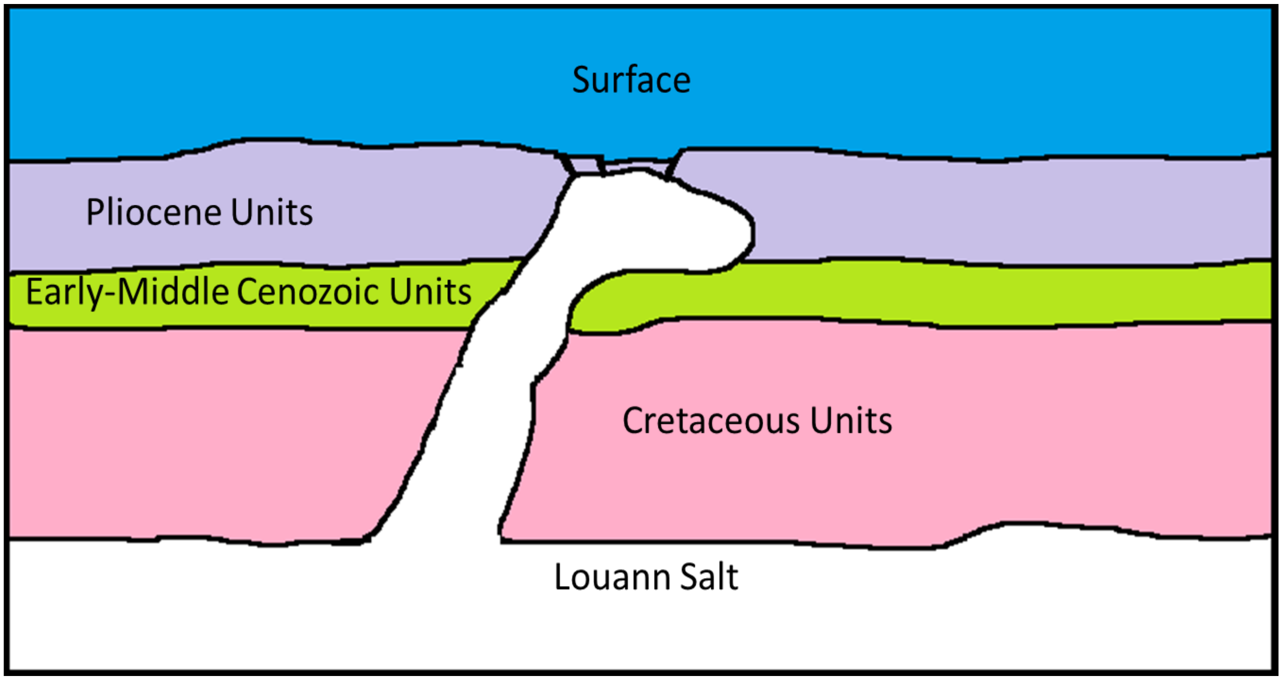


Figure 31 Stage 4 With the pressure from the overlying units still acting on the salt it will begin to move in the direction where there are weaknesses in the rock. The salt begins to move deeper into the basin changing from the vertical movement to the horizontal movement.

