SEISMIC INTERPRETATION AND ANALYSIS OF THE ETOUFFEE RESERVOIR SANDS AND THE SURROUNDING AREA IN TERREBONNE PARISH, SOUTHEAST LOUISIANA

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SEISMIC INTERPRETATION AND ANALYSIS OF THE ETOUFFEE RESERVOIR SANDS AND THE SURROUNDING AREA IN TERREBONNE PARISH, SOUTHEAST LOUISIANA

By

KENNETH LEE STOVER, Bachelor of Science

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ABSTRACT

The western Terrebonne Parish area in South Louisiana contains various amounts of geologic features and processes. Slumping, growth faulting, anticlines, and salt tectonics are only a few that are present here. One of the largest oil and gas discoveries during the 1990’s in South Louisiana was the Etouffee Prospect. Located south of Kent Bayou Field in Terrebonne Parish, the Etouffee Prospect developed estimated reserves of about 250 BCFE. Newly acquired 3D seismic data of the area developed in the 1990’s helped identify this prospect. The survey was one of the first to fully explore and provide deeper imagery of the onshore of South Louisiana.

This thesis provides an explanation and interpretation on how the Etouffee and other sand horizons formed. Along with this, various maps were produced to illustrate thicknesses of multiple sand horizons and the overall structure of the area. Both isopach and structure maps, were developed in Petra software. When comparing the Etouffee Sands to the other sands in the area, the final results of these maps showed a significant change in thickness and depth. Correlating well logs throughout the area further helped the interpretation and understanding of the depositional environments in which these sands were deposited in. These correlations were done in Petra software and showed the locations of several faults that were present. The well logs around the Etouffee Sands produced higher gamma ray, resistivity, and neutron density measurements than the other logs in the data set. Using 3D Kingdom software, horizons and faults were picked and interpreted. Some of these horizons include the Textularia L (Tex L) and Robulus L (Rob
L) sands. Interpreting these horizons helped understand not only the structure of the area, but to see how the horizons develop and change across the region. The biggest faults and most developed horizons were identified around the Etouffee Sands area, including the Etouffee Fault. Multiple paleontological reports were retrieved displaying the paleobathymetry of the different foraminferal biostratigraphic units in the area. These reports helped in determining the paleoenvironment of the foraminfera associated with the Rob L unit. The WesternGeco division of Schlumberger licensed the 3D seismic data of the area for this study, which allowed for mapping and analysis of the sand horizons.
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DEDICATION

The completion of this research is dedicated to my entire family, especially my parents. The love and emotional support from my mother was always felt from home. The constant reminders to never give up and keep pushing forward from my father was the primary driving force for the completion of this project. Thank you so much for everything you do.
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INTRODUCTION

Terrebonne Parish is located along the coast of Louisiana (Figure 1). The coast was deposited in the Holocene epoch (Figure 2). North of the coast lies Holocene Alluvium and Pleistocene terraces, which cover the majority of the southern part of the state (Louisiana Bureau of Land Management, 2008). In terms of surficial sediments, Louisiana is primarily comprised of Tertiary and Quaternary units (Figure 3).

Since the Gulf of Mexico began to form, deposits located in Louisiana have indicated a major river system flowing through the state. These deposits are young sedimentary sequences that lie in the subsurface of Louisiana and were deposited adjacent to or in deltas and rivers (Louisiana Geological Survey Staff, 2010). The processes that formed the sedimentary sequences are still occurring today.

Surface rocks of Louisiana date back to about 50 million years ago (Louisiana Bureau of Land Management, 2008). Massive amounts of sediment were carried by the Mississippi River and deposited on the rim of the Gulf of Mexico. This process took place during sea level fluctuations over the low-lying region (Louisiana Bureau of Land Management, 2008).

Hydrocarbons were first generated in the area from organic clay sequences (Louisiana Geological Survey Staff, 2010). Onshore and deltaic sedimentation from the Gulf of Mexico formed the aforementioned sequences. Various folds, faults, and interfingered strata trapped the hydrocarbons. The developments of these geological features were caused by sedimentation, salt migration, and high rates of subsidence.
Figure 1. Index Map showing Terrebonne Parish and the study area near the Kent Bayou and Turtle Bayou fields in southeastern Louisiana (modified from World Atlas, 2015).
Figure 2. Geologic map displaying the vast range of lithostratigraphic units in Louisiana. The black outlined box shows the approximate location of the study area (modified from Louisiana Geological Survey Staff, 2010).
Figure 3. Stratigraphic column of south Louisiana representing Cenozoic aged formations. The red outlined box represents the age of the units for this study (modified from Louisiana Bureau of Land Management, 2008).
result, oil and gas operations became the largest industrial enterprise in Louisiana (Louisiana Geological Survey Staff, 2010). However, a decline in production in the early 1970s forced that to change.

The age of the Etouffee Sands can be defined as the Middle Miocene Rob L (Figure 4). Robulus L, or commonly named Robulus “43” by economic paleontologists, has been used to mark a biostratigraphic zone in the Miocene post-Anahuac sedimentary sequence of South Louisiana (Butler, 1962). The closest production from the Middle Miocene age trend for the Rob L fauna was located roughly 5 miles to the northeast. Large growth faulting was the primary reason why the Rob L trend was discovered significantly higher in this particular area (Fletcher, 2003).

Regionally, the Rob L zone lies stratigraphically below the Cibicides opima (Cib op) and Amphistegina “B” zones. The Cib op zone is located below the Cristellaria I (Cris I) zone and has been associated with the *Globopecten fohsi barisanensis* fossil (Hamilton, 1983). In some Louisiana fields, the Cib op fauna is considered to be the oldest sediment to penetrate such areas. The Amphistegina “B” fauna generally occurs 100 to 200 feet above the Rob L zone, but was not able to be identified within the study area (Butler, 1962).

Early hydrocarbon migration more than likely took place as the Etouffee Sands began to form. This was mainly due to the development of a rollover anticline and growth faulting associated with it. Subsidence of Cib op sediments and Cris I aged deposition completed the formation of the Etouffee structure as it appears today (Fletcher, 2003). The Cris I zone consists of sands that are Middle Miocene in age and tend to be slightly
Figure 4. North-South structural cross-section in North Turtle Bayou Field, Terrebonne Parish, Louisiana. The *Spiroplectammina Barrowi* or Tex L sand is located around the 8,000 foot marker, while the Rob L sand can be found around 15,000 feet (modified from Sellars Jr., 1965).
calcareous to calcareous. These sands are composed of several discontinuous lenses and contain a variation of gas-water levels, which are caused from a lack of pressure connection between some sand members (Seglund, 1965).
OBJECTIVES/PURPOSE

The purpose of this study is to analyze the Etouffee Sands and how they became such a significant reservoir within the western Terrebonne Parish area of south Louisiana. Secondary objectives for this project include: creating structure and various isopach maps for a better interpretation of the different sands in the area, a seismic stratigraphic interpretation of the strata present, the correlation and interpretation of the available well logs in the area, and the identification and analysis of the paleoenvironment and modern physical environment of the Rob L horizon.
SIGNIFICANCE

This thesis provides an explanation and interpretation on how the Etouffee Sands were deposited and formed. Horizon and fault interpretation can assist with comprehending the geologic trends and the structure of the study area. Acquiring knowledge on the geological history of the area and analysis of the Miocene sands can help better understand the geology of the area. A better and more complete understanding of the area can provide traces to potential prospects and leads. Finally, well information and production history can help assist any similar study in the future.
DEPOSITIONAL HISTORY OF SOUTH LOUISIANA

The state of Louisiana is located in a low-lying region and its surface rocks date back some 50 million years ago (Louisiana Bureau of Land Management, 2008). As fluctuations in sea level were occurring, a large amount of sediment was gathered up on the rim of the Gulf of Mexico. The sediment was carried by the Mississippi River from the core of the North America continent (Louisiana Bureau of Land Management, 2008). Throughout time, the entire groups of fluvial, deltaic, and coastal deposits have progressed farther into the Gulf and are currently filling it with sediment (Louisiana Geological Survey Staff, 2010). Beneath the entire state of Louisiana, deeply buried organic matter from prolific marine waters created vast amounts of petroleum. The more significant oil-producing trends of the Cenozoic occur at the subsurface of Texas and South Louisiana (Williamson, 1959). Large amounts of salt were also deposited through evaporation during other dry periods. However, the Early Miocene is likely where the movement of salt mass began (Sellars Jr., 1965).

