MAPPING STRUCTURAL DEFORMATION ASSOCIATED WITH THE FORMATION OF THE BLUE RIDGE SALT DOME

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THESIS

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William J. Moulton, Committee Chair
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ABSTRACT

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Mason Bonner, M.S. The University of Texas at Arlington, 2017

Supervising Professor(s): William J. Moulton, John Wickham, Qinhong Hu

Geologic mapping and subsurface imaging around salt has remained difficult. Seismic imaging is difficult near salt due to the large velocity contrasts between salt and the surrounding rocks, the steeply dipping salt and sediment interface, and the presence of pinching beds on the flanks of the dome; but when combined with well control from previously drilled wells on top and on the flanks of a salt dome, a more complete profile of the subsurface structure becomes possible. Previous work has produced models of salt dome formation and the surrounding structural deformation, and when compared to seismic data, show a good correlation. In this study, well log and seismic data from the Blue Ridge Salt Dome in Fort Bend County, Texas will be used to generate a structural profile. The comparison from this structure profile produced from field data to previously modeled dome centered deformation will also be made. By creating this structural profile in conjunction with previous works, this study will test previous models of salt dome evolution as compared to the Blue Ridge Salt Dome.

ACKNOWLEDGEMENTS

I would like to acknowledge and thank Matt Ferguson for allowing myself access to the data and information needed to complete this study and for my employment flexibility while completing this work and fulfilling the requirements for my degree. Without his support this study would not have been possible.

Special thanks also goes to my supervising committee for their guidance while I completed this report. On an individual note, I truly appreciate the help Dr. John Wickham provided when I was struggling to initiate thesis work and assemble a committee. William Moulton has been a great asset to contact with the numerous questions that arose regarding the data, project formatting, and general exploration forays, as well as agreeing to be the committee chair. I would like to express my gratitude towards Dr. Qinhong (Max) Hu for accepting the last position on this thesis committee even though he has many other students to advise and projects of his own to occupy his valuable time.

Lastly, I would like to that Thomas “Chap” Brackett, as he mentored me through my first months of employment as a geologist and studying salt dome geology. His wealth of knowledge concerning salt dome exploration and Blue Ridge in particular has greatly improved my own understanding of the topic.

DEDICATION

I would like to dedicate the work completed here to several people that have influenced my life up to this point.

Foremost, the steadfast support of my family through my extensive collegiate career has allowed me to finish this thesis and meet the requirements for a Master of Science degree. My parents have supported my delayed and elongated secondary education, even when my own motivations were wavering and in question, and for that I am extremely grateful. My father has been a statue of guidance and provision throughout not only my academic career, but also my life in general. His words of wisdom, while sometimes falling on deaf ears, have never been misaligned. My mother has been a figure of unconditional love and support. Even my when life choices have been questionable at best, she has always seen the light in every situation.

Although no longer with us, I believe it would appease John Beasley to know his influence on my careers, both academic and employment related. His hard-nosed style of business and tough approach to life has made myself a better leader, worker, and person in general. The drive and work ethic instilled in me during my time spent under his leadership has taken me much farther than I ever anticipated and lead me to accomplishments I never thought possible. I also credit John Beasley for my start in the exploration and production industry, which lead me to pursue higher education in a subject applicable to the industry.

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CHAPTER 1

INTRODUCTION

The Blue Ridge Salt Dome is located in eastern Fort Bend County along the upper Texas Gulf Coast just south of the city of Houston (Figure 1). Historically, exploration and production on the dome began in the early twentieth century with the discovery of oil in 1919 from the Gulf Oil Corporation No. 2-C Blakely. The dome itself was discovered in 1903 by surface geology, the natural occurrence of gas seeps, and a surface mound (Kiatta, 1987). The area of the dome covers approximately one thousand surface acres and has a structural pattern similar to most domes on the Gulf Coast. The dome's cap rock reaches as shallow as 143 feet and production from the Frio (Oligocene) and Vicksburg (Oligocene) formations, and an undifferentiated assemblage of Plio-Miocene age sands occurs mostly on the flanks of the dome (see figure 2). Common structural features include radial faults that disrupt the reservoir sand continuity and high dip angles of strata near salt that decrease away from the dome (Hinson, 1953). Stratigraphic pinch outs near salt are also a common effect of the dipping beds.

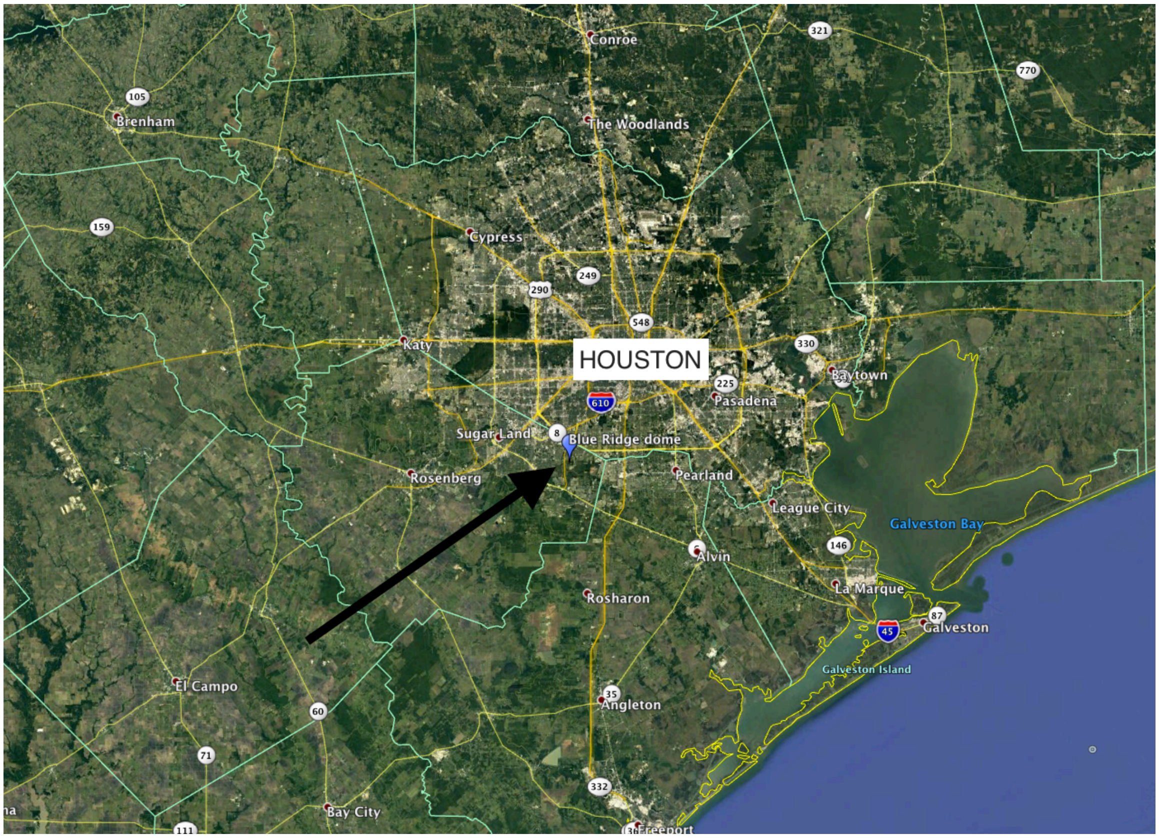

Figure 1 – Location of Blue Ridge Salt Dome as notated by black arrow and blue pin on map image. The dome is located between the cities of Pearland and Missouri City. Image modified from Google Earth, 8/22/17.

Large portions of the world's conventional reserves of hydrocarbons are related to salt structures (Weijermars, 1993). With over 300 salt diapirs in the Gulf basin (Murray, 1966) and the uplift of domes through thousands of feet of strata, the conditions for oil accumulation around them is excellent (Halbouty and Hardin, 1955). The discovery of salt domes and salt related structures is the product of subsurface geology done in great detail with knowledge of the mechanics of salt dome growth (Halbouty and Hardin, 1955). The migration of low permeability salt provided an extremely effective seal and trapping mechanism for oil and gas, thus becoming and continuing to be a target for production opportunities. In addition to salt directly acting as a seal or trap, the upward movement of salt influenced the surrounding deformation that contributes to the evolution of faulting, structure traps and migration pathways. Subsurface imaging around salt structures for the purpose of developmental drilling also continues to be a difficult objective. To resolve this problem, this study will use both extensive well log and 3D seismic data from the Blue Ridge Salt Dome to produce a more accurate subsurface geologic profile.

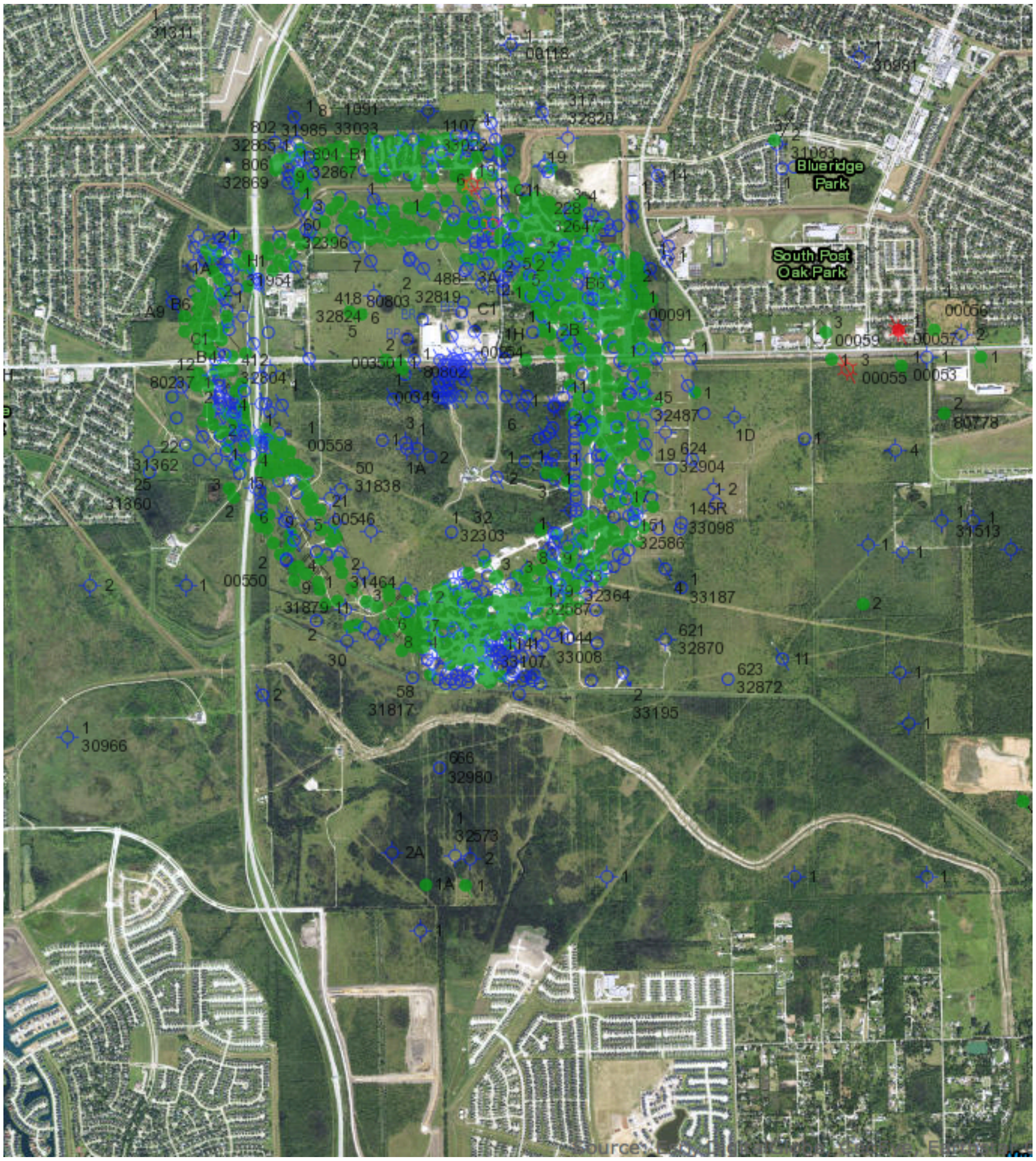

Figure 2 – Image showing well locations on flanks of Blue Ridge Salt Dome. Also note surrounding culture limitations. Image accessed from Texas RRC GIS viewer, 8/22/17.

Production of hydrocarbons along the gulf coast and from salt dome structures is by no means a cutting edge endeavor. The famous discovery at Spindletop that ignited the oil and gas industry in Texas was drilled on top of a salt dome South of Beaumont, Texas. Because oil associated with salt domes became the primary exploration target along the Gulf Coast of the U.S., considerable research on piercement salt dome structures has been undertaken over the last century. To paraphrase Halbouty and Hardin (1955b), while the absence of major structural features along the gulf coast is notable, accumulations of hydrocarbons are present in less intense features, such as small anticlines, faulted anticlines, stratigraphic traps of all types, reefs and any combination of these, massive tertiary deposits have resulted in prominent structural features, the most outstanding of which are the piercement style salt domes. The growth of a salt dome is complex, as structures may grow and punch through sediments (piercement) while others develop as sediments are deposited around them, and still others deform layers above so thinning anticlines are formed and so on (Dusseault et al. 2004). In a production sense, traps can be found in the anticlinal structures and normal fault blocks above piercement and non-piercement style domes, updip traps in upwarped and sometimes-overturned strata that terminate against the dome flank in piercement regions, in gentle flank anticlines, or under salt tongues (Dusseault et al. 2004). Salt dome overhangs have also been found to be a producible trapping mechanism (Judson and Stamey, 1933).

The Cenozoic structural evolution of the northern Gulf of Mexico Basin is controlled by sediment progradation over deforming, largely allochthonous salt structures derived from an underlying autochthonous Jurassic salt (Diegel, 1995). Many other applicable research articles have been published on the subject of salt, including Nettleton (1943), McCullom and Larue (1931), Halbouty and Hardin (1954) (1955a) (1955b) (1959). Jackson and Talbot (1986) explain that salt must be buried under later deposited sediments in order for diapirs to form. But even when a primary density inversion between the salt and strata is present, a tabular, laterally uniform salt body overlain by a uniform and dense overburden is still stable if the relief of the sedimentary overburden is not enough to initiate salt flow at geologic strain rates. Alas, such conditions of uniform overburden above a salt body is extremely rare due to lateral variations (Jackson and Talbot, 1986).

As with this case and other salt related structures along the Gulf Coast, the Frio formation has been highly productive, with other productive intervals in the deeper Paleogene and shallower Miocene aged strata. Sheets (1987) refers to the Frio as the most important producing formation in southeast Texas. The Cenozoic history of the northwestern Gulf of Mexico is characterized by rapid ongoing sediment input and thick prograding depositional sequences exhibiting considerable gravity deformation. This massive influx of sediments within recent geologic history combined with the diapirism of salt bodies makes a complex sedimentary record affected by regional and localized tectonic features. An analysis of regional scale on the Cenozoic depositional framework shows that the sand rich depocenters correspond to major deltaic systems (Galloway, 1989). Among others, Bebout et al. (1978) also performed extensive research on the Frio sandstone reservoirs, noting that contemporaneous deltaic sedimentation, movement along growth faults, and mobilization of deep salt into domes resulted in the accumulation of several hundred feet of sandstone with permeabilities greater than 20 millidarcys.

Many studies have examined structural patterns of gulf coast salt domes. A history of dome modeling perspectives with the intent to recreate the surrounding structural traits is provided by Weijermars et al. (1993). Withjack and Scheiner (1982) recreated the doming effects with models with and without the influence of regional strain. The two major factors affecting the pattern of faulting on and around a dome structure are the shape of the dome, and the presence of regional strain during doming. It is also noted that regional extension of the Gulf Coast can be inferred from the presence of normal faulting, and possibly in conjunction with salt diapirism (Withjack and Scheiner, 1982). Depending on the timing of the regional extension and the upward movement of the salt, some domes may have formed in conjunction with regional extension, while others may have developed without regional strain. Weijermars et al. (1993) shows simplified versions of the mechanisms of salt dome tectonics (Figure 3). Jackson and Talbot (1986) also summarize the debate on the initiation of salt flow processes from lateral tectonic forces to buoyancy/gravity driven, to the involvement of crustal extension in the initiation of gravity driven salt rise. Ge et. al. (1995) explains that due to the weakness of salt in comparison to the overlying and surrounding sedimentary rocks, salt diapirs are sensitive to regional extension and performed experiments to support this statement.