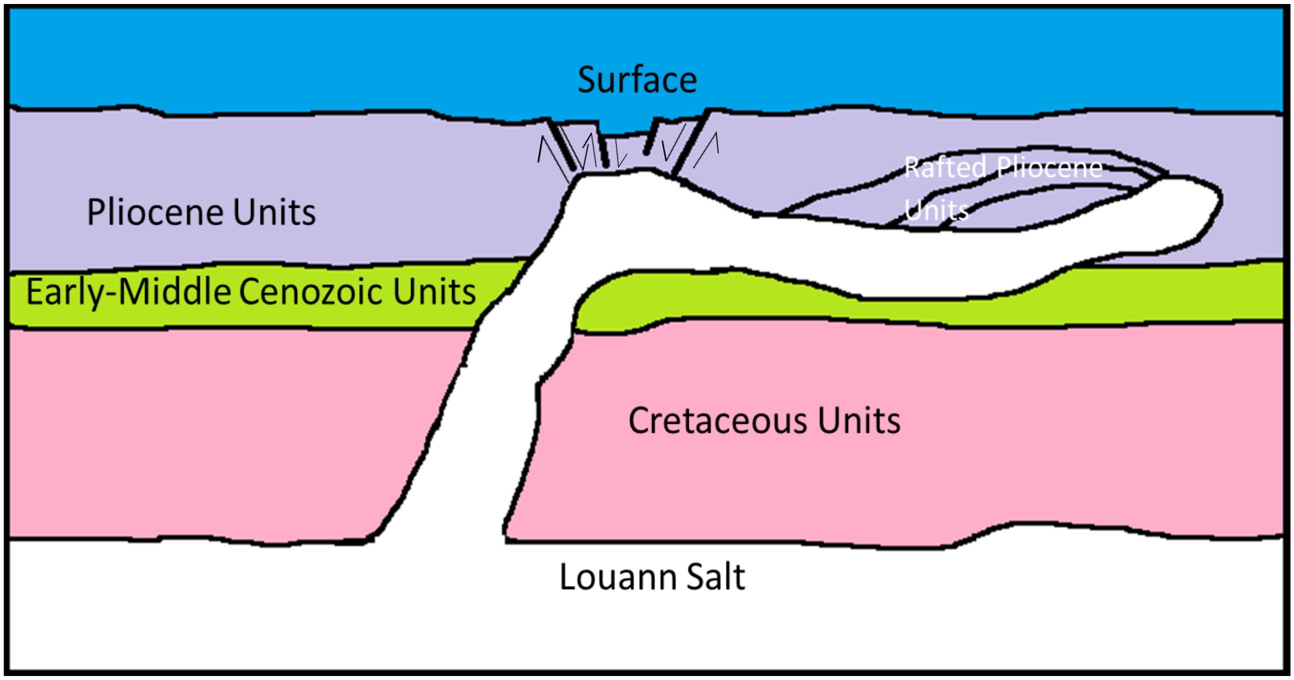


Figure 32 Stage 5 As the salt moves deeper into the basin it will begin to move some of the units that are present on top of the canopy in the rafting process.