The Paleozoic era in south Louisiana is minor when compared to that of the Mesozoic. Devonian and Carboniferous rocks are present well beneath the subsurface, but are primarily igneous and metamorphic. Rocks older than Devonian in age seem to be absent in Louisiana. South Louisiana is believed to be positive through all of the Paleozoic and not submerged by marine waters until the Jurassic (Ocamb, 1961). All of the sedimentation from the Paleozoic was likely of a terrestrial origin as a result of the degradation of the uplifted landmasses of that era (Ocamb, 1961).
The Cretaceous was an important period of the Mesozoic era in the southern Louisiana region. During the Late Cretaceous, rates of subsidence and deposition were variable. This resulted in repeating regressive-transgressive phases of sedimentation (McDowell et al., 1981). These phases produced a series of offlapping and onlapping depositional sequences, which formed a distinctive stratigraphic column (McDowell et al., 1981). The rocks within this stratigraphic column consist of organic-rich, marine shales alternating with porous and permeable terrigenous sands (McDowell et al., 1981).
MIocene DEPOSITIONAL HISTORY

The Cenozoic history of southern Louisiana, specifically the Miocene age, is important for this study (Figure 5). Miocene geology is essential because the Etouffee Sands were deposited during this time (Figure 6). The beginning of the Cenozoic saw a major transgression of the sea override the older Mesozoic surface (Williamson, 1959). Advancing far inland was the Midway Sea, which deposited sediments that make up the majority of the Midway Group (Williamson, 1959). Most of the sediment in Louisiana is comprised of Cenozoic deposits. These deposits were formed as the sea advanced and retreated several times, producing interfingering of marine and non-marine beds (Figure 7) (Williamson, 1959).

Early Miocene

The main characterization of the Miocene age was the constant retreat of the sea, which was interrupted numerous times as transgressions (Williamson, 1959). Strata in the up-dip areas consist primarily of non-marine sands and clays, while marine shale dominates the down-dip portion (Williamson, 1959). Early on in the Miocene, the Gulf basin was relatively stable in terms of geologic activity. Sediment influx during the Early Miocene showed the first change to the central Gulf fluvial axes that dominate the later Neogene (Buffler et al., 2000). Geographic dispersion of depocenters around the northwest and central Gulf margins reached its greatest extent during this time (Figure 8-11). Succeeding the Anahuac transgression, the Norma axis shortened quickly from its prominence in the Frio episode (Buffler et al., 2000). Widespread wave-built shore-zone
Figure 5. Miocene subsurface nomenclature of coastal Texas and south Louisiana, including generalized marine cycles. The red outlined box represents the age of the units for this study (modified from Williamson, 1959).
Figure 6. Correlation chart of Louisiana representing the Miocene. Divisions C, D, E, and F of the Fleming Formation consist of the stratigraphic units associated with the thesis area. The red outlined box highlights the aforementioned divisions (modified from Rainwater, 1964).
Figure 7. Marine shale units, paleontologic markers and depositional sequences associated with the Gulf of Mexico during the Cenozoic. The units in the study area correspond to the Middle and Upper Miocene depositional sequences. The red outlined box represents the age of the units for this study (modified from Buffler et al., 2000).
Figure 8. Symbols explaining Paleogeographic maps (Figures 9 - 11) (from Buffler et al., 2000).
Figure 9. Paleogeography of the first early Miocene depisode occurring 25-18 million years ago. Abbreviations of basin-margin structural features and principal and secondary Cenozoic sediment dispersal axes of the Gulf of Mexico include: no = Norias; RG = Rio Grande; RD = Red River; CM = Central (from Buffler et al., 2000).
Figure 10. Paleogeography of the middle Miocene depisode occurring 15.6-12 million years ago. Abbreviations of basin-margin structural features and principal and secondary Cenozoic sediment dispersal axes of the Gulf of Mexico include: no = Norias; cr = Corsair; CM = Central Mississippi; EM = East Mississippi (from Buffler et al., 2000).
Figure 11. Paleogeography of the late Miocene depisode occurring 12-6.4 million years ago. Abbreviations of basin-margin structural features and principal and secondary Cenozoic sediment dispersal axes of the Gulf of Mexico include: cr = Corsair; CM = Central Mississippi; EM = East Mississippi (from Buffler et al., 2000).
systems and narrow shelves captured and deposited sediment volumes equivalent to those stored in the delta systems. This process took place mainly in the areas bordering the deltas and between them (Buffler et al., 2000). Subregional, geologically brief episodes of hypersubsidence and downfall affected both Miocene delta and shore-zone systems of the Gulf of Mexico (Buffler et al., 2000). This formed temporary continental-margin embayments that accumulated anomalously dense sequences of slope deposits. Although being in close proximity to the Mississippi system, slow shelf and ramp sedimentation characterized the northeast Gulf of Mexico margin. The widespread dispersal of sediment input from the west to central Gulf of Mexico margin can be seen reflected across most of the basin floor in a similar distribution of sandy, heterolithic apron deposits (Buffler et al., 2000) (Figure 9).

**Middle Miocene**

The basin-margin sequence of the middle Miocene consists of a 3 million year episode within the 5.5 million year middle Miocene interval. Unique additions were brought in from this episode that exemplified the paleogeography and sediment dispersal systems of the Gulf of Mexico: the Corsair delta and slope apron and the sandy McAVLU submarine fan, which is named for its location beneath the Mississippi Canyon, Atwater Valley, and Lund outer continental shelf areas (Buffler et al., 2000) (Figure 10). A composite delta system was created from Central and East Mississippi dispersal axes that controlled central Gulf margin paleogeography. Two deltaic depocenters were connected by the Texas/Louisiana shore-zone system, which was divided by a narrow shelf from the offlapping, muddy shelf-fed apron (Buffler et al.,
Sediment input was centered in the Burgos Basin along the northwest Gulf of Mexico margin, while the northeast area was surrounded by sand-rich shore-zone and clastic shelf systems. The Corsair apron and McAVLU fan produced the two prominent sandy depositional elements on the mainly muddy Gulf of Mexico floor (Buffler et al., 2000).

**Late Middle to Early Late Miocene**

An extended episode of relatively stable sediment dispersal and paleogeography characterized the Upper Miocene (UM) genetic sequence (Buffler et al., 2000). This depisode records a long-lived family of sediment dispersal systems that continued with little variation for nearly 7 million years. The UM episode demonstrates extensive margin offlap and the final decline of the northwestern and western sediment dispersal axes, as well as late Neogene emergence of the central Gulf of Mexico axes (Buffler et al., 2000). A broad sandy shore-zone and clastic shelf succession extends eastward from the Mississippi delta system (*Figure 11*). Small, wave-dominated, platform systems represented the Corsair, Rio Grande and Norma deltas, while a broad sandy strand plain dominated the northwest Gulf of Mexico margin (Buffler et al., 2000). The Campeche apron was formed by Miocene deltaic progradation and slope offlap in the Veracruz and Campeche areas.

**Latest Miocene to Early Pliocene**

Renewed sediment influx in the late Messinian came shortly after the regional transgression that terminated UM deposition (Buffler et al., 2000). Mississippi axes primarily contained sediment supply and accumulation during this episode. The central
Gulf of Mexico paleogeography was defined by a single, large fluvial-dominated delta system (Buffler et al., 2000). Deltas of the East Mississippi axis and subordinate Central Mississippi axis were both associated with this system. The delta system prograded onto the central Gulf of Mexico delta-fed apron. Despite the relative proximity of the central Gulf depocenters, sediment starvation expanded across the eastern Gulf of Mexico basin floor (Buffler et al., 2000).
CENOZOIC SEDIMENTS

Miocene Sediments

Miocene formations of the northern Gulf of Mexico region vary in thickness and extend from Mexico to central Florida, spanning a total distance of about 1,200 miles (Figure 12) (Rainwater, 1964). Overall, the Miocene lies beneath roughly 200,000 square miles of the northern Gulf of Mexico region (Figure 13) (Rainwater, 1964). According to some, the total thickness of Miocene sediments in southern Louisiana is approximately 48,000 feet (Rainwater, 1964). By adding together the thickest section of each Miocene unit, which would be on the downthrown side of faults, the total thickness of the Miocene is likely closer to 40,000 feet (Rainwater, 1964). The thickest section of Miocene sediments is located offshore of southeastern Louisiana, whereas the thinnest section is found in carbonate facies of peninsular Florida (Rainwater, 1964).

Fluvial and fluviodeltaic sandstones and shales extend from south Texas to Mississippi. As these sediments trend eastward, they grade into marine marls and limestones (Curtis, 1970). Miocene deltaic sediments and Cretaceous-to-Holocene rocks form the present Gulf Coastal Plain and continental shelf (Curtis, 1970). Several Miocene sub-deltas make up the numerous amounts of major delta masses in the Louisiana Gulf Coast. These delta masses formed as a result of drainage from the Mississippi and Atchafalaya rivers (Curtis, 1970). They each consist of a series of cyclic units and a thick regressive sequence of alternating sands and shales, as well as a thin transgressive sequence of marine shale with extremely thin basal transgressive sand (Curtis, 1970).
Figure 12. Map displaying the thickness of the Miocene formations extending from Mexico to central Florida. The thickness varies over the total distance of 1,200 miles in which the formations cover (from Rainwater, 1964).
Figure 13. Miocene trend in southeastern Louisiana and northern Gulf of Mexico. The Miocene lies under about 200,000 square miles of the northern Gulf of Mexico region (from Thorsen, 1964).
The lithology of Miocene sediments along the western and central Gulf Coast consists primarily of sand, silt and shale (Figure 14). The size of the sands is mainly fine-grained, but coarse-grained quartz and chert have been spotted (Rainwater, 1964). Sand and shale occur in alternating layers and vary in thickness from a few feet to several hundred feet (Rainwater, 1964). These alternating layers take place in the “mid-dip” belt of each interval and are characteristic of deposits in the following environments: deltaic, lagoonal, and strandline (Rainwater, 1964). Sand percentages are generally higher in continental deposits, increasing to 65 percent or more in the alluvial belts of the regressive sections (Rainwater, 1964).