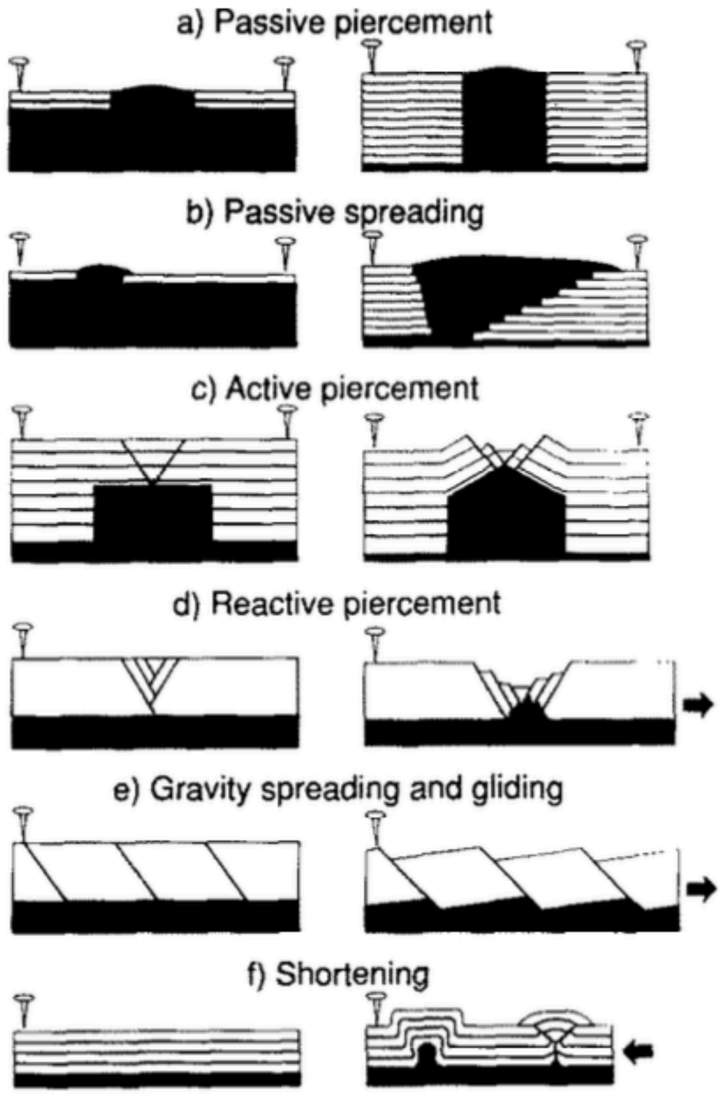

Figure 3 – Highly generalized mechanisms of salt tectonics. Taken from Weijermars et al. (1993). The author notes the lack of congruent sedimentation among other factors that would affect the aforementioned mechanisms during salt dome formation.

Jackson and Talbot (1986) summarize the continuing debate of salt flow as it pertains to regional tectonic movement. The role of lateral tectonic forces in the flow of salt has been continually debated since the discovery and subsequent study of salt domes and other salt structures. In the early part of the 20^{th} century, compression was considered a driving force for salt intrusions; this was based upon descriptions given by the Romanian Carpathians. Later, gravity measurements over many of the Gulf Coast salt domes provided support for establishing the role of buoyancy as a major force affecting salt movement. In the most recent stage of conceptual ideals, science has begun to support evidence proving crustal extension greatly influences the initiation of gravity driven rise of salt structures in petroleum basins (Jackson and Talbot, 1986).

As detailed by Murray (1966), once salt structures have initiated growth, the density contrast between the salt and the overlying and surrounding sedimentary layers coupled with the plasticity of the salt, appear to be sufficient to maintain growth of such structures. Among other works, Ingram (1991) is in fair agreement with Murray (1966) and specifies the primary mechanisms of continued salt growth as isostatic force, buoyancy, and tectonic forces in some areas during certain times of dome development.

Salt structures are commonly assymetrical and do not necessarily rise vertically through their sedimentary cover. Salt movement is driven by buoyancy, which requires a density inversion, or differential loading, at rates about 10% of those seen in orogenic movement (Jackson and Talbot, 1986). The work by Weijermars et. al. (1993) expands on the concepts of Withjack and Scheiner (1982), "The structural evolution and faulting of sedimentary sequences underlain by salt sheets can be simulated in scale models involving a ductile substratum overlain by an elasto-plastic overburden, using silicone putty for the substratum and fine-grained sand for the overburden." The findings of such experiments show faulting patterns very similar to those observed in seismic data.

The introduction of three-dimensional (3D) seismic data in the mid-1970's was one of the most significant technological leaps for the hydrocarbon exploration and production industry (Guglielmo et. al. 1997). But seismic data can be problematic when attempting to image around salt bodies as the extreme dip angles of the sediments and the salt and sediment interface. Guglielmo et al. (1997) explains the interference caused by the steeply dipping interface is to blame for troubles imaging fault geometries near salt. The 3D seismic survey used here was completed, the data processed and depth converted in 2014. While most of the well logs used are by most standards 'modern', some historical well data dates back nearly a century to the discovery of the dome. The main criteria of classifying modern versus historical well log information are digital log curves versus paper logs. Well control at the Blue Ridge Salt Dome is very good; log information used for the Blue Ridge projects is included (Table 1). For correlation purposes, formation picks were based upon spontaneous potential (SP) and resistivity curves, with other log curves being employed in some cases in some modern logs. These curves were chosen for correlation based on their overlap in both modern and historic logs and their ability to identify unique markers within wellbores. While wellbore data encompasses the entire dome and is readily available, the extent of the seismic data will limit the extent of this work. The 3D seismic shoot covered a large portion of the dome, flanks, and some areas off salt. However, in some areas of the dome, the scope of seismic data is severely limited by surrounding culture to the flanks of the dome near the salt plug. For this reason, this study will mainly focus on the southeastern portion of the dome (Figure 4).

Wells	Number of wells
Total in Blue Ridge Project	1097
Digital Logs	302
Digitized Raster Logs	232
Any Picked Formation Top	553
First Frio Sand Pick	445
Middle Frio Sand Pick	387
Vicksburg Pick	157
Salt	163

Table 1 – Well log information used for Blue Ridge evaluation.

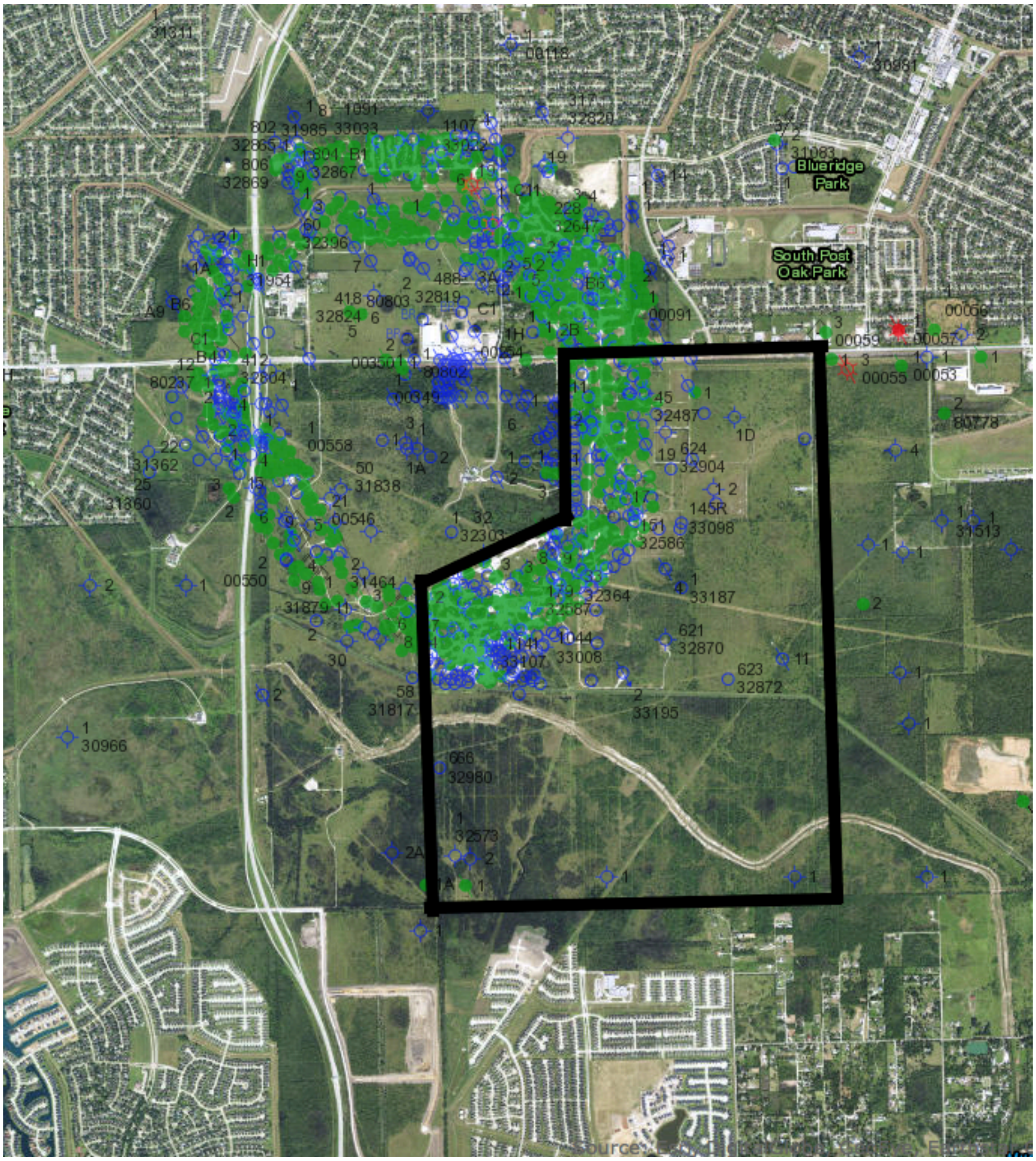

Figure 4 – Aerial image of Blue Ridge Salt Dome with overlain area of study. Image accessed from Texas RRC GIS viewer, 8/22/17.

CHAPTER 2

STRATIGRAPHY

Regional Stratigraphy

Many of the world's sedimentary formations housing oil and gas reservoirs are found at continental shelves and slopes and were deposited by the basinward migration of such shelf sequences (Weijermars et al. 1993). Mesozoic and Cenozoic sedimentary deposits reach thicknesses of 50,000-60,000 feet near the current coastline of Gulf Coast, and are commonly disrupted by fault systems that in some areas can be considered complex (Baker, 1995). Southeast Texas and the broadly defined Houston embayment are dominated by Tertiary sedimentation and characterized by salt diapirism and faulting accompanying salt withdrawal subbasins (Galloway et al, 1982). As part of the Texas Gulf Coast Tertiary basin, the sand-rich, fluvio-deltaic Oligocene to Miocene aged Frio formation (Swanson and Karlsen, 2009) forms a principle progradational wedge exceeding 10,000 feet in thickness in parts of the Houston embayment and has produced a total of 16 billion BOE at the time of Galloway et al (1982), making it one of the most important oil and gas reservoirs found in the Gulf Coast basin.

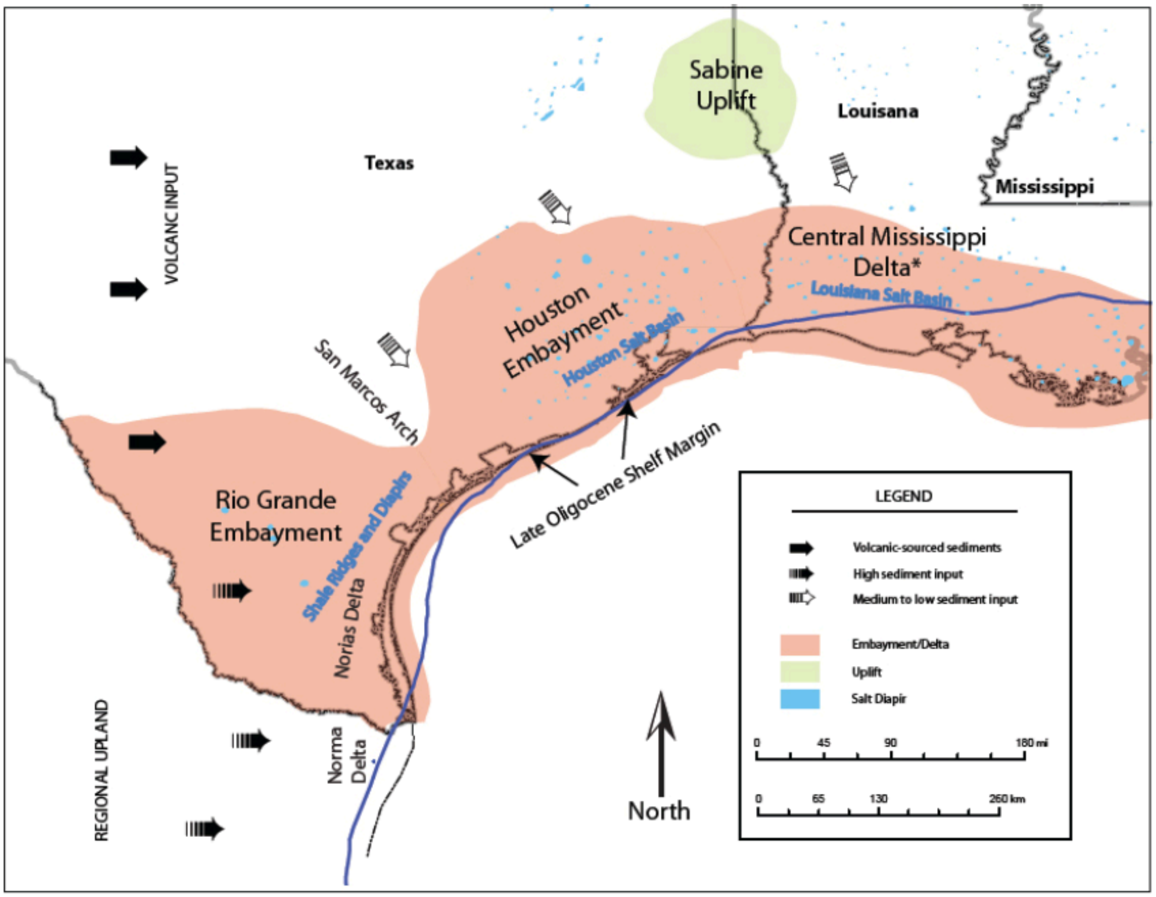

Figure 5 - Location of salt diapirs, principal sediment sources and depositional systems in the northern Gulf of Mexico during Oligocene time. From Swanson and Karlson (2009).

The Frio is stratigraphically correlated to its updip equivalent, the Catahoula formation and is composed of a series of deltaic and marginal-marine sandstones and shales (Swanson and Karlsen, 2008). It is underlain by the Oligocene Vicksburg; the Vicksburg formation is best developed in the Rio Grande Embayment of South Texas (Galloway et al, 1982) (Figure 5), but is regionally expansive through East Texas and the Houston embayment as well. The Houston embayment (Figure 5) comprises most of southeastern Texas and includes the salt basin and is separated from the Rio Grande embayment by the San Marcos Arch (Combes, 1993). The Houston delta system that was centered in the Houston embayment was comprised of several laterally coalescent and vertically repetitive deltaic cycles that was the distributary system responsible for the accumulation Frio formation sediments, (Galloway et al 1982). In the Houston embayment, end of Frio deposition is marked by the Anahuac marine transgression and associated Anahuac shale formation. The overlying Anahuac formation is a transgressive marine shale, having deltaic, shoreface and slope sandstones, in addition to carbonate sediments (Swanson and Karlsen, 2008). A Tertiary stratigraphic section of Texas is included (Figure 6). The total thickness of the Frio section deposited by the Houston delta system ranges from 1,800 to 7,500 feet with sand content reaching local highs of sixty percent but decrease distally to as low as ten percent (Galloway et al. 1982). This high sand content of the section is unsurprising, as explained by Galloway (1989), regional analysis of the Cenozoic depositional framework will show the relationship between major deltaic systems, such as the Houston delta system, and centers of sand rich deposition.

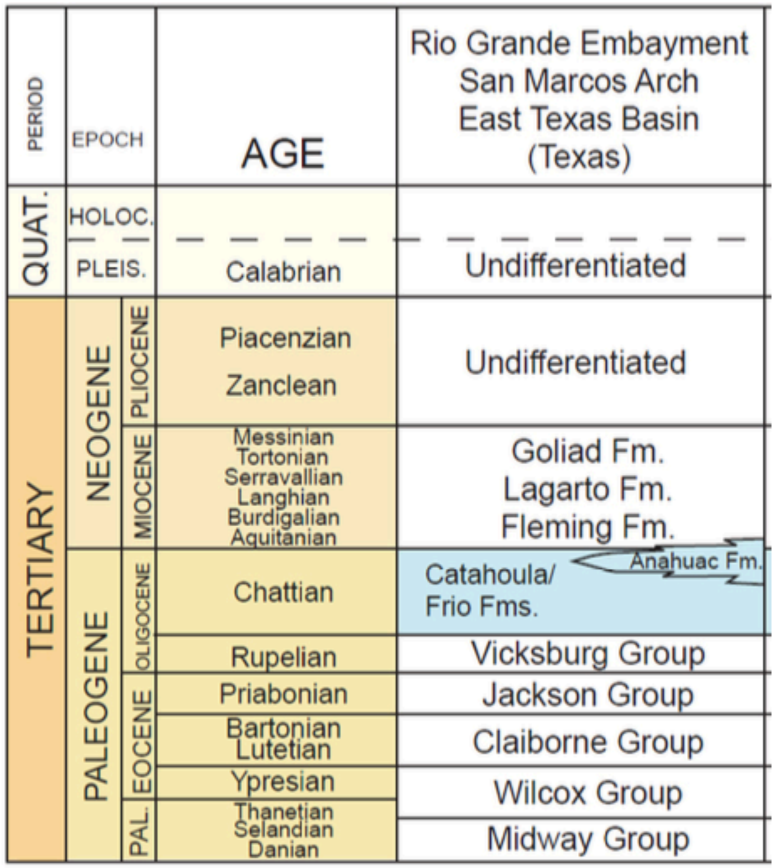

Figure 6 – Stratigraphic section of Texas Gulf Coast. From Karlsen and Swanson (2008).