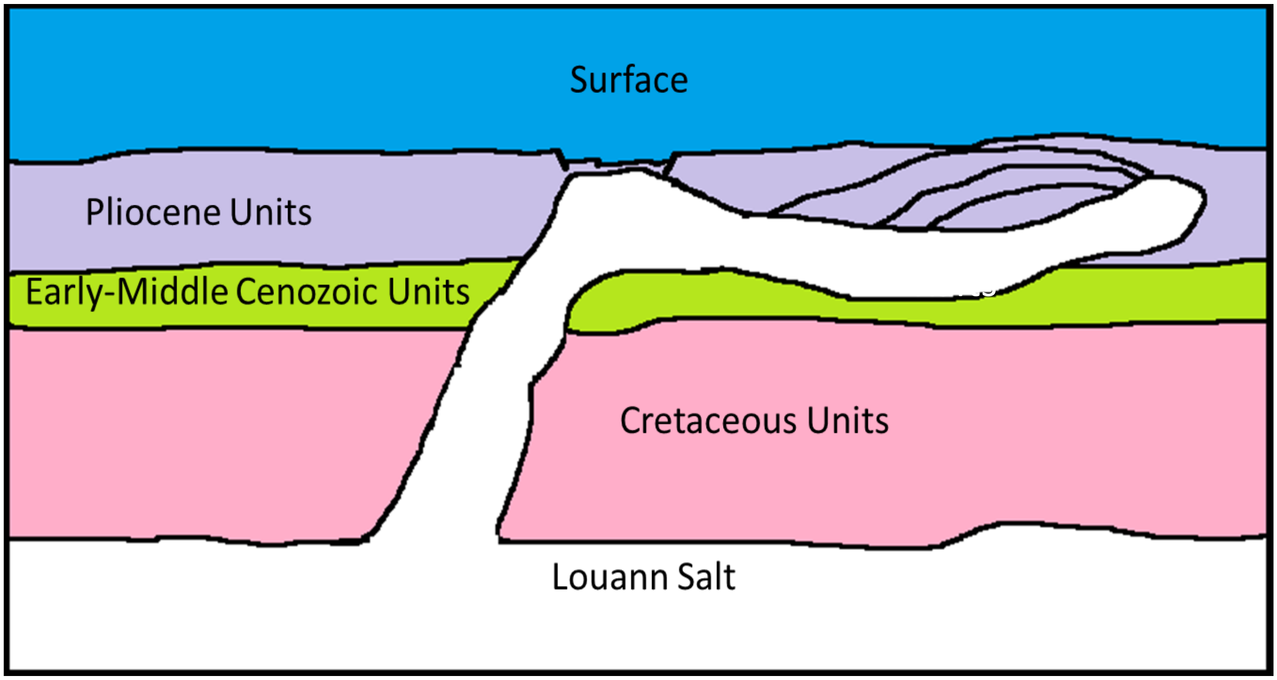


Figure 33 Stage 6 During this stage there is little to no deposition of new units causing an unconformity along the top of the Pliocene units.

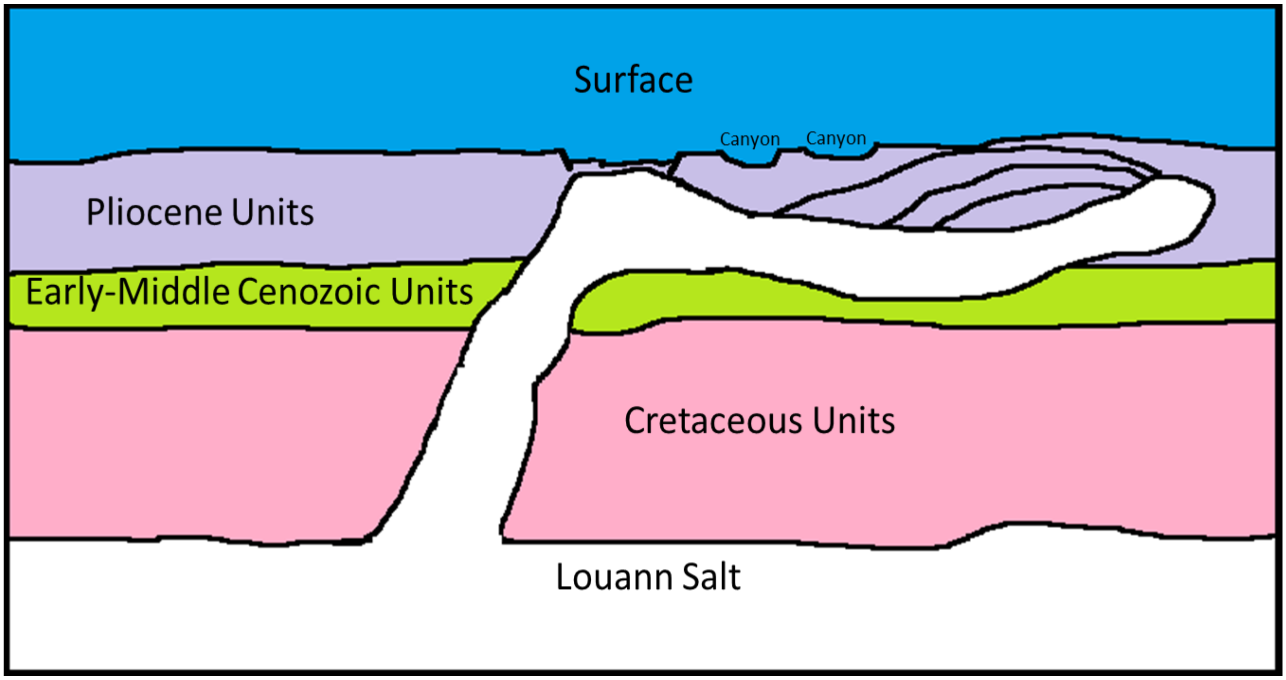


Figure 34 Stage 7 Before the deposition of the new unit's sections of the landform canyons in the surface exposed units.