**Tertiary Sediments**

The Tertiary consists of a depositional pattern that contains a series of sediments, which are progressively younger seaward (Sellars Jr., 1964). The grade of these sediments range from a continental facies of predominantly sand into increasingly more marine, predominantly shaly facies (Sellars Jr., 1964). Each unit of these sediments tends to thicken as you go down-dip. Greater accumulations of hydrocarbons are generally found in the shallow-water marine intermediate facies (Sellars Jr., 1964). This facies consists of alternating sand and shale, as well as forming a series of concentric bands that run parallel to the coastline (Sellars Jr., 1964).

**Pleistocene Sediments**

Terrace and outwash deposits dominate the Pleistocene sediments. These sediments consist of gravel, mud, and sand. An unconformity between the Pliocene and Pleistocene beds marked a major regression of the sea during the beginning of the
Figure 14. Generalized NW-SE cross-section of Miocene units in southern Louisiana. Various environments and lithology are shown to demonstrate how the strata changes from up-dip to down-dip (modified from Rainwater, 1964).
Pleistocene (Williamson, 1959). The start of the Pleistocene consisted of a transgression, which led to deposition of thick marine shale near the coast and offshore (Williamson, 1959). After this, the sea continued to withdrawal episodically to the present time.

**Holocene Sediments**

Holocene sediments are represented by alluvium deposits from the major river systems (Louisiana Bureau of Land Management, 2008). Also present are coastal marsh and tributary deposits made up of mud and organic material. Holocene deposits, including the coastal marsh deposits, occupy about 55% of the surface (Louisiana Geological Survey Staff, 2010). Since Terrebonne Parish is located next to the Gulf of Mexico, the area is primarily made up of coastal marsh deposits.

**Surface Sediments**

The largest surface area of Louisiana is represented by the Miocene Fleming, Paleocene Wilcox, and Eocene Claiborne Groups (Louisiana Bureau of Land Management, 2008). Secluded in the southeastern part of the Sabine Uplift is the Fleming Group. The strata that are included within this unit are sandstones and mudstones (Louisiana Bureau of Land Management, 2008). The Wilcox Group can also be identified in the Sabine Uplift in the northwestern part of the state. Various exposures ranging from terrestrial to marine can be found here (Louisiana Bureau of Land Management, 2008). Near the north Louisiana salt-dome basin lays the Claiborne Group. The units exposed at the surface from the Claiborne and Wilcox Groups are made up of mainly clastics (Louisiana Bureau of Land Management, 2008). These clastics were deposited in both shallow marine and deltaic environments.
REGIONAL TECTONICS OF SOUTH LOUISIANA

The structural features of Louisiana can be separated into two regions: north and south. The north region contains the Monroe Uplift, Sabine Uplift, LaSalle Arch, Mississippi Salt Basin, and the Northern Louisiana Salt Basin (Figure 15).

The Monroe Uplift can be seen in west-central Mississippi, southeastern Arkansas and northeastern Louisiana (Johnson Jr., 1958). The southwest portion of the structure is bounded by the North Louisiana syncline. Structurally, the Monroe Uplift is a complexly truncated dome that blends into regional structure to the north and northwest (Johnson Jr., 1958).

The Sabine Uplift is located in east Texas and northwest Louisiana. This structural feature was formed by foreland folding from a source of external compression (Adams, 2009). Many believe that the source of external compression came from a large left-lateral wrench fault system, which originated near Saltillo, Mexico (Adams, 2009). In this wrench fault system, the Sabine Uplift formed at a restraining stepover/side-step (Adams, 2009).

The LaSalle Arch was created during the opening of the Gulf of Mexico in the Triassic period (Hart et al., 1990). This structure is bounded by the North Louisiana Salt Basin and Mississippi Salt Dome Basin, in the northwest and northeast respectively. The trend of the arch is an anticline supported by a series of continental crust pieces (Hart et al., 1990). The western limb of the arch formed due to stratigraphic expansion, while the eastern limb was created due to regional tilting towards the east (Hart et al., 1990).
Figure 15. Major structural features in the southern and northern parts of Louisiana, including the Gulf Coast Salt Dome Basin that covers the entire south Louisiana region. The red outlined box represents the approximate location of the study area (modified from Louisiana Bureau of Land Management, 2008).
The Mississippi Salt Basin is primarily located in central Mississippi, but resides in northeast Louisiana as well. The basin is the largest of numerous interior salt dome provinces that exist along the northern margin of the Gulf of Mexico (Erickson et al., 1997). The basin covers a total area of about 6,000 square miles and comprises an interior tectonic depression with well-defined structural borders (Erickson et al., 1997). These borders include: major faults zones and basement uplifts like the Late Cretaceous Monroe Uplift (Erickson et al., 1997).

The Northern Louisiana Salt Basin is located in the north-central/northwestern portion of Louisiana. The basin has an area of about 3,000 square miles and includes at least a section of 11 parishes in the state (Ryals, 1983). The basin is bounded in the west by the Sabine Uplift and in the northeast by the Monroe Uplift.

The northern region is defined by a variety of stratigraphic and structural traps, while the southern region is made up of down-to-the-basin fault trends and structures linked with several piercement salt domes. These faults are east-west trending and are mostly growth faults (Louisiana Bureau of Land Management, 2008). Specifically, the Gulf Coast Salt Dome Basin contains low-angle faults and diapiric salt features. The identification of the growth faults comes from the significant amount of oil and gas exploration done in the area. The Middle Miocene saw the growth on the regional fault system reach its maximum (Sellars Jr., 1965). However, the tectonic framework for the growth faults has been constantly in motion for over 100 million years (Gagliano, 2005).

There has been major regional faulting events that have taken place since the modern period of fault activity began in the 1960’s (Gagliano et al., 2003). One of these
events occurred along the Golden Meadow Fault Zone, which spreads across the Deltaic Plain in Southeastern Louisiana for roughly 130 miles (Figure 16). The biggest impact developed in the Empire and Bastian Bay Fault segments of the Golden Meadow Fault Zone. The down-dropped blocks of the fault segments experienced immense submergence and land loss (Gagliano et al., 2003). The primary zone affected by this modern fault movement was the coastal marshes located in the southernmost area of Louisiana (Figure 17). Although not as significant, ridges were also affected by this geologic process.
Figure 16. Map displaying faults and land loss in southeastern Louisiana, which resulted from fault induced subsidence. Faults most active in the modern era include: Lake Hatch and Golden Meadow (from Gagliano, 1999).

Figure 17. Map showing the actual and projected areas of land loss and gain in coastal Louisiana. The most active areas of land buildup are the Atchafalaya Delta, south of Morgan City, and limited areas around Head of Passes, at the present mouth of the Mississippi. The dark blue outlined box represents the approximate location of the study area (from Penland, 2005).
The south region is different in that it is only comprised of the Gulf Coast Salt Basin (Louisiana Bureau of Land Management, 2008). Although the south only contains one structural feature, it covers the majority of the area. Both of the regions not only contain different sediment, but dissimilar structural processes as well.

The Gulf Coast Salt Basin contains an abundant amount of salt domes. These salt domes comprise one of the most intensely explored areas for hydrocarbons in the world. The salt contained within the basin is responsible for numerous salt anticlines that help produce prolific hydrocarbon accumulations (Andrews, 1960). The salt in this area is widely known as the Louann Salt. The lithology of the salt is white to gray, clear, coarsely crystalline with anhydrite streaks (Andrews, 1960).
DEPOSITIONAL ENVIRONMENT OF SOUTH LOUISIANA

Terrebonne Parish is an abandoned delta complex that is categorized by a thick unit of unconsolidated sediments (CWPPRA, 2001). It resides within the Terrebonne Basin, which itself is located within the larger Barataria-Terrebonne Estuarine System (Halcrow, Inc., 2009). These sediments are constantly undergoing two main geologic processes: dewatering and compaction. Besides this, Terrebonne Parish has experienced high rates of subsidence and a series of old distributary ridges that extend southward.