Frio deposition in relation to sea level cycles by Galloway et al (1982) notes the progradation of the Frio wedge occurred at or just before a major fall in sea level. Deposition then continued through a time of generally gradual sea level rise that was interrupted by intermittent sharp, temporary rises during early Miocene time until the onset of the Anahuac transgressive event. After this transgressive time, progradation and the shoreline's seaward advance ensued for a period of several million years prior to the highstand of the Middle Miocene (Galloway et al, 1982). The progradational Frio wedge occurred as a result of well-defined subsidence of the inherently unstable platform edge that accommodated sizeable amounts of terrigenous sediment. Diapirism, growth faulting, and sedimentation associated with such occurrences producing locally distinct sedimentation patterns are all resultant of variances of strata underlying the Frio formation. Salt diapirism, salt withdrawal basins, and the complex fault systems related to such features all characterize the Houston embayment and the sedimentation affected by these structures.

Galloway et al (1982) also separates the Frio into three distinct sections based upon depositional history. During lower Frio deposition, localized shelf edge deltas built seaward over muddy aggrading slope sediments, which were subject to sporadic influxes of resedimented delta front sands. The largest portions of distributary mouth-bar sand were preserved coincident with the seaward terminations of major fluvial axes. Once the middle Frio depositional period arrived, the shelf edge had begun to extend seaward, causing the depositional setting to shift to shallower water conditions. The main focus of coarse-grained sediment had begun an eastward shift, where sandy marine modified deltas were supplied by large fluvial channel systems flowing through Harris, Liberty, and Fort Bend counties. The Anahuac transgression affected the depositional style of the upper Frio Houston delta system. Sequential transgressions extend farther landward but were separated by episodes of delta progradation. Moving landward, the delta lobes decrease in size and wave reworking along the intruding shoreline produced time-transgressive blanket sands near the top of the Frio formation (Galloway et al, 1982).

Local Stratigraphy

According to work done by Halbouty and Hardin (1955), regional shaly sands are often thick and clean on the flanks of salt domes. But as sands are stretched towards the crest of the salt dome, they become gradually thinner and usually pinch out into shale wedges in close proximity to the salt-sediment interface. Regional sands, as is the case of the Vicksburg sands in the North Blue Ridge Field, can also pinch out some distance from the diapir. In the instance of these Vicksburg sands, this occurs roughly 3,000 feet from the edge of salt (Halbouty and Hardin, 1955) (Figure 7). In some cases, sands pinch out along a common line around the dome, while in others lower sands pinch out at a deeper horizon with upper sands extending farther up the flank of the dome. As stated by Galloway et al. (1982), the thickness of the Frio section ranges from 1,800 to 7,500 within the Houston delta system, this is perturbed locally by the formation of the Blue Ridge Salt Dome. The entire Frio section thins moving upward towards the crest of the dome and pinches out rather than extending over the top of the dome. From wellbore data, the interpreted full Frio section reaches a maximum thickness of roughly 2,000 feet in some areas. This number represents the depth from the First Frio sand to Salt.

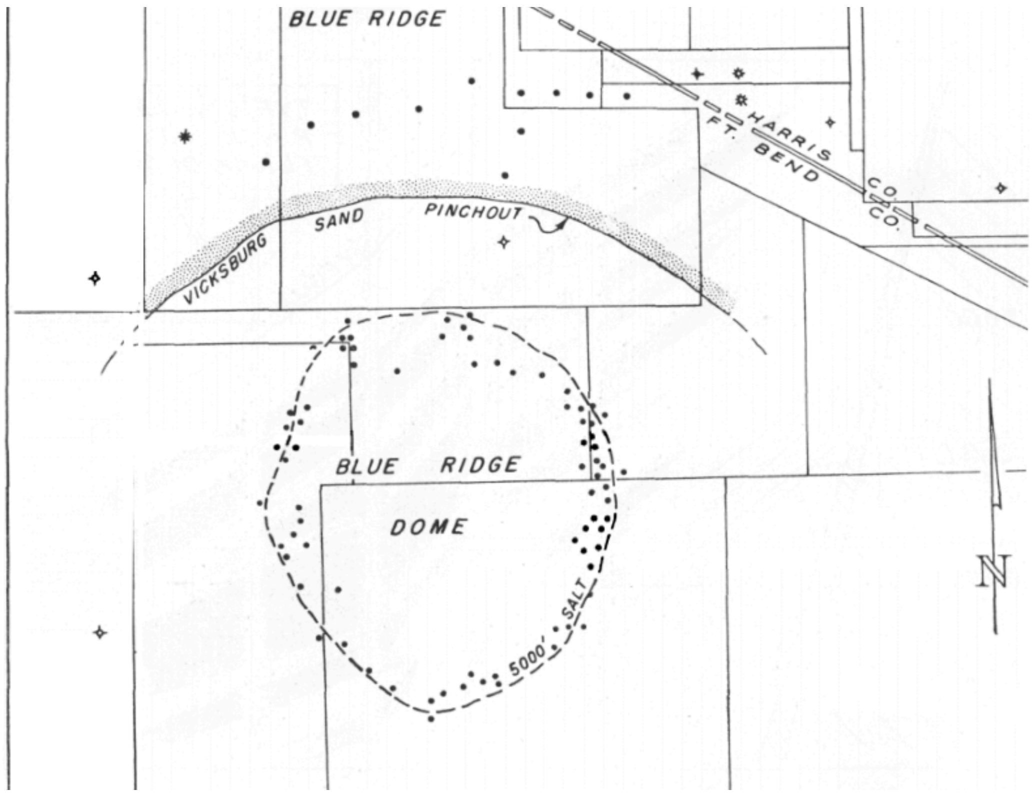

Figure 7 - Vicksburg sand pinchout in Blue Ridge North Field, from Halbouty and Hardin (1955).

Kiatta (1987) also discussed Vicksburg sands specific to the Blue Ridge Salt Dome. The presence of the second Vicksburg sand is apparent due to its deposition in the dome's peripheral sink or rim syncline. This sand is not continuous around the entirety of the dome, as the fluvial distributary system for Vicksburg deposition produced sand channels limited to areas around the dome. Kiatta (1987) notes this sand pinches out quickly towards the dome and becomes shaly and thin away from the dome, comparable to the statements concerning regional sands by Halbouty and Hardin (1955).

From production data, the Frio is responsible for the majority of the hydrocarbons within the study area. A general estimate would place Frio production as well over 95%

of the total production. Few wells on the South section of the dome produce from Vicksburg sands and some Miocene production has occurred on the eastern flank, but very little current Miocene production occurs within the study area.

Reservoir characteristics vary across the Blue Ridge Salt Dome and across the study area. The southern flank of the dome is dominated by water driven Frio reservoirs when reservoir sands are connected. However Vicksburg production in this area is markedly gassier. Moving around to the eastern flank of the dome, depletion drive becomes more common as total fluid production will decline over the life of the producing zone. It is important to note the generalization of extremely limited spatial expanse of reservoir sands in the complex areas near salt. This is supported by variations in sand package signatures in log data. While correlating in section, sands in adjacent wellbores often appear unconnected as SP and resistivity profiles differ. However, production data suggests some downdip sands exhibit better connectivity. These also return similar characteristics in log signatures, leading to the assumption of a better correlated and connected reservoir package in comparison to sand packages with variations in log profile.

Through evaluating the productive sections at the Blue Ridge Salt Dome, the termination point of markers within the interval have been approximated in relation to the face of the salt plug. A map view of the idealized dome with marked pinch out or termination points is included (Figure 8), it is important to note that this rendering is solely for conceptual purposes and is not drawn to scale. To supplement the map view, a conceptual cross section shows the same points of termination at the salt plug (Figure 9).

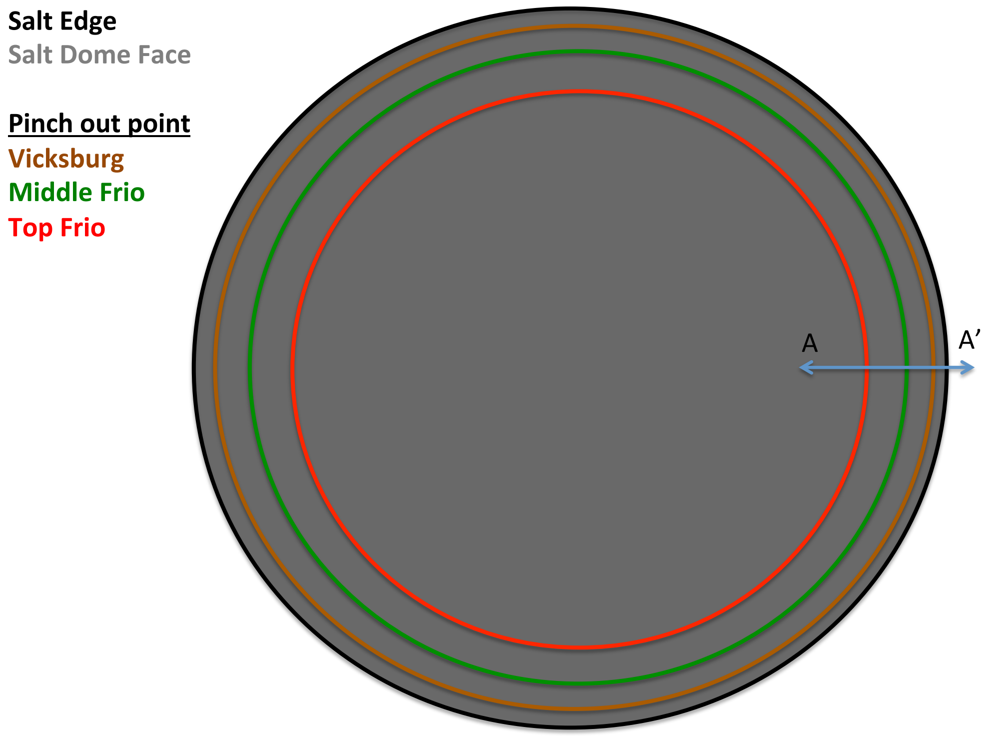

Figure 8 – Conceptual map view of Blue Ridge Salt Dome with marked termination or pinch out points notated by colored circles. These pinch outs are characteristic of the study area and extrapolated to the entire dome here for visualization purposes. Figure is not drawn to scale. Cross section A-A’ shown in Figure 9.

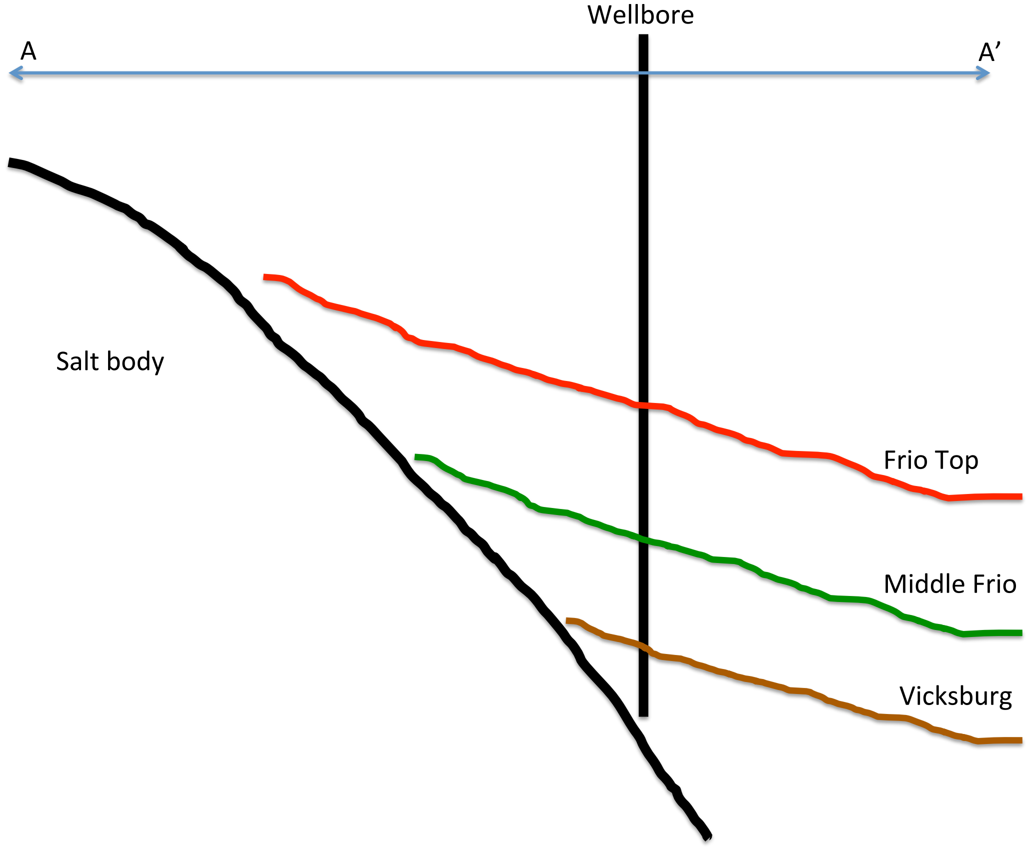

Figure 9 – Conceptual cross section A-A' from Figure 8 showing termination of stratigraphic markers at the salt/sediment interface. Figure is not drawn to scale.

CHAPTER 3

STRUCTURE

General Structure

Faulting is a common feature of most salt masses with considerable relief. The faulting may be directly associated with the migration of the salt mass or related to regional faulting which has manipulated or masked local displacements (Murray, 1966). By examining fault patterns around salt bodies, evidence for the initiation of the diapir, sealing faults, and migration pathways can be discovered (Guglielmo et al. 1997). Unfortunately, the application of vertical sections alone to physical models often overlooks the 3D aspects of fault systems and fault surfaces. But recording accurate reflections to resolve fault planes near salt remains challenging due to the heterogeneity of the salt plug, steeply dipping interface, and the thinning or pinching out of sedimentary layers near the salt surface. On the subject of faulting in the sediment surrounding piercement salt, Murray (1966) states that faulting is common in or surrounding domes with applicable relief. The occurrence of faulting can be localized or directly related to the migration of a salt plug. Other instances suggest faults that are related to regional faulting, which also may influence or disguise local displacements. The patterns vary from simple to highly complex, but the lack of data usually restricts construction of the entire fracture complex. But, "with very few exceptions, known faulting associated with salt structures can be interpreted to be normal or gravity faulting" (Murray 1966).

The primary objective of a study completed by Howard (1971) was to "simulate the changes in form that occur during the development of salt domes". To summarize the findings of Howard (1971) on domal growth that apply here, as the formation of the dome initiates and continues, the overall shape of the dome will change, in turn affecting faulting in the surrounding sedimentary layers. During dome formation, some portions of the dome are stationary while some parts are moving; Howard (1971) describes this sporadic motion as random and also notes the small-scale dome shape may be primarily controlled by surface stresses acting at the salt-sediment interface. However, the direction of displacement for the moving portion of the salt and sediment interface may also be described as random. To add to the convolution of salt structure formation, the work done by Guglielmo et al. (1997) note the style and shape of salt structures change relative to the structure's location within the basin, notably moving seaward or landward- The salt layer surface area and number of emergent diapiric structures increase landward, which would also locally alter the oil maturation window as the salt migration would cool deeper strata in conjunction with heating shallower reservoirs.

A notable exception to the generalization made by Murray (1996) is the thrust fault bounding Oligocene Frio production in the south Boling oil field discussed in depth by Halbouty and Hardin (1954), which was found to be apparently related to the growth of the piercement type salt dome. Dusseault et al (2004) also displays generalized deformation regimes around a domal structure that include thrust and strike-slip offsets in addition to normal fault throws (Figure 10). Dusseault et al. (2004) also includes an interpretation of strata overlying a salt dome from the Gulf of Mexico (Figure 11). The figure shows radial and circumferential faulting patterns. This arrangement of large-scale discontinuities show that both tangential and radial stresses were the smallest principle stresses during the time of the dome's emplacement that confirms the general extensional strain conditions in the materials overlying the salt (Dusseault et al. 2004).

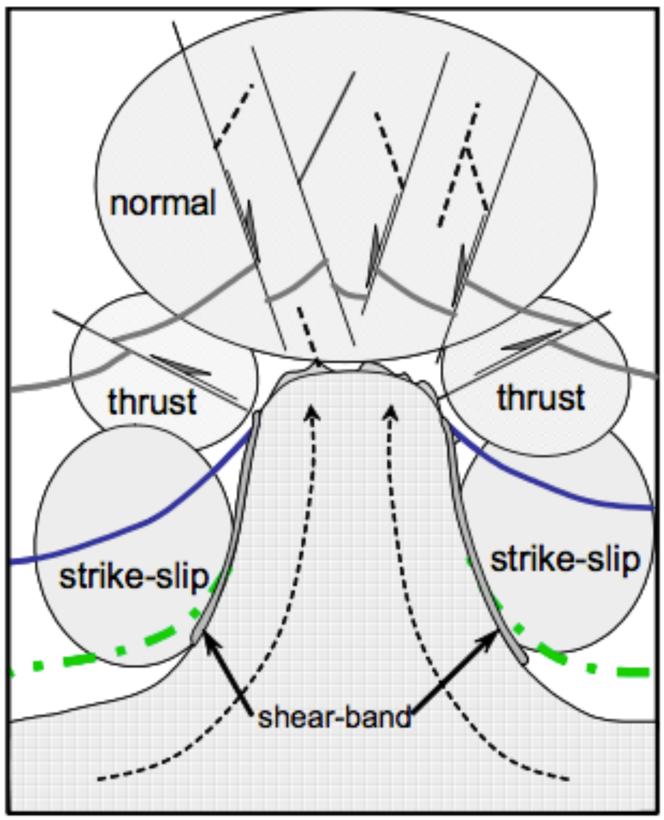

Figure 10 – Generalized stress regimes around salt domes, from Dusseault et al (2004).