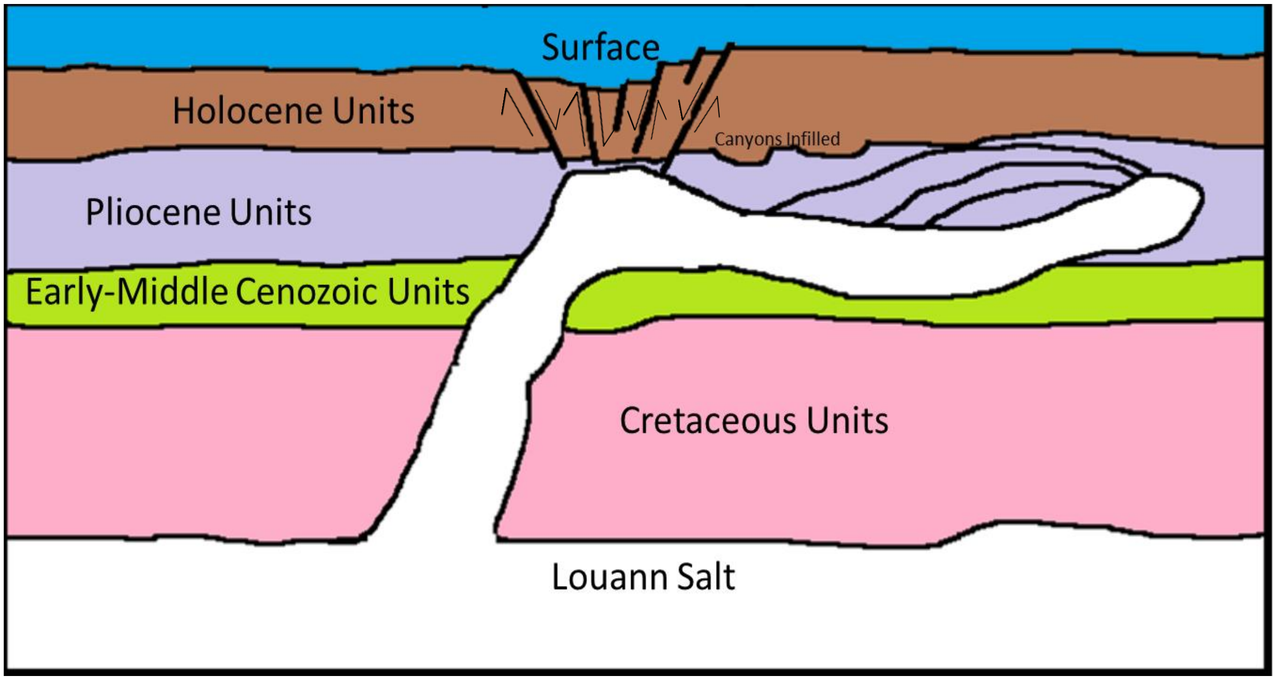


Figure 35 Stage 8 After a time the deposition of units begins again filling in the canyons that were made and covering the once exposed sections.