More than half of the surface of Louisiana is made up Holocene sediments, which includes the coastal marsh deposits of the Terrebonne Parish area (Louisiana Geological Survey Staff, 2010). The composition that makes up the coastal marsh deposits is primarily mud and organic matter. These deposits are part of a paludal environment. This environment consists of half land and half water, with most of it being marshes and swamps (Kolb et al., 1966).

Marsh development in southeastern Louisiana is generally created by the formation of lakes and tidal channels (Kolb et al., 1966). Thick deposits, generally made up of organic material, are formed in marshes from subaerial oxidation and decay processes. Constant subsidence in the coastal area thickens the marsh deposits even more, while deposition sustains the surface elevation (Kolb et al., 1966).

Marsh strata are primarily identified as being in the form of peat (Kolb et al., 1966). Decreases in the supply of flood-borne or coastal-drift inorganic sediment are noted by peat horizons in the marsh system (Kolb et al., 1966). Wind and hurricane tides
have the ability to cover the marsh with significant depths of water. Depths around five feet are more common, but depths of up to ten feet have been observed (Kolb et al., 1966).

There are four marsh types that exist in southern Louisiana (Figure 18). These include: fresh-water marsh, floating marsh, brackish-fresh water marsh, and saline-brackish water marsh (Kolb et al., 1966). The study area for this project is located within a fresh-water marsh (Figure 19). Like the name suggests, a constant amount of fresh water floods certain parts of the area. The floor of the marsh consists of vegetation underlain by organic clays and inorganic clays. As depth increases, the organic clays become firmer and less organic. Peat layers are common strata within the marsh, but are frequently sporadic. Organic content ranges from 20 to 50 percent in the marsh (Kolb et al., 1966).
Figure 18. Water bodies and various types of marsh deposits in south Louisiana, ranging from freshwater marsh to saline water marsh. The black outlined box represents the approximate location of the study area (modified from USGS, 2002).

Figure 19. Physical environments of the Barataria-Terrebonne estuaries, including the freshwater marsh found within the study area. The black outlined box represents the approximate location of the study area (modified from Halcrow Inc., 2009).
GEOLOGIC SETTING OF STUDY AREA

The study area for this thesis resides in eight oil and gas fields throughout the 127,000 acres of freshwater marsh (Figure 20). The main focus of this thesis is directed towards the Turtle Bayou-Kent Bayou-North Turtle Bayou Complex. The location of this area is approximately 65 miles southwest of New Orleans and 25 miles west of Houma (Ferguson Jr., 1960). This complex contains the Etouffee Sands and the most significant faults within the study area. The area lies within a significant hydrocarbon-producing trend in southeast Louisiana. This trend consists of the uppermost Lower Miocene and Middle Miocene ages (Moore, 1982). The faunal zones that help characterize this trend include: Bigenerina Humblei (Big Hum), Cibicides Opima, Cristilleria I, Robulus L and Textularia W (Tex W). All of these faunal zones are Middle Miocene in age and experience high sedimentation and subsidence rates that have been known to be present during this time. Strata of this age represent a major regressive sequence and an overall progradation that developed during this time (Figure 21) (Moore, 1982). The rate of deposition must have exceeded the rate of subsidence since the delta advanced seaward and the deposition was accompanied by a marine regression (Curtis, 1970).
Figure 20. Map showing the location and shape of the study area. All eight fields and their locations within the study area are shown. The Etouffee Sands area is marked by the red star. New Orleans is approximately 65 miles away, while Houma is about 25 miles (modified from CL&F, 2009).
Figure 21. Schematic map illustrating the evolution of the Miocene deltaic coastal plain of south Louisiana resulting from prograding deltas. The phase sequences are in order from oldest to youngest starting at the top. The red outlined boxes indicate the study area (modified from Curtis, 1970).
The use of electric logs helped identify certain signatures from faunal zones that are associated with a progradation including: the Tex W and Hollywood A (HW A) sands (Figure 22). Faults were another significant component during the Middle Miocene. Growth on the regional fault system reached its maximum, with faults extending upward to a depth of about 3,000 feet (Sellars Jr., 1965). Across the northern third of Terrebonne Parish is the Houma embayment (Figure 23). The northern limit of this feature contains a rather large down-to-the-basin growth fault system (Moore, 1982). Growth of the embayment probably took place no later than the start of the Middle Miocene. By the time the Big Hum zone was deposited, active subsidence of the embayment was completed (Moore, 1982). This area was believed to be near the edge of the continental shelf during the Lower Middle Miocene, due to character changes of the sediments and thickening in the section below the Big Hum marker across series of faults (Sellars Jr., 1965).

No confirmed salt structures have been identified in the area, but the closest known salt dome structure is located 15 miles north-northeast of Kent Bayou field in Chacahoula Field (Figure 24) (Moore, 1982). Although salt has not entered into this area, a gravity anomaly suggests that the fields are underlain by salt (Sellars Jr., 1965). This gravity anomaly is a good indication that deep-seated salt may be present. The Early Miocene perhaps marks the start of the salt mass movement.
Figure 22. Diagram showing the three stacking patterns associated with a parasequence. The progradational pattern is the most important sequence as it relates to the study area. This diagram helped with the interpretation of progradational signatures in well logs for this study (from Hardenbol et al., 1988).

Figure 23. Geographic location of the Houma embayment and the fault zone associated with it. This feature is located in the northwest portion of Terrebonne Parish near the Kent Bayou and Turtle Bayou fields (modified from Moore, 1982).
Figure 24. Index map showing the location of the Chacahoula Salt Dome in Chacahoula field. The field is located 15 miles north-northeast of Kent Bayou field (modified from Looff et al., 2007).
DEPOSITIONAL FRAMEWORK

With the use of paleo reports from wells in the study area, a depositional framework of the Rob L sands could be determined. The depositional age of the Rob L sands is the Middle Miocene, which is common for this area (Figure 25). The common planktonic foraminifera associated with the Rob L are *Globigerinatella insuetas* (Ventress, 1991). For example, the paleontological report for the sidetrack of the Continental Land and Fur #4 well represents the paleobathymetry of this foraminferal biostratigraphic unit. In this report, *Globigerinatella insuetas* are located at a depth of 18,340 feet (Nault, 2000). This corresponds to the paleoenvironment of the horizon to be outer or deep neritic. The neritic zone can be defined as a shallow marine environment extending down to about 660 feet deep (Figure 26) (Bone et al., 2011). The outer or deep neritic zone begins at a depth of about 330 feet and extends down to approximately 660 feet, which marks the end of the neritic zone and the edge of the continental shelf (Figure 27) (Setzer et al., 1966). This depth is in close proximity to the where the continental shelf resides. Sediments at this depth are usually characteristically muddy (Bone et al., 2011). Large deposits of sand do not usually accumulate in an area so close to the shelf edge. This rare occurrence could be from a decrease in regional dip due to subsidence along the bounding fault zone, or maybe even a dip reversal (Moore, 1982). In the neritic zone, the process of photosynthesis continues uninterrupted due to the availability of sunlight at all times (Choudhury, 2016). Abundant nutrients and biologic activity characterize the neritic zone, because of how close it is to land (Choudhury, 2016).
Figure 25. Biostratigraphic chart of the Gulf of Mexico offshore region showing Middle and Upper Miocene foraminifera. This chart displays the Tex L and Rob L sections, as well as all the sections between them. The majority of them can be seen deposited during the Middle Miocene. The chart represents the youngest to oldest sections that are found in the study area and the different time periods of the Miocene they were deposited in: Miocene Lower Upper (MLU), Miocene Upper Middle (MUM), Miocene Middle (MMM), and Miocene Lower Middle (MLM) (modified from Nixon et al., 2003).

Figure 26. Sketch representing the different morphological and neritic environments on the continental shelf (modified from Bone et al., 2011).
Figure 27. Classification of marine environments with depth in meters. The foraminifera associated with the Rob L were deposited in the outer shelf or outer neritic zone, which is represented by the shaded light blue area (modified from Setzer et al., 1966).
DRILLING ACTIVITY HISTORY WITHIN STUDY AREA

The first discovery of oil in Terrebonne Parish was founded by The Texas Company in 1929 (McGuire et al., 2008). Caillou Island became the first major field in the area and started producing in 1930 (Figure 28). From here, numerous fields started to develop in the 1930s and 1950s. By 1965, roughly three dozen oil and gas fields were mapped in the parish by the New Orleans Geological Society (McGuire et al., 2008). Production of oil in Terrebonne Parish primarily came from inshore marshes, lakes, and coastal areas. Inshore oil and gas development reached its peak in the 1960’s and 1970’s (McGuire et al., 2008). Offshore production began to take off after 1970 with inshore production starting to decline shortly after 1980 (McGuire et al., 2008).