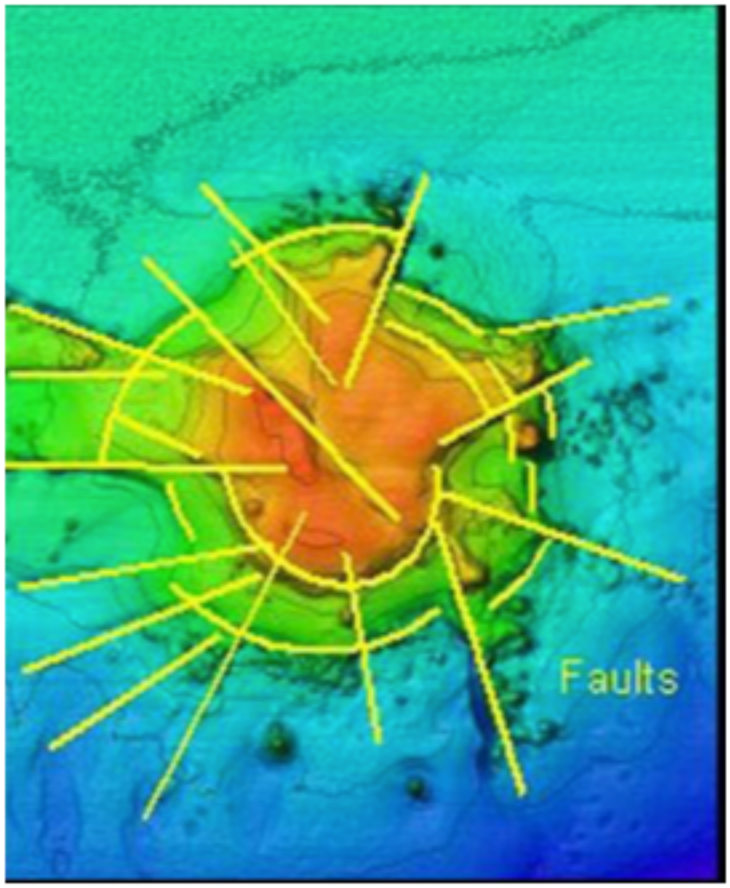

Figure 11 – Interpreted structure of Gulf of Mexico salt dome. From Dusseault et al (2004)

Withjack and Scheiner (1982) investigated the effects of regional strain on domal fault patterns. Their models of domal growth and formation and show the presence of strike-slip, and thrust faulting in conjunction with normal faulting, each type of which are limited by distance from salt (Figure 12). The experimental data compiled by Link (1930) also show the presence of thrust faults occurring at depth.

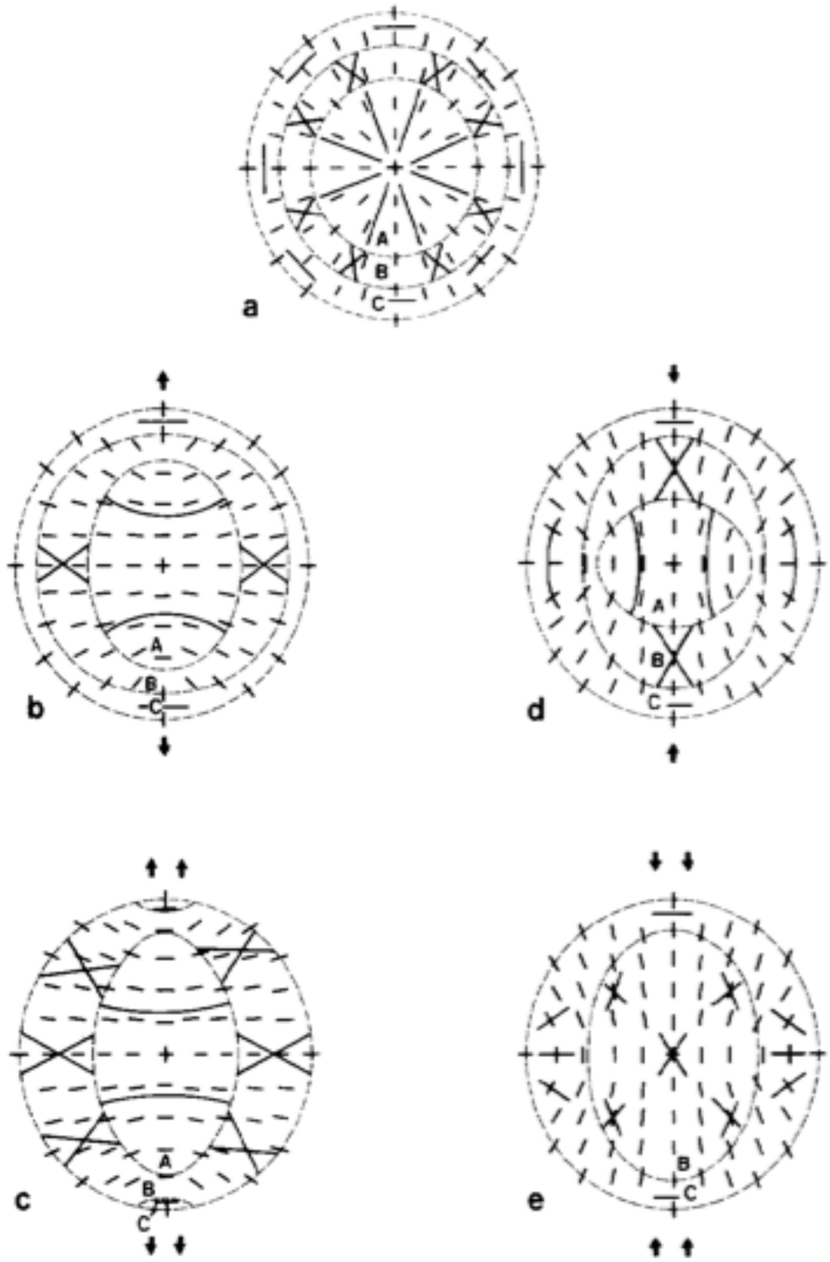

Figure 12 - Circular dome surface fault patterns in relation to regional strain applied to the dome. Zone A contains normal faults with expected 60-degree dip. Zone B contains strike slip faults with near vertical orientation. Zone C houses concentric thrust faulting with 30-degree dip. Arrows indicate direction and relative force of regional strain. From Withjack and Scheiner (1982).

Local Structure

As early as Halbouty and Hardin (1955), evidence of multiple fault orientations and displacements in relation to salt diapirs is presented. The authors show radial, tangential, and peripheral faults “in an assortment of complex systems” in relation multiple domes along the Texas and Louisiana Gulf Coast that develop during uplift in the surrounding strata. In the examples listed by Halbouty and Hardin (1955) most peripheral and tangential faults are down thrown towards the dome, which would indicate normal, non-thrust displacement of fault planes. Kiatta (1987), on the subject of Vicksburg production around the Blue Ridge Salt Dome notes a “complex system of radial faulting” that limits productive intervals around the dome.

CHAPTER 4

RESEARCH DESIGN AND PROCEDURES

Improvements in technology and a more thorough approach to research has led to the renewal and expansion of interest by the petroleum industry to the physical modeling of faulting associated with “halokinesis” or salt movement. Furthermore, fault patterns in scaled models bear striking resemblance to those observed in depth-converted seismic sections (Weijermars et al, 1993).

Workflow

The building of an adequate project in the software programs is the first major order of business. This includes loading all forms of data- digital logs, raster logs, well locations, and survey lines/lease lines/other culture, to produce an adequate database of information. It is important to note the large amount of previously compiled data used for exploration and developmental purposes. Historical and modern data including (but not limited to) logs, driller’s logs, scout tickets, and map plats are all scanned and stored in picture form prior to the initiation of this work. While extremely helpful, this does not include setting up or inputting any of the respective data into the software used here for analyzing seismic or well logs.

The work done here will mainly employ two software programs by IHS- Petra and Kingdom. The work in Petra will involve the logs from wells, both historic and modern, on the salt dome. Modern and historic logs loaded into the program will be used to pick markers characteristic of the strata around the dome. These markers or formation tops can illustrate the differences in depths in neighboring wells when displayed in a grid format, which would be indicative of throw along a fault plane.

To maintain continuity between historic and modern electric logs, only a few specific curves will be utilized for correlation: spontaneous potential (SP), resistivity curves and others in modern logs when available. While technology has continued to evolve for well logs, the limitations here stem from the quality and quantity of historical log data. While modern digital logs provide a plethora of log curves to analyze and correlate, historical data is usually limited to resistivity and spontaneous potential curves. For integrating well top information with the seismic, the focus will be on a few distinct markers that are uniformly found in all or most of the wells around the dome.

The main producing formation here, as with many of the salt domes on the Gulf Coast is the Oligocene Frio, so the data used in this study will concentrate on that interval. Moving upward through stratigraphic sequence, the first marker is the top of the Vicksburg formation or base of the Frio, marking the onset of Frio deposition. The second marker is the top of the middle Frio depositional unit, a common productive interval that extends fairly high up onto the dome. The final marker is the last deposited, uppermost Frio depositional unit (Figure 13). Another marker of importance to this study is the top of salt. It is not uncommon for wells drilled on the flanks on the dome to drill until reaching salt, which also returns a distinct log signature (Figure 14).

The interpreted formation tops will be used to identify fault blocks within the study area as best as the data allows. The spatial extent of the well control will limit well log data interpretations to the productive areas around the dome. But once identified with log data, seismic data will be employed in an attempt to identify or further pinpoint fault planes if possible. After manufacturing a structural profile for the southeast flank of the dome, the findings of this work can be analyzed and compared to prior modeling works pertaining to dome structure.

Marker Characteristics

The top of the Vicksburg (or base of Frio) marks the starting point of the Frio formation. The Vicksburg is found in most of the wells on the flanks of the dome but does pinch out as it extends closer to the salt plug. Halbouty and Hardin (1955b) noted the Vicksburg sand pinchout on the North side of the dome roughly 3000 feet from the salt plug, but it also occurs on the eastern and southern flanks as well. In log section, two sands can identify the Vicksburg top, with lower gamma ray and SP log values and an increase in resistivity. The regional contact between Frio and Vicksburg can be identified by a resistivity marker that corresponds to a change in depositional mode (Combes, 1993). But perhaps the most identifiable trait of the Vicksburg top is its depth and the large, commonly wet, basal Frio package that overlays the shaly Vicksburg sequence (Figure 13).

The Middle Frio depositional package is the largest interval in the formation and is overlain by a sizeable shale section. Ranging up to a few hundred feet of thickness, it is fairly easy to identify, but it does pinch out toward the dome and terminate on the salt face. The Middle Frio is not a clean or continuous interval, but more a series of sand, shale, and sometimes carbonate dominated intervals, with producing intervals varying from four to ten feet, but rarely exceeding twelve to fourteen feet in thickness. In log sequence, the entire interval can be recognized by a long series of spontaneous potential, and resistivity curves that both rise and fall, and change quickly, which gives the Middle Frio a somewhat ratty log appearance in some instances (Figure 13).

The uppermost Frio is depositional unit is comprised of mostly sand and is underlain and overlain by shaly intervals. This zone varies in thickness, but is roughly 50 feet from top to bottom and water bearing, causing a distinct drop in the resistivity log curves relative to the strata above and below it, with lower SP log signatures that would be expected of a highly permeable sand. Another identifiable trait of this interval is its relation to the clip point. In log section, the clip point is recognized as the point at which formation waters change from brackish to salty water, and can be marked on a log as the place in which the deep resistivity curve falls below and continually stays under one ohm unless in permeable zones. The uppermost Frio sand is typically found less than a few hundred feet below this clip point (Figure 13). The clip point should not be used as a regional marker, but is used in the local case of the Blue Ridge Salt Dome.

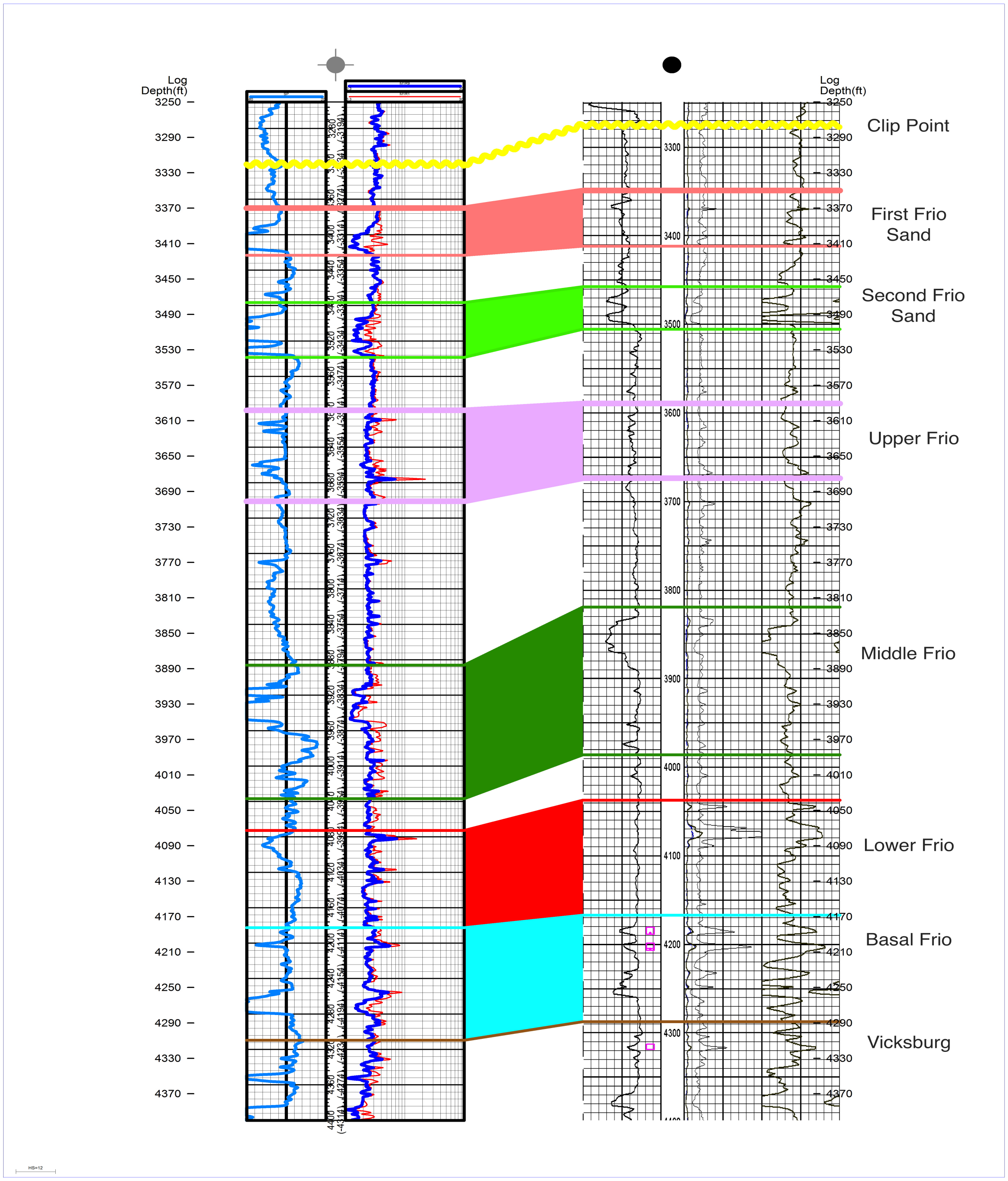

Figure 13 – Type logs displayed in structural cross section from study area. Included is a raster (paper) log and modern log with digital curves. For correlation purposes modern logs are displayed to mirror historic logs. Track 1 houses the SP (light blue), track 2 shows deep resistivity (blue) and shallow resistivity (red), similar to tracks on the raster log. Frio marker labels are shown next to their respective tops.

Top of Salt is an important marker for this study as well. While not in a uniform stratigraphic position, it does provide a unique log signature for identification. In log, salt returns distinct SP values, and very high resistivity. In some instances as with historical data, salt depth data was gathered from sources other than electric logs, such as scout tickets and drillers logs. Typical log responses to salt encountered at the Blue Ridge Salt Dome can be seen here (Figure 14). An atlas of log responses can be found in Appendix 1.