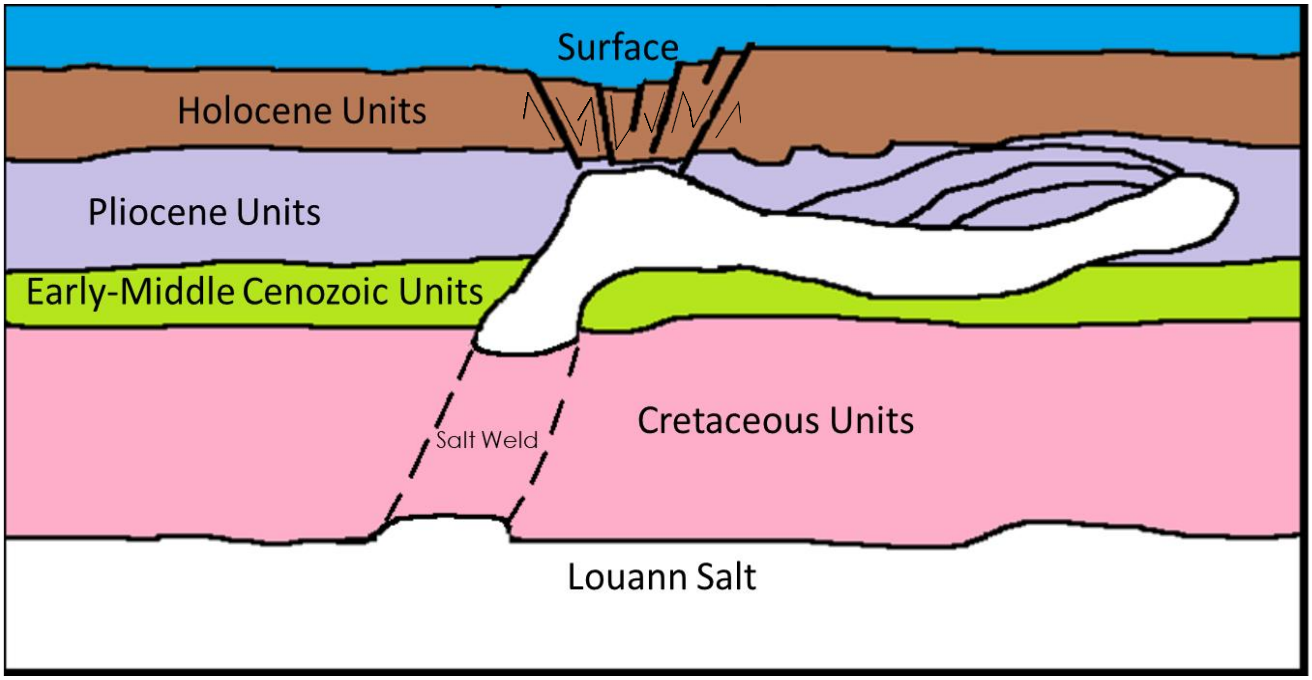


Figure 36 Stage 9 Lastly the salt canopy's neck thins and eventually detaches from the original feeder unit. This means that the unit no longer has a new influx of salt.

Future Work

One of the major improvements on this study would be to examine if the sea floor structure correlation can be done with other salt canopies in the Gulf of Mexico as well as any other places where salt canopies can be found. If salt diapirs and canopies can be better described by just seeing the seafloor than exploration could be aided as well.

Another way to improve on this study is to acquire better seismic data with more detailed shallow sections. This will allow for a better description of the shallow units while ignoring the data below the salt.

References

Bartok, Peter. "Prebreakup geology of the Gulf of Mexico-Caribbean: Its relation to Triassic and Jurassic rift systems of the region." *Tectonics* 12.2 (1993): 441

Burger, Henry Robert, Anne F. Sheehan, and Craig H. Jones 1940-. Introduction to Applied Geophysics : Exploring the Shallow Subsurface. New York :W.W. Norton, 2006.

Dragoset, Bill. "A historical reflection on reflections." The Leading Edge 24.s1 (2005): s46-s70.-459.

Duval, Bernard, Carlos Cramez, and M. P. A. Jackson. "Raft tectonics in the Kwanza basin, Angola." *Marine and Petroleum Geology* 9.4 (1992): 389-404.

Galloway, William E., et al. "Cenozoic depositional history of the Gulf of Mexico basin." *AAPG bulletin* 84.11 (2000): 1743-1774.