Major Discoveries

The Shell Oil Company #1 Continental Land and Fur was the discovery well for the Turtle Bayou Field. This well was completed in 1949 and flowed at a rate of 2,750 MCF of gas and 65 BCPD (Ferguson Jr., 1960). Kent Bayou Field was discovered soon after by the Union Producing Company #1 Continental Land and Fur. This well flowed at a rate of 3,275 MCF of gas and 97 BCPD (Ferguson Jr., 1960). In 1957, the Shell Oil Company #E-1 Continental Land and Fur was completed as the discovery well for the North Turtle Bayou Field. This well flowed at a rate of 4,500 MCF of gas and 16 BCPD (Ferguson Jr., 1960).
Figure 28. Index map of southeast Louisiana showing Caillou Island and several other fields. The island is located on the border of Terrebonne Parish and Lafourche Parish. The red outlined box represents the location of the study area (modified from Nelson, 2012).
ETOUFFEE PROSPECT

Wells

A total of six wells were drilled, the discovery well and five development wells, to target the Etouffee Sands. With the exception of CL&F #5, all of the wells are currently still producing hydrocarbons from the Etouffee Sands today. The discovery well, Union Pacific Resources Continental Land & Fur #1, reached a total measured depth of 19,271 feet and logged 156 feet of productive sand (Figure 29). The spud date for this well took place in August of 1999. Productive sand counts as high as 306 feet in CL&F #4 marks the largest column of production in all the wells (Figure 30) (Fletcher, 2003). This well spudded in September of 2000 and extends to a total measured depth of 19,600 feet. CL&F #3 is not far behind consisting of about 286 feet of productive sand (Figure 31). The spud date for this well occurred in May of 2000 and reached a total measured depth of 20,500 feet.

The only well without any Etouffee Sand found within it is CL&F #5 (Figure 32). This well spudded in February of 2001 and extends to a total measured depth of 20,317 feet. A total of three separate sections of Etouffee Sand are identified from the well logs. They are named as the following: Etouffee 1, Etouffee 2 and Etouffee 3. Etouffee 1 is located in all the five wells that consist of the Etouffee Sand. Etouffee 2 is found in every well containing the Etouffee Sand, except for CL&F #2 (Figure 33). The spud date for this well took place in November of 1999 and reached a total measured depth of 20,450 feet. This well only accounted for about 25 feet of productive sand. Lastly, the Etouffee 3
Figure 29. Well log for the UPRC CL&F #1 discovery well. Etouffee 1 and Etouffee 2 Sand sections are recognized in this well. The horizontal black line towards the top represents the top of the Rob L horizon and the horizontal black line towards the bottom is the gas/water contact. The Etouffee productive sand count is 156 feet with the total amount of the Etouffee Sands being 277 feet.
Figure 30. Well log for the CL&F #4 well. Etouffee 1 and Etouffee 2 Sand sections are recognized in this well. The horizontal black line towards the top represents the top of the Rob L horizon and the horizontal black line towards the bottom is the gas/water contact. The Etouffee productive sand count is 306 feet with the total amount of the Etouffee Sands being 334 feet.
Figure 31. Well log for the CL&F #3 well. Etouffee 1 and Etouffee 2 Sand sections are recognized in this well. The horizontal black line towards the top represents the top of the Rob L horizon and the horizontal black line towards the bottom is the gas/water contact. The Etouffee productive sand count is 286 feet with the total amount of the Etouffee Sands being 301 feet.
Figure 32. Well log for the CL&F #5 well. Although sand is present, no Etouffee Sand sections are recognized in this well. The sand interval, 19,600-19,650 feet, was the closest to being a section of Etouffee Sand. The conductivity log, shown in the right column, and the neutron/density log from another well log were not displaying good enough signatures for it to be considered Etouffee Sand. The horizontal black line towards the top represents the pick for the Rob L horizon. The gas/water contact is not pictured, but is located at 20,291 feet.
Figure 33. Well log for the CL&F #2 well. Only the Etouffee 1 Sand section is recognized in this well. The horizontal black line towards the top represents the top of the Rob L horizon and the horizontal black line towards the bottom is the gas/water contact. The Etouffee productive sand count is 25 feet with the total amount of the Etouffee Sands being 152 feet.
Sand section is only contained within CL&F #6 (Figure 34). This well spudded in June of 2001 and extends to a total measured depth of 19,550 feet.
Figure 34. Well log for the CL&F #6 well. All three Etouffee Sand sections are identified within this well. The horizontal black line towards the top represents the top of the Rob L horizon and the horizontal black line towards the bottom is the gas/water contact. The Etouffee productive sand count is 194 feet with the total amount of the Etouffee Sands being 348 feet.
**Production Rates**

Maximum production rates for the six wells peaked in April of 2002 at 95,400 MCFD and 18,600 BCPD (Fletcher, 2003). Current production rates, as of December 2015, sit at 29,500 BPD and 135,273 MCFD.

**Reserves**

The original estimated reserves for the Etouffee Prospect were 250 BCFE (Fletcher, 2003). This is a primary indication of why this discovery was a significant success and one of the largest discoveries in southern Louisiana during the 1990’s. After being converted to gas, the field has produced 153 BCFE as of 2003 (Fletcher, 2003).

**Post Etouffee Attempts at Finding Rob L Production**

One of the main attempts to find more Rob L production resulted from the Beignet prospect (Figure 35). The Beignet prospect, owned by Anadarko Petroleum Company, is located about six miles southwest of Kent Bayou field (Larson et al., 2001). The prospect spudded in October 2001 with a proposed depth of 20,500 feet (Larson et al., 2001). The Rob L sands were being targeted in an upthrown fault closure syncline, which is separated from the Kent Bayou field (Larson et al., 2001). Anadarko expected the well to reach TD in early January 2002.
Figure 35. Map showing the location of the Beignet field in relation to the Kent Bayou field. The Beignet field is approximately six miles southwest of the Kent Bayou field. A locator map of south Louisiana showing the Kent Bayou field and map area is provided (modified from Larson et al., 2001).
SALT AND SALT TECTONICS WITHIN STUDY AREA

The study area is located within the Oligocene-Miocene detachment province (Figure 36). This province covers most of the modern slope and parts of coastal onshore Texas and Louisiana (Diegel et al., 1995). Large-displacement, dominantly down-to-the-basin listric growth faults and a great thickness of deltaic sediments characterize this region. According to Diegel et al. (1995), this entire province is interpreted as being a salt-based detachment with salt emplacement at an allochthonous level in the Paleogene and subsequent salt evacuation during progradation of the late Oligocene-late Miocene shelf margin. The salt withdrawal or salt reduction process, which will be discussed later, is also present in this area and plays a significant role in the growth of the Etouffee Fault.

Since no salt structures are present within the study area, the salt that is interpreted beneath the Miocene aged sediments can be referred to as a salt sheet or salt extrusion. Salt sheets located in this region usually form by sediment progradation and migrate along with it (Figure 37). Once these sheets are buried, they deform from basinward gravity and differential loading by new wedges (Ge et al., 1997). Normal faults can be found forming along the trailing edge of the salt sheet. At the leading edge, active piercement allows the salt to climb to a higher stratigraphic section and spread out during each nondepositional or erosional break (Ge et al, 1997). Salt extrusions can flow in any direction depending on the local slope. However, salt sites where salt climbed stratigraphic section generally tends to shift basinward (Ge et al, 1997).
Figure 36. Tectno-stratigraphic provinces of the northern Gulf of Mexico Basin. The black outlined box represents the location of the study area. The red numbers and lines refer to profiles that apply to another study (modified from Diegel et al., 1995).

Figure 37. Tracing showing an example of multiple salt sheets formed by sediment progradation. TFS1-TFS3 represents peripheral faults at trailing edges of salt sheets. LEB1-LEB3 represents leading edge breakouts of salt sheets where these climbed stratigraphic section (modified from Ge et al, 1997).
NATURE OF FAULTING

South Louisiana is underlain by a network of faults, which are known and studied from exploration for oil and gas in the area (Gagliano, 2005). Most of the faults in south Louisiana are normal growth faults (Figure 38) (Gagliano, 1999). The faults are primarily east-west trending structures, which are the predominant trend in the Gulf Coast Salt Dome Basin (Figure 39) (Gagliano, 1999). They are considered to be growth faults because the majority of the sedimentary beds cut by the faults are thicker on the downthrown block (Gagliano, 2005). This is indicative of the faults moving during deposition and throughout time. These growth faults contain a steep dip, 50 to 60 degrees, in the upper surface, but tend to flatten out with depth (Gagliano, 1999).