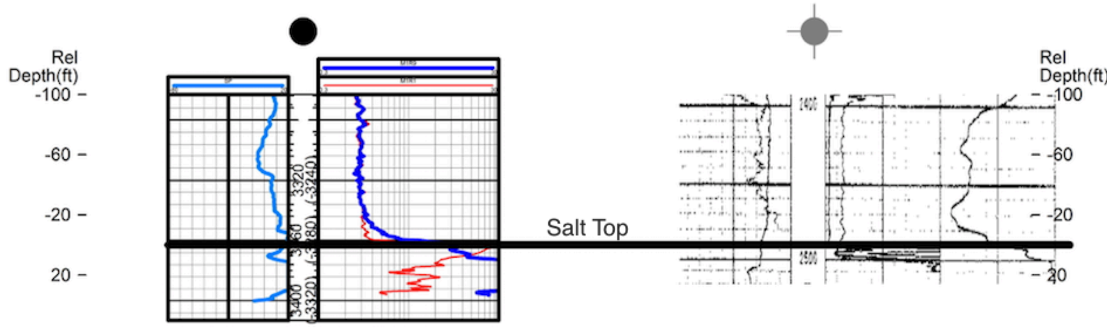

Figure 14 – Typical log response to salt as seen in stratigraphic cross section (flattened on Salt top) in both digital and raster logs from wells producing from the area around the Blue Ridge Salt Dome. Salt was encountered just before reaching TD for the well and marked by black line across the log. Salt identified by SP (Blue in Track 1) and marked rise deep resistivity (Blue in Track 2) and shallow resistivity (Red in track 2). Similar responses can be seen on the raster log.

Study Limitations

Kingdom software is mainly employed to evaluate subsurface seismic data. The three-dimensional survey used here encompasses portions of the flanks of the salt dome, but was limited by the surrounding culture and lease rights and subsequently affected the quality of data. For the work done here the focus will be on best data that extends far enough off the dome to properly image the high dip angles of the formations affected by the piercement of the salt. This best data is found on the southern to eastern flanks where the seismic survey had adequate offset from the salt plug.

Limitations of the seismic data can be directly linked to the design of the survey and the processing of the data after the shoot. When analyzing this data, it is very apparent that quality of the data declines with depth and essentially becomes unusable below 5,000 to 6,000 feet and even less in other areas. This can be directly attributed to the lack of offset needed to image the high dip angle strata characteristic of piercement style salt domes. In addition to depth issues, resolution near the salt plug also presents challenges for the dataset. As the strata moves up onto the salt plug, the beds thin and pinch out. Consequently, frequency and wavelength to image the beds on the flanks and off the dome become inadequate at some point moving up the dome flanks. This imaging issue is further complicated by the depositional characteristics and the complexity of structural deformation often found near salt.

The seismic data used here was previously depth converted, which can also present accuracy issues stemming from a velocity function used during depth conversion, as it is model based (Moulton, personal communication, 2017). As this function would be derived from the velocity/time interpretation model, the velocity function used in depth conversion would therefore be subject to the accuracy of the velocity model as well. If the velocity model does not accurately take into account velocity changes at, or near, faults or other factors, this can create artifacts within the depth dataset (Moulton, personal communication, 2017). On a positive note, the depth-converted data allows for the display of depth based well log data within the seismic data. Given the economic climate of the industry, in some instances, it is necessary to utilize previously gathered data rather than discard it entirely, even if the data does not meet the requirements for the full potential of the area.

Well log data and interpretations from such are not exempt from limitations either. Foremost is the spatial arrangement of wells. Wells on the dome are concentrated along the flanks of the dome where stratigraphic and structural updip traps are most common (Figure 2, Figure 4). As a result of this, well control in these historically productive areas is high, but as distance from the salt plug increases well control decreases fairly rapidly. The same well control scenario occurs for shallower parts of the dome. Similar to the seismic, the quality of log data can also be a notable limitation. While modern well logs present minimal issues, historic data presents cause for concern. The quality of historic data can be linked to several factors. Understandably, a paramount constraint on the data is the technology employed at the time the data was collected. In this case, historic paper logs were digitized prior to the incorporation into the software programs.

Connectivity between Petra and Kingdom is paramount for the interpretations made in the seismic. Gridding produced by formation tops previously interpreted in Petra can be loaded into Kingdom to be viewed in conjunction with the seismic data.

Regridding of the data in Kingdom is also possible to achieve a better fit for the data. By doing so, the formation tops can be assigned to specific seismic markers and tracked across the dataset to determine if the seismic survey can accurately image the structure surrounding the dome as interpreted from Petra. Alternatively, interpretations made from the seismic will be compared back to the Petra dataset to determine if any structural features were missed or misinterpreted. The anticipated result of this work will be a subsurface structure profile along the flanks of the salt dome that is more accurate than existing ones.

CHAPTER 5

RESULTS

Through evaluating procedures, a number of interesting structural features and trends have been revealed. As the structural characteristics around the dome are directly related to the formation of the dome, the salt dome face for this portion of the dome has been mapped and displayed in subsea depths (Figure 15). Both well control and seismic data are lacking over the top of the dome, so the grid extrapolation was limited to the producing interval area.

Due to the issues of imaging near salt, all gridded figures were produced using only data from well logs or drillers logs/scout tickets. This imaging issue is exhibited in a seismic line extending from the southeast part of the dome.

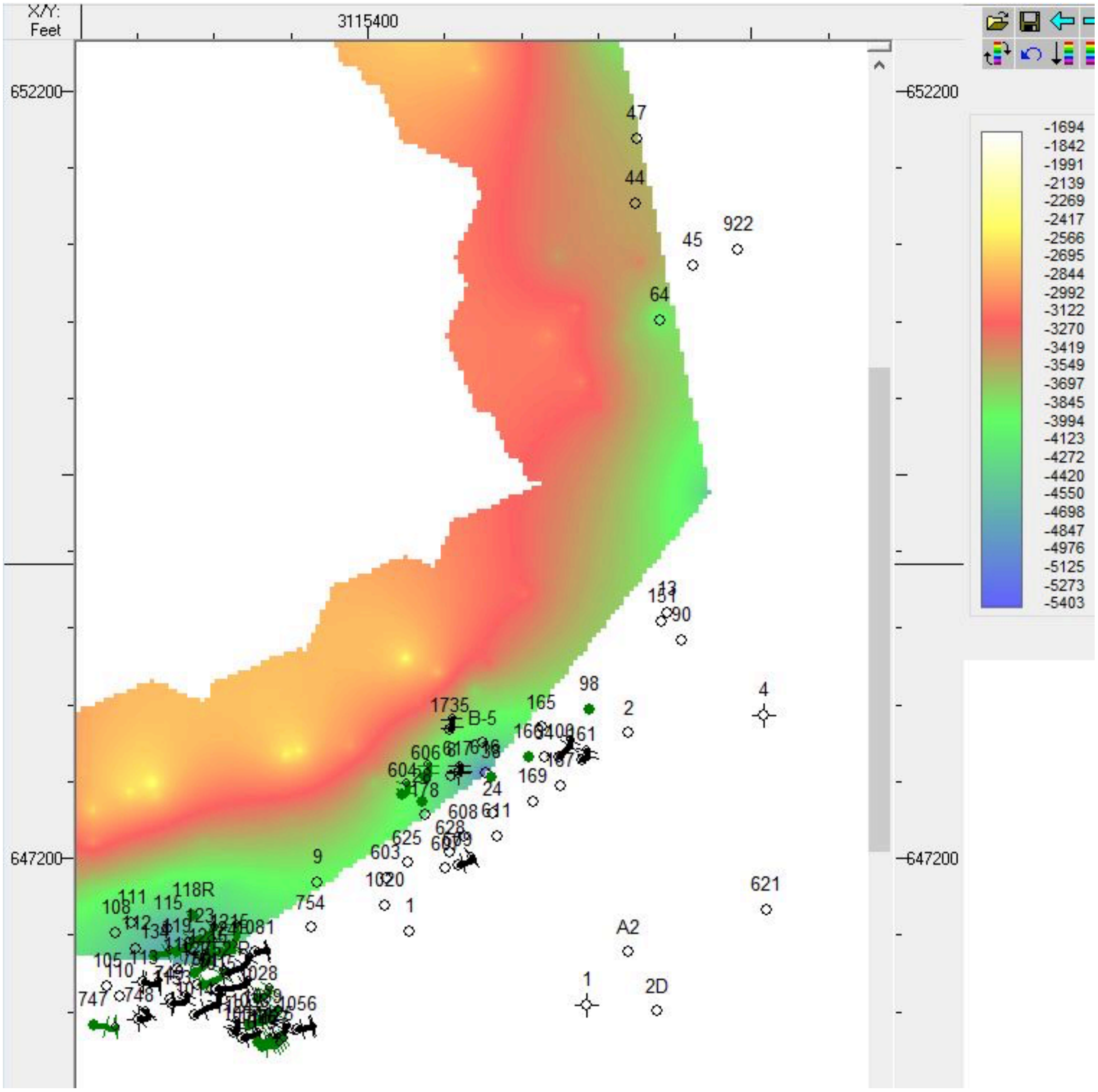

Figure 15 – Grid on southeastern portion of the Blue Ridge Salt Dome showing the subsea depth to Salt. The wells displayed on the grid are wellbores that encountered the Vicksburg formation. Well control over the top of the dome is very minimal and data for the few wellbores that exist there was not accessible for this study.

A subsea depth map of the Middle Frio produced from wellbore data is included (Figure 16); this figure also shows interpreted radial faulting and an approximated termination line. As this grid data was not as limited in the process of extrapolation, the program has filled in the area on top of the dome. However, anything inside of the termination line (dashed) should be considered speculation due to the lack of well control. Faulting in this figure has been marked by discrepancies in gridded data extending outward from the center of the dome. The northern most fault returns a displacement much larger than the other radial faults. While most faults throws in this figure only measure up to a couple hundred feet, this northern most fault displaces formation markers in excess of one thousand feet at its greatest point but the throw decreases rapidly as the fault trace travels towards the center of the salt plug. This same data can be seen in a 3-dimensional view (Figure 17). The view of the middle Frio in this manner better illustrates the offset along the radial fault planes that seem somewhat irregular and discontinuous in some aspects. Some displacements transverse the entire dome flank, while other offsets are focused to smaller sections. In conjunction with these views, an isopach of the Middle Frio can be seen (Figure 18). This isopach also has a line indicating the deepest section of salt penetrated in wellbore and the approximated termination of the Middle Frio at the salt face. As with other grids, the presence of data outliers is apparent but the spatial relation of the Middle Frio thickness to the edge of salt is easily identifiable.

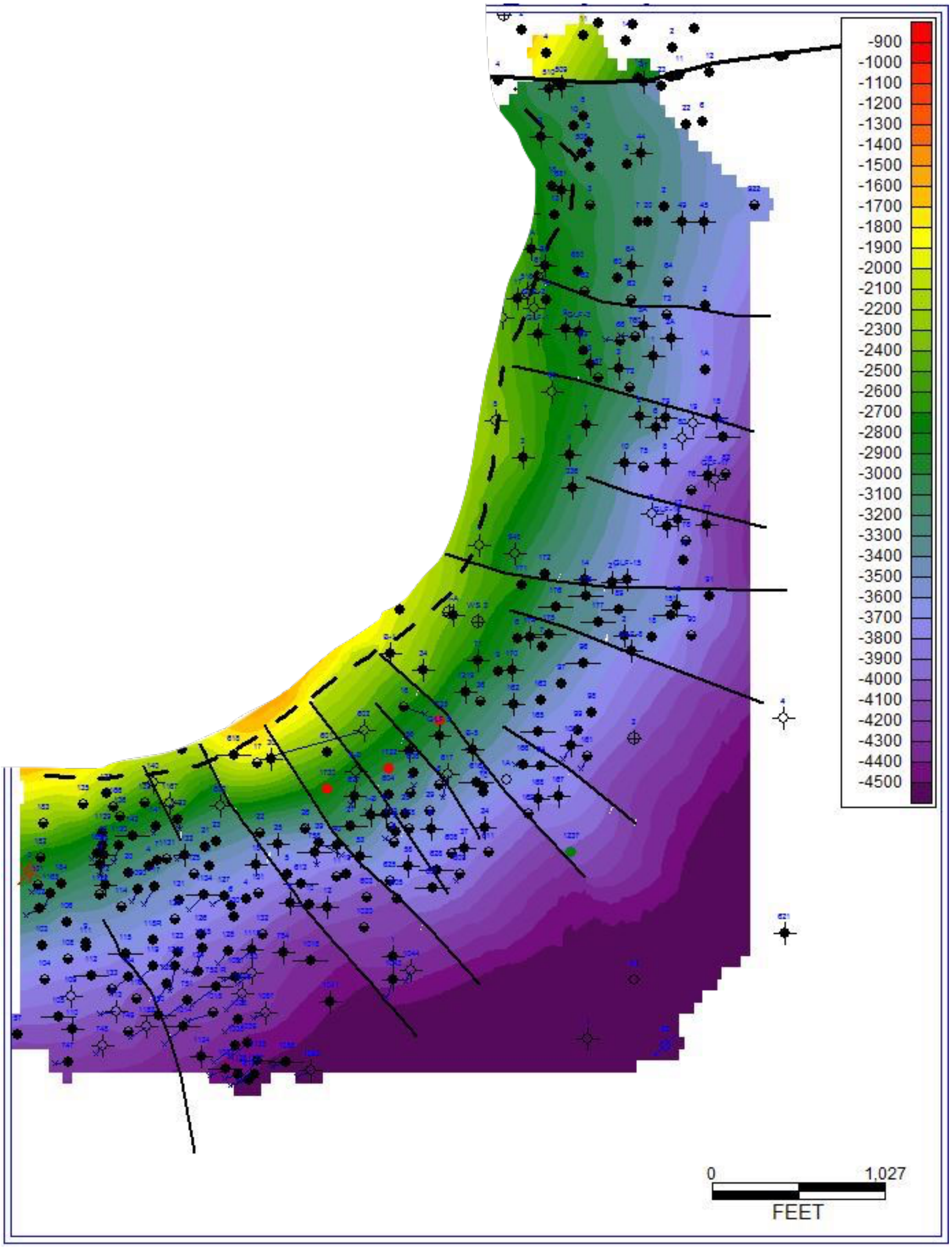

Figure 16 - Subsea structure grid of Middle Frio section on the southeastern portion of the Blue Ridge Salt Dome. Overlain is interpreted radial faulting (solid lines) and approximated Middle Frio termination at salt (dashed line). Note the fault near the top with displacement much larger than other interpreted fault throws.

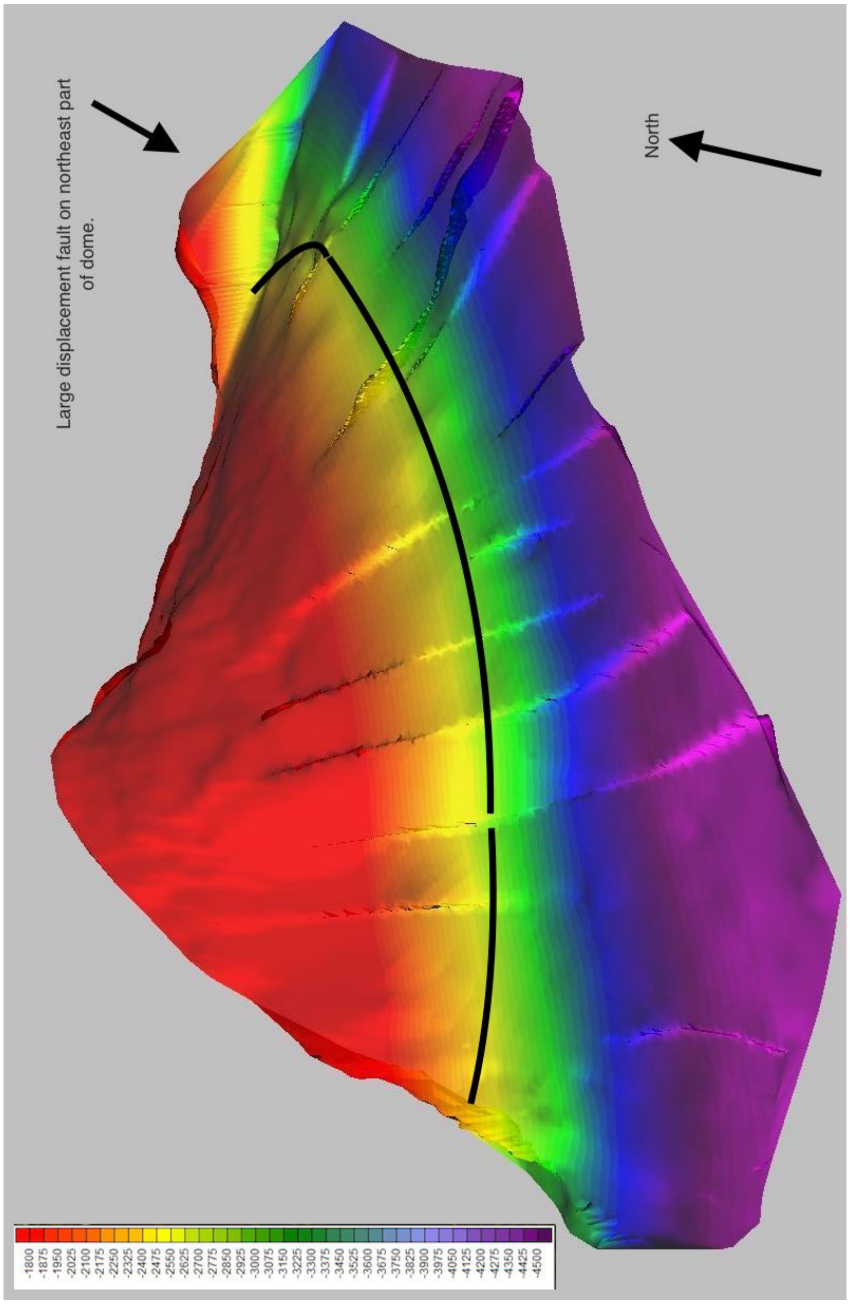

Figure 17 – 3D view of the Middle Frio top across the southeast portion of the Blue Ridge salt dome with interpreted fault displacements. The large throw at the top of the figure corresponds to the large displacement seen in the previous figure. Viewed in 3D the grid has been turned slightly for illustrative effect, north is notated. Black line notates approximate pinchout of Middle Frio at salt piercement.