Galloway, William E., Timothy L. Whiteaker, and Patricia Ganey-Curry. "History of Cenozoic North American drainage basin evolution, sediment yield, and accumulation in the Gulf of Mexico basin." *Geosphere* 7.4 (2011): 938-973.

Ge, Hongxing, Martin PA Jackson, and Bruno C. Vendeville. "Kinematics and dynamics of salt tectonics driven by progradation." AAPG bulletin 81.3 (1997): 398-423.

Gradmann, Sofie, et al. "Salt tectonics off northern Israel." *Marine and Petroleum Geology* 22.5 (2005): 597-611.

Hudec, Michael R., et al. "Jurassic evolution of the Gulf of Mexico salt basin Gulf of Mexico Jurassic Evolution." *AAPG bulletin* 97.10 (2013): 1683-1710.

Hudec, Michael R., Martin PA Jackson, and Frank J. Peel. "Influence of deep Louann structure on the evolution of the northern Gulf of MexicoGulf of Mexico Salt Influence." *AAPG bulletin* 97.10 (2013): 1711-1735.

Jackson, M., & Hudec, M. (2017). Salt Sheets and Salt Canopies. In Salt Tectonics: Principles and Practice (pp. 119-154). Cambridge: Cambridge University Press. doi:10.1017/9781139003988.009

Jackson, Martin PA. "Atlas of salt domes in the East Texas basin." *Virtual Landscapes of Texas* (1984).

Jackson, Martin PA, and Christopher J. Talbot. "External shapes, strain rates, and dynamics of salt structures." *Geological Society of America Bulletin* 97.3 (1986): 305-323.

Jones, Ian F., and Ian Davison. "Seismic imaging in and around salt bodies." *Interpretation* 2.4 (2014): SL1-SL20.

King, Hobart M. “Geology.com.” Geology.com, https://geology.com/articles/eagle-ford/.

McGowen, Mary K. "Cotton Valley (Upper Jurassic) and Hosston (Lower Cretaceous) depositional systems and their influence on salt tectonics in the East Texas Basin." *Virtual Landscapes of Texas* (1984).

Pindell, James L. "Evolution of the Gulf of Mexico and the Caribbean." *Caribbean geology: an introduction* (1994): 13-39.

Pilcher, Robin S., Ryan T. Murphy, and Jessica McDonough Ciosek. "Jurassic raft tectonics in the northeastern Gulf of Mexico." *Interpretation* 2.4 (2014): SM39-SM55.

Posamentier, Henry W., and Venkatarathnan Kolla. "Seismic geomorphology and stratigraphy of depositional elements in deep-water settings." *Journal of sedimentary research* 73.3 (2003): 367-388.

Ross, Malcolm I., and Christopher R. Scotese. "A hierarchical tectonic model of the Gulf of Mexico and Caribbean region." *Tectonophysics* 155.1-4 (1988): 139-168.

Russell, Brian H. *Introduction to seismic inversion methods*. No. 2. SEG Books, 1988.

Taner, M. Turhan, Fulton Koehler, and R. E. Sheriff. "Complex seismic trace analysis." *Geophysics* 44.6 (1979): 1041-1063.

Wilhelm, Oscar, and Maurice Ewing. "Geology and history of the Gulf of Mexico." *Geological Society of America Bulletin* 83.3 (1972): 575-600.

Worrell, Matthew. "Structural and Stratigraphic Reconstruction of the Whiting Dome Salt Structure in Viosca Knoll-Mississippi Canyon, GOM, Using 3-D Seismic Data." (2017).

Wu, Shengyu, Albert W. Bally, and Carlos Cramez. "Allochthonous salt, structure and stratigraphy of the north-eastern Gulf of Mexico. Part II: Structure." *Marine and Petroleum Geology* 7.4 (1990): 334-370.

Wu, Shengyu, Peter R. Vail, and Carlos Cramez. "Allochthonous salt, structure and stratigraphy of the north-eastern Gulf of Mexico. Part I: Stratigraphy." *Marine and Petroleum Geology* 7.4 (1990): 318-333.

VITA

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