Zones of weakness are where growth faults are initially established. An example where this takes place in south Louisiana is where growing delta fronts extend beyond the continental shelf edge (Gagliano, 1999). Over time, these zones give way as more sediment is deposited above them. Therefore, displacement on a growth fault increases with depth and time (Gagliano, 1999). When these growth faults die out they usually are interpreted to be within either deep water shales or remobilized salt (Gagliano, 1999). The faults in this area are part of a regional linked tectonic framework, which is still active and has been ongoing for more than 100 million years (Gagliano, 2005). More specifically, major fault systems can be contained within the maze of faults that are scattered throughout coastal Louisiana (Gagliano, 1999).
Figure 38. Schematic diagram of a growth fault demonstrating the movement and features associated with it. The depression and rollover features form as the downdropped block slides along the fault plane and rotates (from Gagliano, 2005).
Figure 39. Map showing the major structural features of Louisiana, including the east-west trending growth fault systems scattered throughout the region. The horizontal to slightly angled black lines represents the faults, while the red outline corresponds to the approximate location of the study area (modified from Gagliano, 1999).
METHODOLOGY

Data Acquisition

The majority of this study was completed from the interpretation of 3D seismic data. The name of the seismic dataset is Atchafalaya Complex Emerge 2 and is licensed from the WesternGeco division of Schlumberger. The area number for the seismic survey is 950 and the gridlines are as follows: 2026-2610 for inlines and 104-1300 for xlines (crosslines). The seismic data was processed by using migration and developed into a SEG-Y format. The record length was 9900 milliseconds and the sample rate was 4 milliseconds. This 3D survey was shot in 1997 by Geco-Prakla and Union Pacific Resources (Fletcher, 2003). The survey was one of the first to be truly exploratory in the onshore of southern Louisiana. Other geologic tools, like well logs, were also incorporated for a better overall interpretation. The different types of well logs that were used for this study include: gamma ray, resistivity and neutron/density. Gamma ray logs represent the amount of radiation within a sediment and helps correlate the lithology. Sands are characterized by having high radiation, whereas shale corresponds to low radiation. Resistivity logs are used to represent how strongly sediment opposes the flow of electrical current. High resistivity values are indicative of a hydrocarbon bearing formation. Neutron/density logs help distinguish lithology from porosity and is one of the better log tools for determining the lithology.


**Interpretation**

Interpretation of the data for this study was handled using two primary computer programs. The 3D seismic data was interpreted using the IHS Kingdom version 15 software. Kingdom software is a fully integrated interpretation platform of superior capabilities that combines the power of geology and geophysics. Well log interpretation took place in Petra, but information on the logs was available in Kingdom as well. Petra software is an integrated solution for data management, manipulation, visualization and integration of geological, geophysical and engineering data. Gamma ray logs, resistivity logs and neutron density logs allowed for accurate picking of the Textularia L (Tex L) and Rob L horizons (Figure 40) (Figure 41) (Figure 42). Well-to-well cross-sections for this study were developed in Petra with arbitrary seismic lines from Kingdom to go along with it. The cross-section lines, although not the same, were similar to the seismic lines for a better interpretation. The seismic lines were a little different from the cross-section lines in order for more detail to be displayed.
Figure 40. Gamma ray log for CL&F well #2 displaying a high signature kick to the left. This signature is highly indicative of sand being present. The Rob L pick for this well can be seen around the 18873 foot mark. The red line represents a depth indicator for an easier interpretation.
Figure 41. Resistivity log for CL&F well #6 showing a high signature kick to the right. This type of signature, along with gamma ray, is a good indicator that sand exists. The Rob L pick for this well is located around the 18277 foot mark.
Figure 42. Neutron/Density log for CL&F well #1. The density curve is represented by the solid black line, whereas the neutron curve corresponds to the dashed black line. Hydrocarbons are usually present if both curves cross each other, as shown in the shaded sections above. The Rob L pick is not seen in this image, but is located around the 18470 foot mark.
Map Development

Two horizons were picked to better understand the geology of the area. These horizons include the Tex L and Rob L from the Miocene age. The horizons were picked on a well-to-well basis. Cross-sections consisting of four or five wells were developed to efficiently pick the horizons. This was primarily done for the Tex L horizon since it appears throughout the entire study area, unlike the Rob L horizon. Since the study area for this thesis was so large, synthetics were not required or used. If horizon picks were slightly off, the objectives of the study would not be affected due to the large-scaled nature of this study. With help from literature, the signatures and depths of the horizons were able to be identified. Various biostratigraphic charts assisted with placement of the horizons. Knowing which horizons deposited before or after one another helps simplify the picking process. Faults made the picking process more difficult by displacing the horizons. The depth maps that were created helped with identifying the changes in depth throughout the study area. These maps also assisted in observing how faulting altered the horizons. Structure maps were created to show depths of the study area, specifically the productive area. These maps also represented the geologic trend of the area. In order for the depth maps to be created, a certain processing flow had to be followed for both horizons:

- Picking the horizon and faults throughout the study area (Figure 43)
- Making a time map from the picks that were made (Figure 44)
- Contouring the time map for a more precise interpretation (Figure 45)
- Converting the time map and computing an average velocity map (Figure 46)
Figure 43. Map view of the study area showing all the lines and faults picked for the Rob L horizon. The faults are represented by a shaded brown region with a colored outline around it. The outline color corresponds to how the fault is shown in seismic sections. The massive fault in the center of the map is the Etouffee Fault. A color bar is displayed to help identify the time at which each line was interpreted at.
Figure 44. Time map for the Rob L horizon showing a dip towards the middle. Time varies from 2.909s-5333s. This map was produced after picking the horizon and faults associated with the Rob L. A time color bar is displayed to assist with interpretation of the map. The deepest depths are represented by shades of blue, whereas the shallowest depths correspond to shades of yellow.
Figure 45. Time structure map of the Rob L horizon with contours dipping towards the center. Time varies from 2.909s-5.333s. The contours allow the interpretation of the map to be easier to follow. Anticline and syncline folding can be seen throughout the study area. Each contour line is separated by 0.04 seconds and every fifth line is 0.2 away from one another. The closely spaced contours on the downthrown side of the Etouffee Fault indicate that more Rob L picks were made here compared to the upthrown side. A time color bar is displayed to help interpret the map.
Figure 46. Average velocity map of the Rob L horizon. This map was produced from the time map. The creation of this map was the final step before making the depth map. Velocity varies from $8018 \text{ft/s}$ to $8480 \text{ft/s}$. An average velocity color bar is displayed to help with interpretation of the map. The highest velocity is located to the north and the lowest to the south and east.
• Producing a structural depth map from the average velocity map (Figure 47)

• Contouring the depth map to illustrate the overall depth trend of the area (shown in results section by Figure 57).

Further information, like the depth of the bottom of the well and when drilling was stopped, was provided from the total depth (TD) of the available well logs. Isopach maps were produced to display the stratigraphic thickness of the study area. An Etouffee productive sand and sand isopach maps were both developed. The Etouffee productive sand isopach map illustrated the thickness of the highly productive Rob L sands of the Etouffee reservoir. Multiple sand isopach maps were created to provide comparisons in thickness between the Rob L sands and other sand horizons.
Figure 47. Depth map of the Rob L horizon without contours. This map was produced from the average velocity and time map. Depth varies from 13554 ft to 21685 ft. The deepest depths are near the center and the shallowest to the north. A depth color bar is displayed to assist with interpretation of the map.
DATA

Summary

The 3D seismic data used for this study covers roughly 127,000 contiguous acres in Terrebonne Parish, southeastern Louisiana (Figure 48). The main fields for this study that reside within this data include: Turtle Bayou and Kent Bayou fields. The data is located on the fee land of a private oil and gas company; Continental Land & Fur (CL&F).

Well Logs

The well logs for this study were available in electronic form. These helped with the correlations for the study and a better overall geologic understanding of the area. The electronic logs were retrieved from the IHS website and interpreted in Petra Software. The maximum depth of these well logs extends down to approximately 20,500 feet. The deeper wells are located on the downthrown side of the Etouffee Fault, which covers the southern half of the study area.
Figure 48. The study area shown within the red boundary line. All the wells available for this study are shown on the map. The area covers roughly 127,000 acres of freshwater marsh.
CAUSE AND AGE OF FAULTING

The most common age of faulting in the study area is Middle Miocene (Moore, 1982). This age represents an overall regressive pattern in southeastern Louisiana. Several other tops of sand horizons were picked in Petra and Kingdom to help identify the age of the faults: Robulus 5, Textularia W, Bigeneria Humblei, Cristellaria I, and Hollywood A (Figure 49). The Cib Op sand may be an equivalent facies to the Hollywood sand due to its stratigraphic position (Moore, 1982). This sand can be defined as a shale/sand sequence, which usually contains no more than 25 percent shale (Moore, 1982). These additional horizons were only picked in the primary six wells used in the study. These horizons were deposited during the Middle Miocene (Figure 50). The six primary wells are considered to be gas wells and are located near the center of the study area, where the Etouffee Sands were produced from.