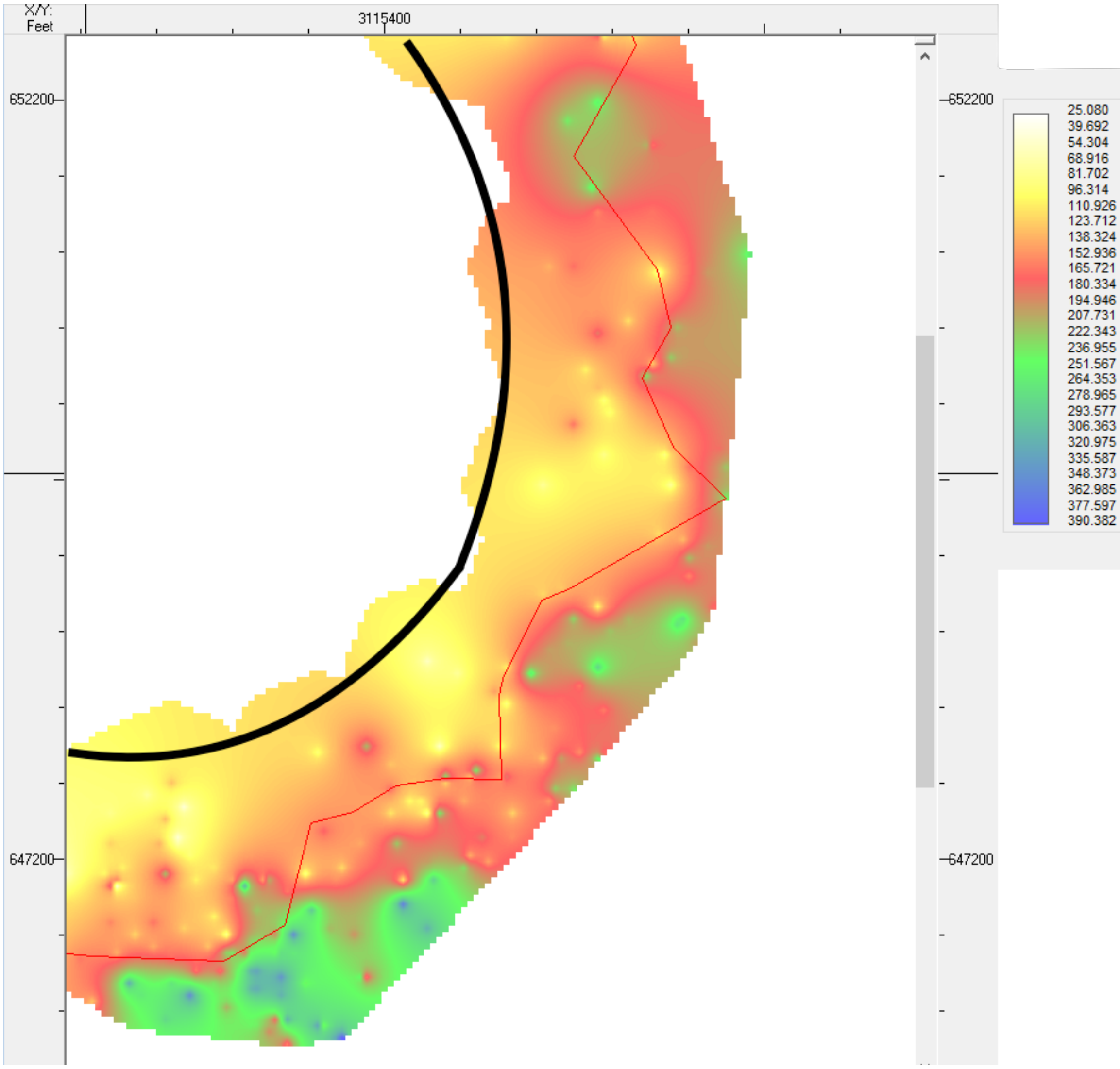

Figure 18 – Isopach of Middle Frio section with overlain salt penetrations marked by the red line running through gridded data. Note relation of thickness to edge of salt. Approximate pinch out line of the Middle Frio at the Salt face is marked in black. This pinch out line is approximated due to lack of well control over the top of the dome and it meant for spatial reference.

A grid from the First Frio sand to top of Salt illustrates the thickness in feet of this section across the southern and eastern portions of the dome (Figure 19). This figure was manufactured in the Kingdom software by gridding the imported formation top data from Petra. To produce this visual, only wells with both First Frio and Salt top markers were used. As a result of this, the edge of the colored data shows the outermost extent of salt encountered in wellbores. It is of importance to note the limits of exploration that restrict the data in this case. Both historical and modern data suggest the major productive intervals are limited to the Frio section and sands near the top of the Vicksburg formation. This being the case, wells drilled on the flanks of the Blue Ridge Salt Dome only targeted these intervals and were subsequently considered to have reached total depth (TD) when penetrating the Vicksburg sands or drilling into the surface of the salt plug. Whichever scenario occurred first halted further drilling. A grid showing the thickness of section from the Middle Frio to Salt is also shown (Figure 20). As with all the depth grids shown, this was manufactured from wellbore data.

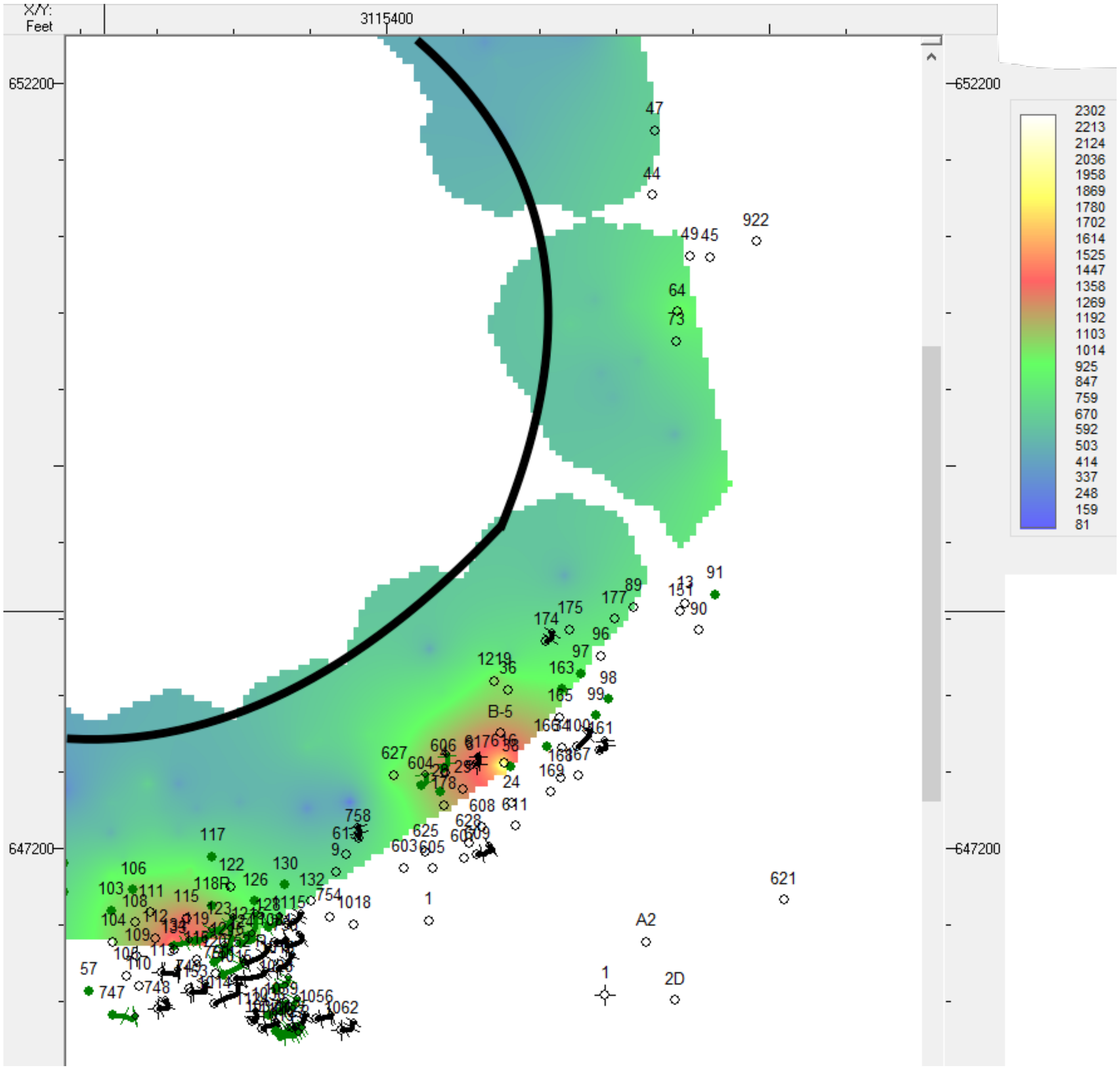

Figure 19 – Grid showing the thickness of section from the First Frio sand to the top of Salt. As can be seen from the gridding, data is not extrapolated away from the grid. Since this thickness was calculated from wellbore data, the edge of the salt dome as encountered in drilling efforts is limited to the outward edge of gridded data seen here. The subset of wells displayed is wellbores that encountered the Basal Frio package. The black line indicates the approximate pinch out point for the Frio section.

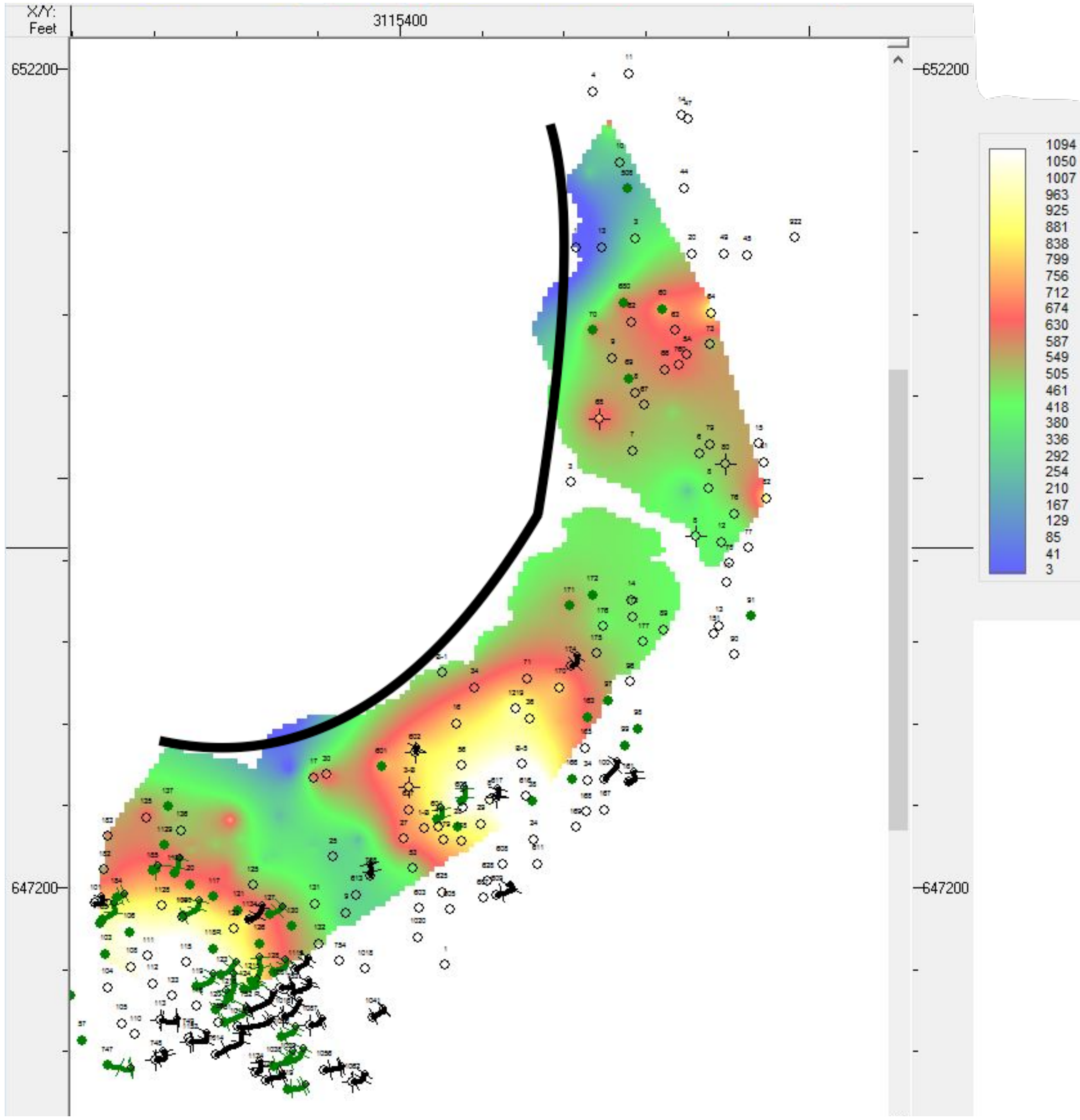

Figure 20 – Middle Frio to Salt isopach. The Salt top grid limits the inward and outward edge of this isopach. Wells shown are the available data points for the area. Overlain black line is the approximate pinch out point for the Middle Frio at the Salt face. As previously noted, the line is not absolute due to lack of well control over the top of the dome and is meant for general spatial reference.

An isopach of the First Frio depositional unit is also included (Figure 21). As with other data, this grid exhibits inconsistencies in the data that can be attributed to the process of selecting the formation markers. The figure also shows a line overlaying the isopach that shows the edge of salt penetrated in wellbore.

An arbitrary line is shown (Figure 22) spanning the study area from the southern to eastern edges of the dome. Seismic data on the dome face here is highly compromised so it has been removed for this visual to prevent possible misinterpretation of displaying well top grids on seismic data. The line is meant for depth illustration only. The location of the arbitrary line can be seen on the Middle Frio to Salt isopach that is overlain in the figure.

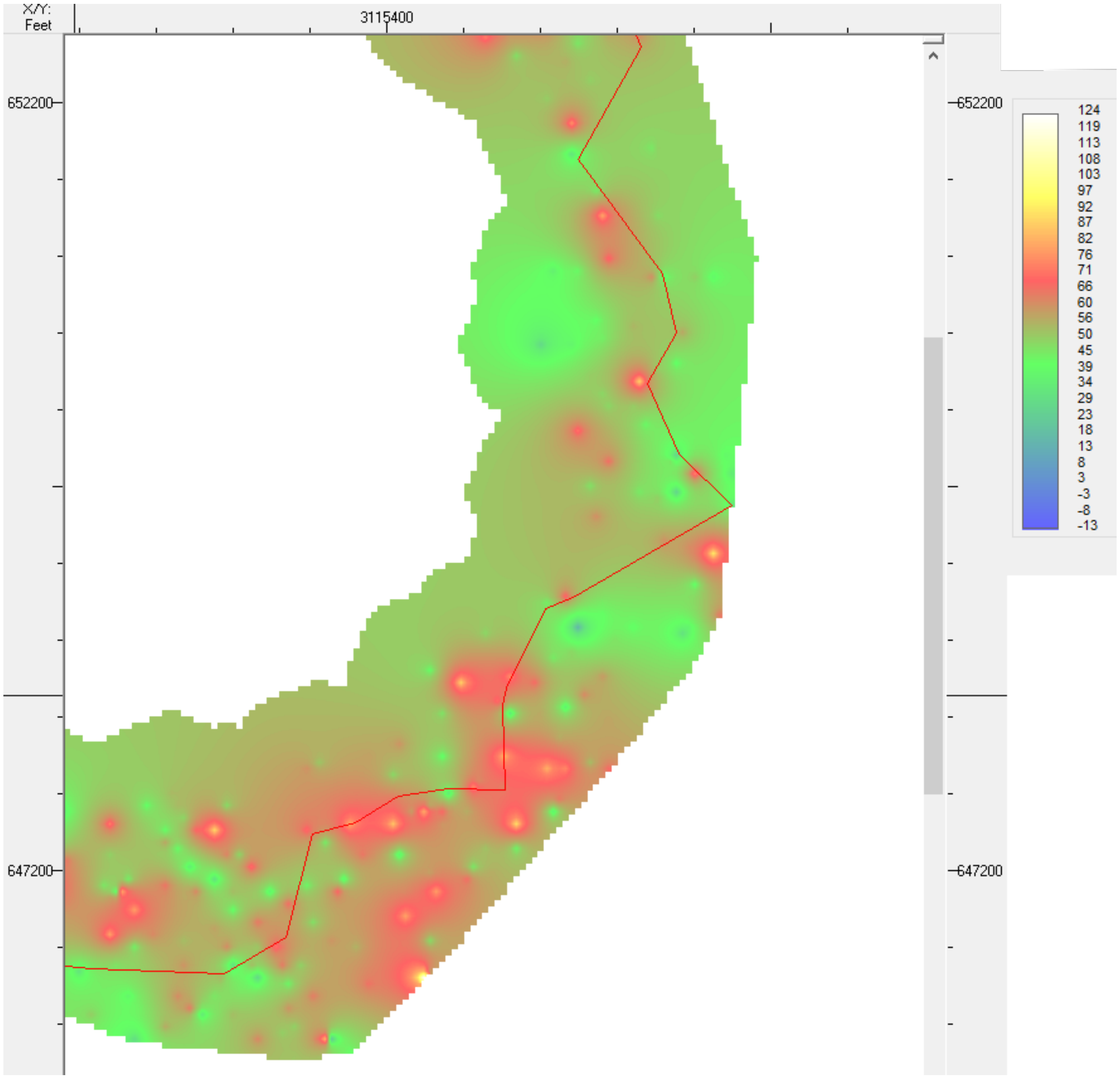

Figure 21 – Isopach of the First Frio depositional unit. Variations in thickness over the study are common but with no real relation to structural features. The line through the colored data indicates the edge of Salt penetrations as discovered through drilling efforts. This is the same line shown in Figure 18.