One of the main types of faulting in the area is regional down-to-the-coast faults. These faults are highly thought to be formed by a series of hinge lines (McLean, 1957). The hinge lines were generated from a great down-dip thickening, which is present throughout southeastern Louisiana (McLean, 1957). As a whole, the fault structures in the area are created from the direct or indirect result of movements. These movements are due to isostatic adjustment, which are generated by geological processes that include: compaction and slumping (McLean, 1957).
Figure 49. South-North seismic line showing where and in which horizons the faults terminate. A total of seven horizons are shown in the CL&F #3 well: Textularia L (TEX L), Robulus 5 (ROB 5), Textularia W (TEX W1 UT), Bigenerina humblei (BIG HUM3), Cristellaria I (CRIS I), and Hollywood A (HW A). Each of the horizons were deposited during the Middle Miocene, except the Textularia L. The pink and magenta fault lines represent the Etouffee Fault and the light blue and dark green lines correspond to the top of the Textularia L and Robulus L horizons respectively.
Figure 50. Interpretation of south-north cross-section (Figure 49). Normal growth faults are displayed in black to identify them easily. The Etouffee Fault is labeled to help with the interpretation. Black arrows are shown to help identify the downthrown and upthrown sides of the faults. The horizons picked in the CL&F #3 well are shown to help with the age of the faults. They correspond to the horizontal black lines in the middle of the figure. The Tex L and Rob L horizons are the horizontal black lines that span the entirety of the figure. The middle five horizons are not interpreted in the entire figure because they were not needed to be picked throughout the study area.
ETOUFFEE FAULT

A significant type of fault in the study area is the up-to-the-coast fault. This specific type of fault represents the primary trapping mechanism for the Etouffee Sands. This fault, described here as the Etouffee Fault, can be found running through the center of the Kent Bayou anticline, which makes up the structure of the field (Figure 51) (Sellars Jr., 1964). This fault separates Kent Bayou from Turtle Bayou and contains a large amount of throw. The up-dip limit of hydrocarbon accumulation at Kent Bayou is formed by the Etouffee Fault.

When comparing the size of this fault at both the Tex L and Rob L horizons, differences can be seen. When observing the fault at the Tex L horizon, the upthrown and downthrown thicknesses are relatively the same. This indicates that the fault is not growing at this time and that the rocks are just under stress. Compaction, slumping or salt related processes do not seem evident with the deposition and faulting associated with the Tex L horizon. This horizon was deposited during the Upper Miocene, which shows little sign of any major geologic activity or processes occurring. Several minor faults, with no more than 100 feet of throw, cut the Kent Bayou structure and are mainly Upper Miocene in age (Sellars Jr., 1964). The thickness of the downthrown side of the fault is significantly greater than the upthrown side during Rob L time (Figure 52). This shows that the fault was growing during the Middle Miocene, which is when the Rob L sands were deposited. Complexity of the faulting in this area is known to increase with depth (Sellars Jr., 1964).
Figure 51. South-North seismic line showing an outline of the rollover anticline features and limbs associated with them. The shaded yellow region represents the extent of the rollover anticline features. The dashed black line represents the northwest-southeast trending axis of the anticline. The tilting and rotating features can be seen on the limbs of the anticline features.
Figure 52. South-North seismic line showing the salt withdrawal process associated with the Etouffee Fault. The southernmost yellow section represents the thickness of the downthrown side of the fault, whereas the northernmost yellow section corresponds to the thickness of the upthrown side of the fault. The light blue line represents the top of the Tex L horizon, whereas the dark green line corresponds to the top of the Rob L horizon. The red and red/white vertical lines represent wellbores from different wells.
**Cause of Growth of Etouffee Fault**

The tremendous size of the displacement of the Rob L sediments associated with the Etouffee Fault is the result of overlying prograding sediment loading and a unique geologic process. This process is called salt withdrawal and it occurs not only here, but in places throughout the Gulf of Mexico as well (Figure 53) (Peel, 2014). Salt withdrawal, or salt reduction, is the process by which denser sediments move downwards and push away the less dense salt to deeper depths (Figure 54). This process can also be defined as a mass transfer of salt over time, resulting in a change in area of salt (Cramez, 2014). Salt withdrawal allows the size of the growth fault to increase because the beds on the downthrown side of the fault are now much deeper than before. Gravity plays a major role in the salt withdrawal process. Gravity helps push the slumping downthrown blocks to deeper depths. As the downthrown blocks move further down the fault planes, they begin to rotate and tilt (Gagliano, 1999). These types of faults are known to remain active for long periods of time (Gagliano, 1999). Salt structures are not present within the study area, but a gravity anomaly suggests the presence of deep-seated salt (Sellars Jr., 1965). Since the Rob L sands deposited during the Middle Miocene, the most reasonable interpretation for the age of the salt mass movement is Early Miocene. Deep salt can be seen in the interpreted seismic section shown below the Rob L horizon as seen in Figures 50 and 79.
Figure 53. Regional seismic line of offshore Gulf of Mexico showing the various salt tectonics that occurs. The sections shaded in purple represent the upthrown and downthrown blocks of a normal growth fault. This area is affected by the salt withdrawal or salt reduction process. This process has allowed the accommodation space of the sediments on the downthrown block to increase significantly. The beds have tilted and rolled over from an anticline located at the top of the downthrown purple shaded region. The black arrows help represent the upthrown and downthrown sides of the fault (modified from Cramez et al., 2014).

Figure 54. Geologic illustration of the salt withdrawal or salt reduction process. The evacuation of salt creates a primary salt weld and local depocenters. The accommodation space for the sediments greatly increases from salt reduction. This process takes place on the downthrown side of the Etouffee Fault (modified from Cramez, 2014).
RESULTS

Various maps were created in Petra and Kingdom to represent different aspects of the study. A regional depth map of the producing Rob L sands is shown in Figure 55. This map illustrates the depth trends of the Rob L sands and where the deepest and shallowest parts of the horizon are throughout the study area. The map also clearly represents the downthrown and upthrown sides of the Etouffee Fault, which is just north of the Kent Bayou anticline and producing area for the Rob L sands. Other faults, located primarily to the north and south of the producing area, are also shown. The deepest parts of the Rob L sands are located mainly to the south of the Etouffee Fault, whereas the shallowest sections can be found to the north. The depth map helps confirm if the interpretation of the picked horizons and faults geologically make sense. The Etouffee Prospect should lie in a structural high since the hydrocarbons are structurally trapped and migrate upwards. Anticlinal traps consist of a structural high and, along with the Etouffee Fault, are the main trapping mechanisms for the Etouffee Sands. Other notable structural features present is synclinal folding, which can be seen trending to the south on the map. The contours displayed on the map help present the depths more clearly, as well as represent the top of the zone for the selected horizon. The contour interval for the Rob L depth map is 200 feet.

Figure 56 shows a zoomed in version of the aforementioned regional Rob L depth map. The contour lines are present and maintain the same interval as before. The contour lines in this map clearly show the displacement and upthrown/downthrown sides of the
Figure 55. Regional depth map of the Rob L horizon showing the layer dipping towards the center of the study area. A color depth bar and a scale bar are provided to help with the interpretation. Depth varies from 13554 ft. – 21685 ft. The wells located on the map reached a total depth of at least 18,000 feet. Anticline and syncline folding are observed from the map.
Figure 56. A zoomed-in version of the Rob L depth map, where the Etouffee Sands were highly productive. Subsea tops for the Rob L horizon are present on the map. The well numbers are located on the map to help easily identify the six main wells in the area. The blue diagonal lines represent the picked Tex L horizon, whereas the green lines correspond to the picked Rob L horizon. An index map is shown to help identify where this zone is located in the study area. The blue rectangular outline represents this location.
fauxs. The two faults shown in this map can be seen intersecting the main hydrocarbon producing wells. These faults serve as a trapping mechanism for the Etouffee Sands produced within this area. They are both normal faults that link together before reaching the Etouffee Fault to the north. Although not as large as the Etouffee Fault, these faults still play an important role in trapping hydrocarbons.

After the regional depth map of the Rob L sands was completed, the same type of map was created for the Tex L sand which can be found at relatively shallow depths (Figure 57). The making of this map enabled comparisons of the similarities and differences between the two sands. When examining both of the maps, one can identify that both contain some of the same faults. Although the big Etouffee Fault polygon is not present in the Tex L map, the fault extends through both horizons. The deepest part of the Tex L sand is generally located in the southeastern area of the map, whereas the shallowest section can be seen in the northwestern and northeastern regions. Unlike the Rob L horizon, the Tex L horizon is found throughout the entirety of the study area. This makes the depth map look different because more picks had to be processed for the creation of the map, therefore, adding a higher risk for depth change areas to be shown on the map. Similar depth trends are noticed between both of the sands. This indicates that no major geologic event occurred over this area that may have caused significant differences in depth trends between both sands.