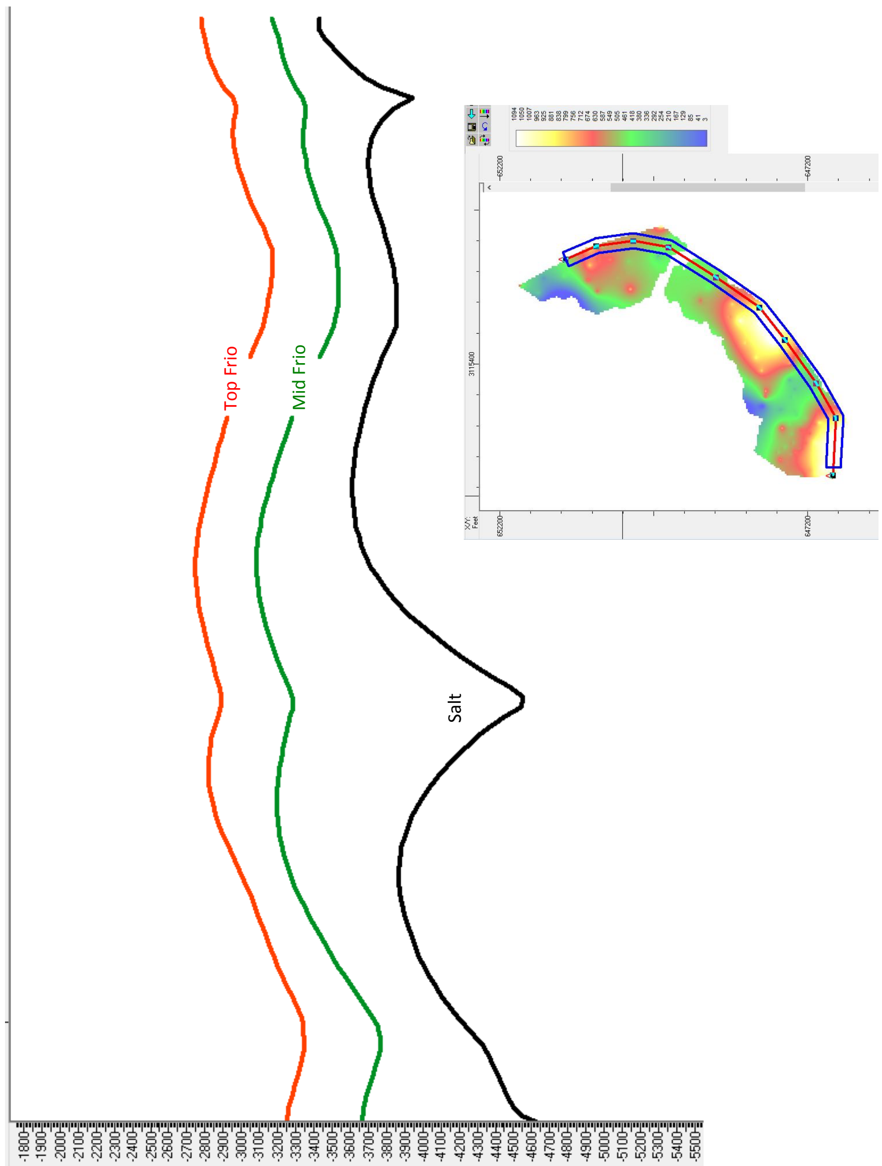

Figure 22 – Arbitrary line around southeastern Blue Ridge Salt Dome. Line location can be seen on the Middle Frio to Salt isopach. The First Frio unit from log data is shown in red, the Middle Frio in green and top of Salt is shown in black. Note changes in Frio thickness compared to Salt depth.

CHAPTER 6

DISCUSSION

While still radially oriented in the Middle Frio grid, the northern most fault has a displacement much greater than other radial faults. As seen in regional structure maps, a larger regional extensional fault intersects this portion of the dome. This northern most fault on the Middle Frio grid should be interpreted as a regional fault due to the throw illustrated here. The dip angle here is unlike other radial faulting- this is apparent when looking at repeated or enlarged sections within well logs along the fault throw, indicating a dip angle more traditionally associated with normal faults in contrast to the other vertical or nearly vertical radial faults.

After studying the features presented here, it can be concluded that the smaller radial faulting have a component of strike slip offset. Because the faults interpreted on the Middle Frio section also fit very well with the First Frio unit as well as the Vicksburg picks, the conclusion can be drawn that the radial faults seen here are vertical or nearly vertical. Due to the close well spacing, this near vertical fault plane can be determined to be accurate. When taking into account the uplifting salt plug, it is believable that these small displacements were gravity activated post deposition.

Using the models given by Withjack and Scheiner (1982), and Dusseault et al. (2004), the presence of concentric oriented thrust faults should be explored. While these two works spot thrust faults differently, they both acknowledge the presence of these types of displacements. Halbouty and Hardin (1954) show an example of a thrust fault around a salt diapir discovered with well log data at the Boling Salt Dome. The work also provides examples of peripheral/tangential/concentric faults discovered in other domes such as the South Liberty Dome and the Hull Dome. Given the complexity of the salt dome environment, identification of these low angled faults with well log data alone is difficult at best. In addition, these types of fault displacements may not be penetrated by the wells found on the dome flanks. The only real possibility for thrust identification in this situation would be in seismic data but as previously noted, imaging fault surfaces near salt is extremely difficult. This is even more problematic given the apparent limitations of the seismic data available here. A possible concentric oriented thrust fault located on the southeast portion of the dome has been acknowledged (Figure 23). It is important to note that the trace of this concentric fault is not continuous around the flank of the dome, but only appears in a limited section.

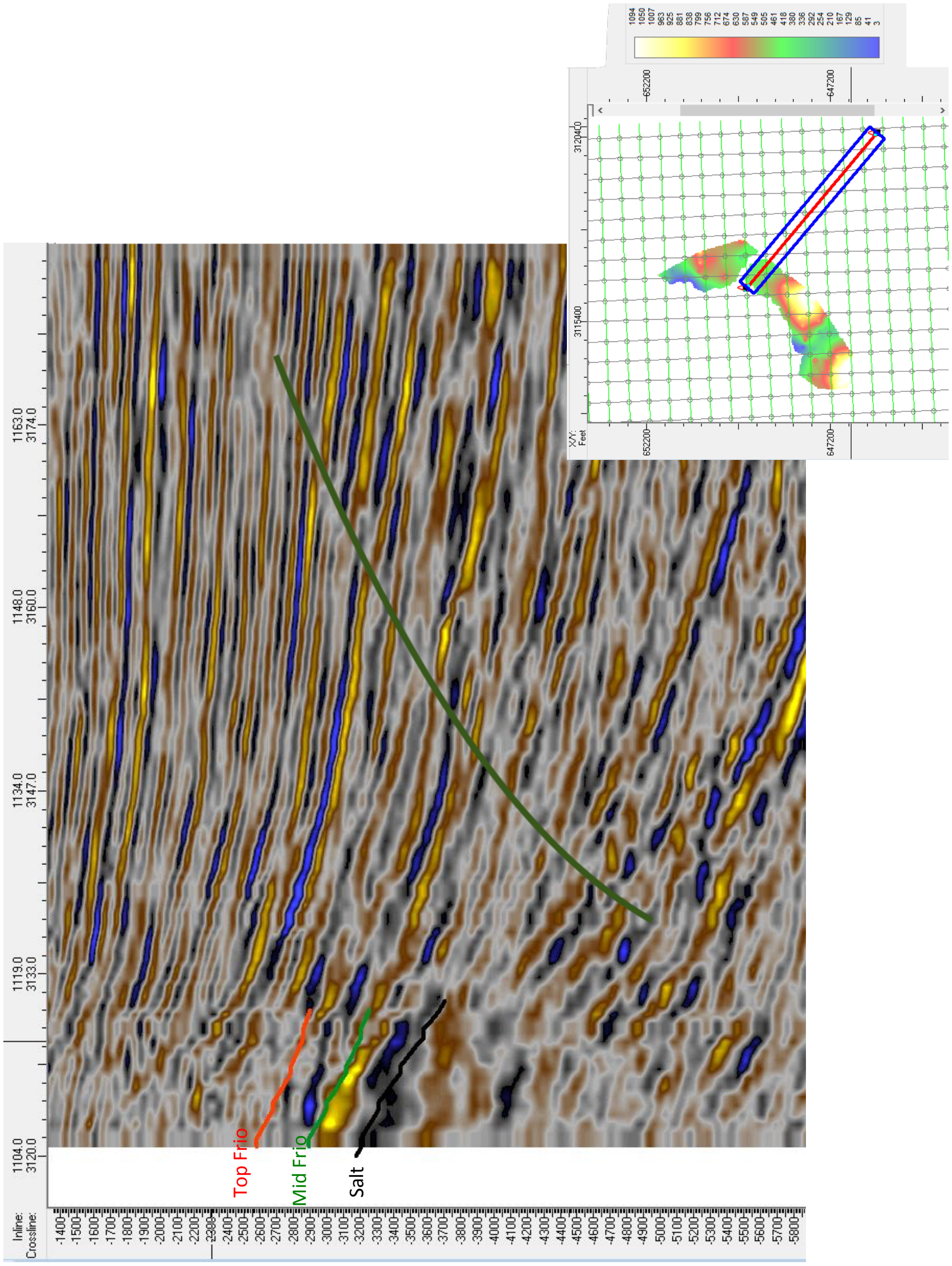

Figure 23 – Seismic line extending from Southeast portion of the dome with interpreted fault plane with potential thrust offset. The seismic section is not vertically or horizontally exaggerated which indicates the fault plane is dipping roughly 45 degrees towards the dome face as marked in green. Colored grids are notated with corresponding colored text.

Underlying these small strike-slip offset radial faults are larger, more pronounced fault blocks were revealed when analyzing the thickness of the productive Frio section (Figure 19, Figure 20, Figure 22). With the amount of well control in the area, identifying these deeper blocks is possible by shear data volume. Interestingly enough, these blocks do not become clear using the same method as used to identify the smaller offset radial faults higher in the Frio section. As seen in the 3D view of the Middle Frio top (Figure 17), no large fault throws are readily apparent, other than the regional fault on the northern edge of the study area. An explanation for the absence of sizeable fault throw in the study area would be the sedimentation rate during uplift and the timing of the salt movement. Timing of the dome's movement plays a major factor in the surrounding structural deformation. As previously noted by Halbouty and Hardin (1956) and Smith and Reeve (1970), salt movement into diapir form can be episodic and related to overburden caused by sedimentation. High sedimentation rates of the Cenozoic gulf coast suggest that sedimentation was greater than the rate of upward salt movement at times during the formation of the dome. This is clear when comparing the thickness of different Frio sections. The isopach of the First Frio sand is a great example of this as it shows relatively constant thickness across well control (Figure 21). Data outliers are to be expected based on formation picks as in some cases this sand returns a thicker resistivity signature, but overall the thickness of the unit is generally around 50 feet with no real spatial pattern related to structure as seen in other thickness figures. With no discernable correlation to structure, these thickness variations are most likely caused by variations in depositional systems. This conclusion would therefore present the case for a period of slower upward salt migration and greater sedimentation. Alternatively, thicknesses of the entire Frio (Figure 19, Figure 22) or deeper sections of the Frio (Figure 20) the aforementioned fault blocks are easily recognizable. This leads back to the effects of episodic timing of the dome. During the deposition of late Vicksburg and early to middle Frio, the dome must have been undergoing substantial uplift. The presence or absence of Vicksburg or Basal Frio section in relation to top of salt supports this (Figure 15, Figure 19). Because these larger fault blocks are defined by up to 900 feet of variation along strike, it seems likely that these blocks formed during a time of major upward salt migration. The absence of Lower Frio or Vicksburg sections supports this. A display of the Middle Frio to Salt thickness with the overlain radial faults is shown (Figure 24). Based upon this illustration, it is tough to determine whether the radial faults seen in the Middle Frio have any relation to the underlying blocks.

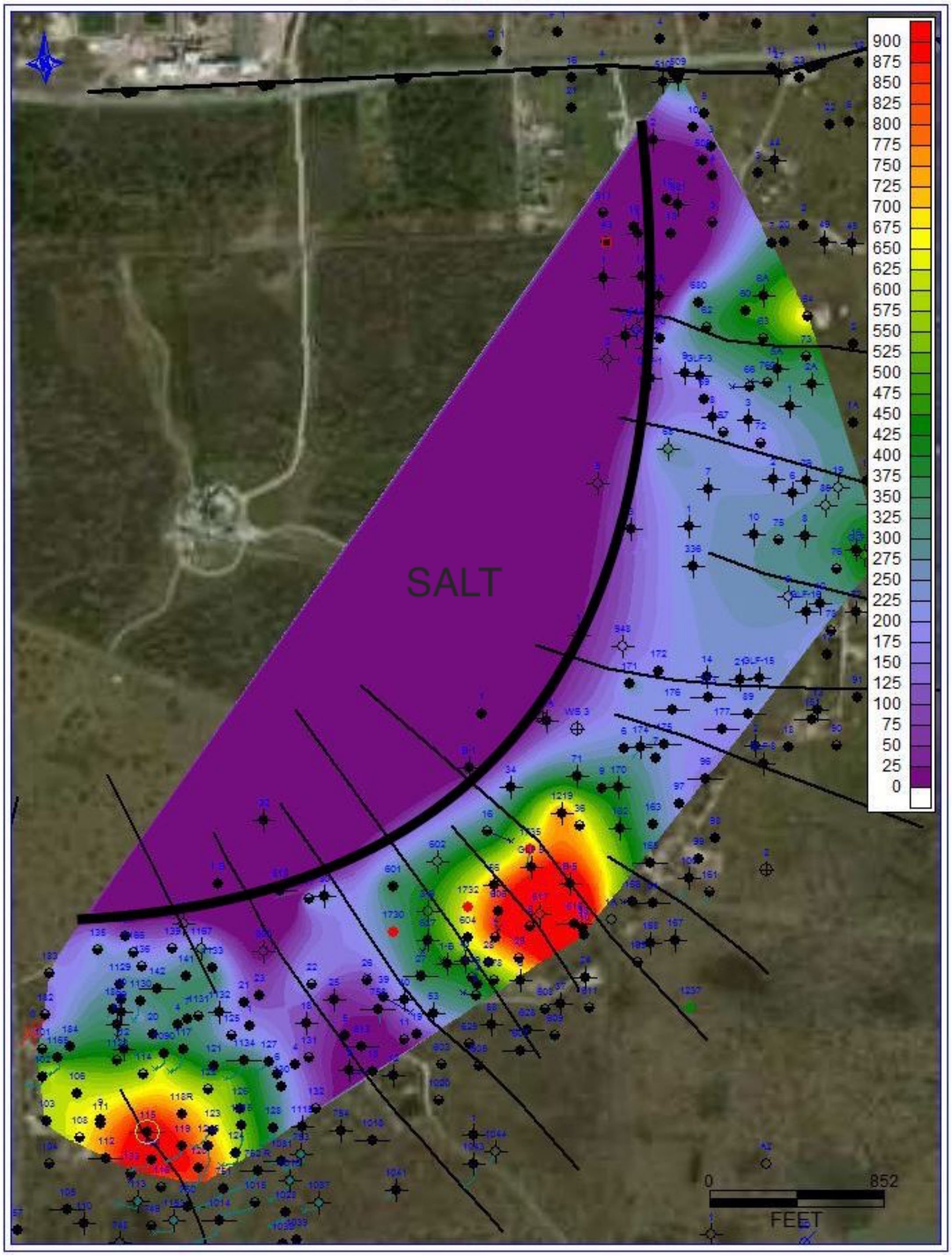

Figure 24 – Isopach illustrating the thickness of the Middle Frio to Salt section. Overlain black lines are interpreted radial faults picked based on well tops information. Larger line near the top of figure indicates large offset fault, downthrown to the south. As with previous figures, the approximate Middle Frio/Salt pinch out line is also indicated.

Alternatively, the smaller scale offsets of the radial strike-slip faults near the top of the Middle Frio and the First Frio sand packages seem to have occurred post-deposition. As the thickness of these units do not vary substantially along strike, the argument can be made that these higher Frio sections were deposited when sedimentation rates were faster than the rate of uplift. At some point after deposition, the sedimentation/uplift relationship inverted with uplift overcoming sedimentation. The increasing degree of uplift after middle to upper Frio deposition could have uplifted some portions of the strata more than others and/or caused the strata to slide down dip- much like a larger extension related growth fault dipping towards its respective basin. This occurrence explains the vertical to near vertical radial fault displacements seen here on the flanks of the Blue Ridge Salt Dome. An idealized radial strike-slip fault similar to what has been interpreted is included (Figure 25).

Another alternative explanation for the small offset radial faults is discontinuities caused by the high sedimentation rates and concurrent uplift which leads to the belief that these are not actually fault planes in the traditional sense. This could easily be the case as the Frio sands are still continuous over these discontinuities and do not show distinct offset. As previously stated, rates of uplift for salt structures is roughly 10% that of orogenic events (Jackson and Talbot, 1986), so it is entirely possible these fault traces are at least influenced by the high sedimentation rates seen in the Cenozoic history of the Gulf Coast.

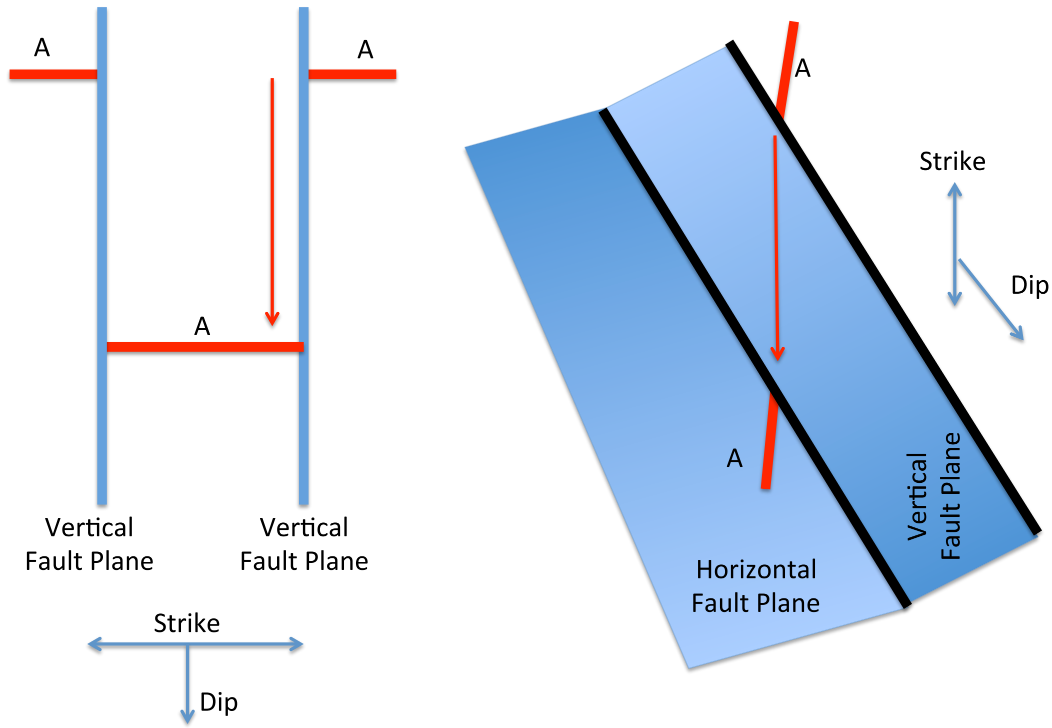

Figure 25 – Illustration of idealized radial strike slip fault offsets.

When comparing the top of salt grid along the flank of the dome (Figure 15) to the findings of Howard (1971), the sporadic movement of the salt and sediment interface is well illustrated. While sedimentation would account for increased accommodation space in downthrown fault blocks, upthrown portions of the salt are still readily apparent. The correlation between the top of salt and the thickness or thinning of the Frio section is a fairly easy connection. Guglielmo et al. (1997) on the subject of salt walls concludes that salt can significantly change along regional strike, varying from passive stocks to reactive walls to immature salt rollers to mature active diapirs. All these variations are possible due to the relationship between differential loading and salt flow along strike, even though initial rates of regional extension, aggradation, and salt supply all remained constant. As this work is examining salt flow, even on a more localized level, the salt behavior along strike is still worth discussing. The depth of salt can be interpreted as sporadic or random with respect to the general domed shape, but when moving along strike comparing the thickness of the Frio section on the dome flanks to the top of salt, the connection between the two is readily apparent (Figure 22). The uplifted portions of the dome face match closely to thinner Frio sections (Figure 20). This correlation leads to the possibility of salt initiating displacement along fault planes and the infilling the upward displacement of such fault blocks. A 3D view of the Frio isopach with a marked pinchout line and fault blocks inferred from this thickness data is displayed (Figure 26). Outlying data points from well bore markers are noticeable but the general trend of the data remains the same. Accompanying this 3D view is an idealized cross section of these fault blocks (Figure 27).

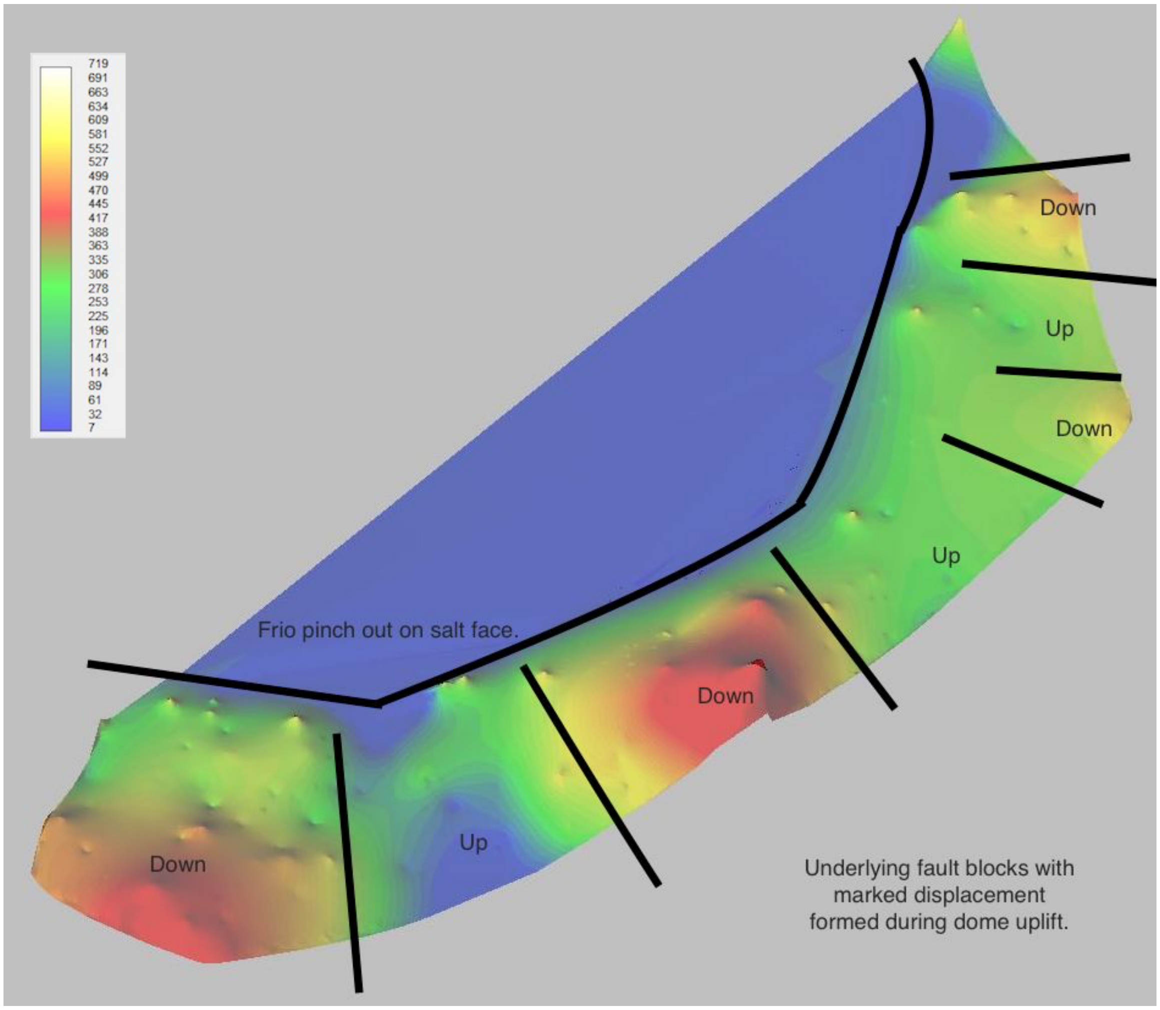

Figure 26 – 3D rendering of Frio thickness from top of Frio to top of Salt. Overlain is the concentric pinch out line of the Frio section at the salt/sediment interface and interpreted radial Frio fault blocks with marked throw of the faulted blocks. Outliers within the data are easily spotted, but the general trend remains the same. Downthrown fault blocks correspond to more accommodation space and a thicker Frio section. Because this is an isopach map viewed in three dimensions, the thickness values were positive rather than negative, creating an inverted apparent depth profile.

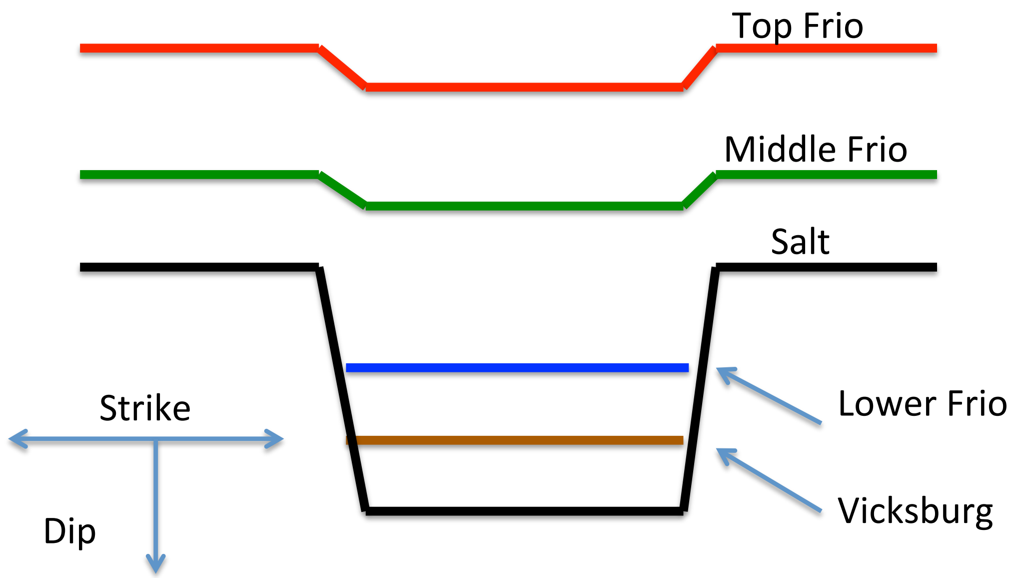

Figure 27 – Idealized cross section relating salt depth to stratum and demonstrating a major fault block seen in section here.

Ingram (1991) indicated that large growth faults associated with domes often determine the productive or nonproductive flanks of the dome and briefly comments on the presence of "trap door" structures. Trap-door style structures were called such due to the uplifting of strata on the upthrown side of a fault, much as one would raise a trap door. While this is applicable to the entirely of the dome the portion studied here is on the downthrown side of the regional growth fault. The area south of the growth fault can still be considered productive, but without extending the bounds of the study, this work cannot determine whether the upthrown or downthrown parts of the dome flanks divided by this fault are more or less productive than the other. But based upon the images from the Texas Railroad Commission (Figure 2, Figure 4) it seems safe to say that there is productivity around the entirety of the Blue Ridge Salt Dome.

CHAPTER 7

CONCLUSIONS

With the presence of a regionally oriented, large displacement growth fault intersecting the Blue Ridge Salt Dome, the influence of regional extension on the dome's formation appears apparent. From this data alone, it is tough to determine if the dome formed in conjunction with extension or if this growth fault merely provided a pathway for salt migration. While unclear whether this was the sole mechanism for initiating tabular salt stock movement into diapir form for the Blue Ridge Salt Dome, the primary or secondary effects of regional strain during dome formation cannot be discounted.

Small displacements seen in radial faults seem to have some strike-slip offset with vertical to nearly vertical fault planes. It is believed these types of displacements are related to discrepancies in sediment depositional systems or formed when the migrating salt plug increases dip angles in the surrounding strata until shear stresses are overcome and gravity initiated sliding occurs down dip. When compared to prior works, it is unclear whether these small-scale displacements have been previously reproduced.

This study illuminates the effects of congruent sediment accumulation and the upward migration of the salt mass. While generalizations of the structural deformation associated with salt domes still align with the findings here, previous local scale model approaches do not account for sedimentation occurring during salt uplift and dome formation. As sedimentation is a major factor of the Cenozoic history of the Gulf Coast and transpires in concurrence with salt migration, future models should attempt to incorporate sedimentation to produce more accurate representations of the deformation associated with salt dome growth. The effects of regional extension and compression have been studied in previous regional and local scale models and the corresponding structural features are documented with good correlation to seismic dome profiles.

Episodic salt dome growth is another factor that complicates salt dome modeling that is usually not integrated into simulating salt migration and the associated deformation. As this intermittent salt migration is related to the salt's buoyancy and sedimentary overburden, integrating sedimentation with varying rates of artificial uplift into future model approaches should produce results indicative to local scale salt structures along the Gulf Coast.

After an improved modeling process has been tested, the approach should be able to reproduce more accurate results of Gulf Coast salt domes than earlier simulations. The work completed here specific to the Blue Ridge Salt Dome will be a useful tool for future exploration and production endeavors. The process used to uncover the results reached in this study will be repeated on other portions of the dome in an attempt to unveil similar structural features. While seismic data for other parts of the dome is unavailable or compromised by the design of the survey, comparable structural features should be identifiable in areas with sufficient well control.

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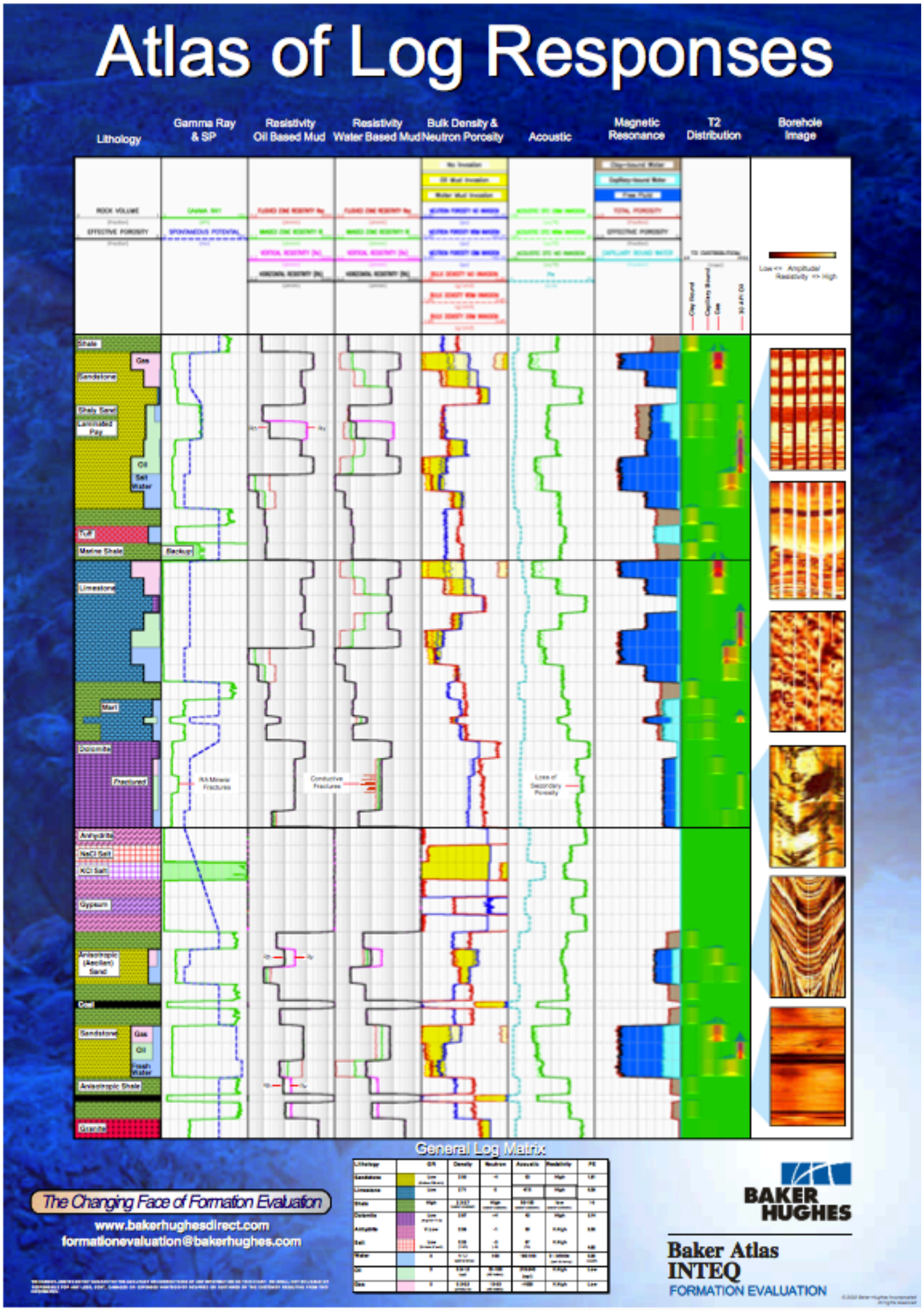
APPENDIX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