The following map is the Etouffee structure map (Figure 58). This map represents the elevation for the top of the Rob L sands. When examining the structure map, it is noticeable that the displacement of the easternmost fault is significantly greater than the
Figure 57. Regional depth map of the Tex L horizon showing the layer dipping towards the southeast. A color depth bar and a scale bar are provided to help with the interpretation. Depth varies from 7591 ft. – 9062 ft. The wells located on the map consist of all the wells drilled within the study area.
Figure 58. Structure map displaying the top of the Rob L horizon. The solid blue lines extending out from the wells indicate multiple wells being drilled from the same platform. The depths shown in the map are posted below the wells in subsea, whereas the well numbers are represented above the wells. The dashed blue line represents the gas/water contact.
fault to the west. The elevation for the zone is the deepest in the eastern part of the area
and the highest to the north. From this, a reasonable assumption can be made that the
greatest amount of Etouffee productive sand was produced out of well number 4. This is
because well number 4 is placed around the structural high of the area. Since well
numbers 2 and 5 are located near the structural lows of the area, it makes sense that little
to no production was developed from these wells.

The Etouffee productive sand isopach map of the Etouffee Sands was developed
after the structure map (Figure 59). This was constructed so that the fault displacement
and the gas/water contact could be assessed. The greatest thickness for the Etouffee
Sands is found in well number 4, which is located in the northern area of the map. This
was expected from observing that the structural high for the area is located around where
this well sits. The only way of knowing this is by creating the structure map of the
producing zone beforehand. Well number 5 did not see any Etouffee productive sand,
which is due to either a fault cutting it out and/or the hydrocarbons did not migrate to this
location. Well number 6 produced the third highest amount of productive sand out of the
six wells, but it could have been even greater. By examining the map, the westernmost
fault can be identified cutting through the well path. This fault is the reason why some of
the productive sand does not appear in the well log. Well numbers 2 and 5 saw little to no
productive sand, which was expected since they are located near the structural lows of the
area.

The Etouffee Sands isopach is somewhat similar to the Etouffee productive
sand isopach map (Figure 60). This map represents sand thicknesses as well, but in a
Figure 59. Etouffee productive sand isopach map of the Etouffee Sands. The solid blue lines extending out from the wells indicate multiple wells being drilled from the same platform. The well numbers for each well are represented above the well, while the thicknesses for the pay of the sand are posted.
different manner. This isopach map shows the overall thickness of the sands in each well log, whereas the Etouffee productive sand isopach map demonstrated sand intervals where hydrocarbons are present. One of the main things that stood out when looking at this map is the sand thickness of well number 5. Like the previous map, the thickness remained at zero. This indicates that this well did not come in contact with the Etouffee Sands. The well logs did not show any signature related to the Etouffee Sands, like the other wells represented. Well numbers 3 and 4 presented overall sand thicknesses that were near the amount shown in the Etouffee productive sand isopach map. This indicates that almost the entire Etouffee Sand thickness for these wells contained hydrocarbons. Well numbers 1, 2 and 6 all had greater than a 100 foot difference between hydrocarbon thickness and overall sand thickness. Well number 6 posted the highest amount of overall sand thickness, while having the third highest amount of hydrocarbon thickness.

Five cross-sections were produced to show the structural trend and horizon variations in different parts throughout the study area. They also represent the amount of displacement for the faults that are shown. Similar seismic lines were also made for an overall better view and understanding of the geology in the area. Cross-section line A-A’ runs south to north through the center of the study area (Figure 61). This line crosses through the productive sand area associated with the Etouffee Sands. The southernmost fault runs through the Tex L horizon and is represented by the purple fault in seismic section (Figure 62). This fault contains a massive displacement of about 600 feet making it the largest amount of movement associated with the Tex L horizon. The related seismic
Figure 60. Etouffee Sands isopach map representing thicknesses for the entirety of the unit. The solid blue lines extending out from the wells indicate multiple wells being drilled from the same platform. The well numbers for each well are represented above the well, while the thicknesses of the sand for each well are posted below.
Figure 61. South-North cross-section running through the main part of the study area. This line contains the greatest amount of fault activity. The up and down arrows help indicate that these are all normal faults. The Etouffee Fault, as well as the Tex L and Rob L horizons, are labeled for an easier interpretation.
Figure 62. Seismic cross-section line A-A' heading south to north and going through the center of the study area. This line shows the massive displacement of the Etouffee Fault, along with the rollover features and anticlinal features associated with it. The Etouffee Fault is represented by the pink and magenta lines coming together. The top of the Tex L horizon corresponds to the light blue line towards the top of the image, whereas the top of the Rob L horizon relates to the dark green line towards the bottom left and middle right of the image.
line shows a rollover anticline and the Etouffee Fault, which is the primary factor responsible for developing the Etouffee Prospect.

Cross-section line B-B’ runs southeast to north through the eastern part of the study area (Figure 63). This line cuts through the Etouffee Fault, like the previously mentioned cross-section line. The displacement of the Etouffee Fault reaches over 3,000 feet. This can be seen not only in this cross section, but in the center and western lines as well. Besides the Etouffee Fault, the seismic line associated with this line displays rollover features (Figure 64). Cross-section line C-C’ heads southwest to northeast through the western part of the study area (Figure 65). This line can be seen going through the Etouffee Fault and ending up in the southwest portion of the study area. The seismic line associated with this cross-section line shows a small amount of rollover structures and anticlinal features compared to the previous lines (Figure 66).

Cross-section line D-D’ moves west to east in the northern section of the study area (Figure 67). This line is placed above the Etouffee Fault to represent the upthrown side of the fault. Rollover and synclinal features are present in the eastern part of the interconnected seismic line (Figure 68). Cross-section line E-E’ travels southwest to east and is the last line used for this study (Figure 69) This line is located on the downthrown side of the Etouffee Fault, allowing for a comparison with cross-section line D-D’. Like cross-section line A-A’, this line passes through the productive sand area associated with the Etouffee Sands. The seismic line that correlates with this cross-section line shows a great amount of rollover and anticlinal features (Figure 70). This is expected due to where the line passes and is located.
Figure 63. Southeast-North cross-section line covering the eastern portion of the study area. This line runs through the Etouffee Fault like the previous one. The up and down arrows help indicate that these are all normal faults. The Etouffee Fault, as well as the Tex L and Rob L horizons, are labeled for an easier interpretation.
Figure 64. Seismic cross-section line B-B' running southeast to north through the eastern portion of the study area. This line represents more of the rollover features that were seen in the previous line. The Etouffee Fault is represented by the pink line in this image. The top of the Tex L horizon corresponds to the light blue line towards the top of the image, whereas the top of the Rob L horizon relates to the dark green line towards the bottom left and middle right of the image.
Figure 65. Southwest-North cross-section line covering the western portion of the study area. Like the previous two lines, this line runs through the Etouffee Fault as well. The up and down arrows help indicate that these are all normal faults. The Etouffee Fault, as well as the Tex L and Rob L horizons, are labeled for an easier interpretation.
Figure 66. Seismic cross-section line C-C’ heading southwest to north through the western section of the study area. This line shows a small amount of rollover and anticlinal features compared to the previous two lines. The Etouffee Fault is represented by the pink and magenta lines coming together. The top of the Tex L horizon corresponds to the light blue towards the top of the image, whereas the top of the Rob L horizon relates to the dark green line towards the bottom left and middle right of the image.
Figure 67. West-East cross-section line located in the northern portion of the study area. This line is on the upthrown side of the Etouffee Fault. The up and down arrows help indicate that these are all normal faults. The Tex L and Rob L horizons are labeled for an easier interpretation.
Figure 68. Seismic cross-section line D-D’ going west to east on the upthrown side of the Etouffee Fault in the northern part of the study area. Rollover and a few synclinal features are present in the eastern part of the image. The Etouffee Fault is represented by the pink line in this image. The Tex L horizon corresponds to the light blue line towards the top of the image, whereas the Rob L horizon relates to the dark green line towards the middle left and center of the image.
Figure 69. West-East cross-section line traveling through the main section of the study area. This line is located on the downthrown side of the Etouffee Fault for a comparison with the upthrown portion. No major faults are present within this line. The Tex L and Rob L horizons are labeled for an easier interpretation.
Figure 70. Seismic cross-section line E-E’ trending southwest to east on the downthrown side of the Etouffee Fault. This allows for a comparison between the upthrown side of the fault in cross-section line D-D’. Rollover and anticlinal features are present and cover a big portion of the image. The Etouffee Fault is represented by the pink and magenta lines coming together. The top of the Tex L horizon corresponds to the light blue line towards the top of the image, whereas the top of the Rob L horizon relates to the dark green line towards the bottom of the image.
The final set of cross-sections represent the Etouffee productive sand and Etouffee Sands in all the six major wells. The amounts shown in these cross-sections correspond with the Etouffee productive sand and Etouffee Sands isopach maps, but instead are shown in well logs. The main purpose for the development of these cross-sections is to compare the similarities and differences of the amounts for the Etouffee productive sand and Etouffee Sands in the six primary wells.

The first cross-section displays the Etouffee productive sand in all the well logs (Figure 71). All well logs contain Etouffee productive sand, except for CL&F #5. The CL&F #3 and #4 well logs contain the greatest amount of Etouffee productive sand. They both consist of two separate sections, which are the Etouffee 1 and Etouffee 2 Sands respectively. The CL&F #2 well log has the smallest amount of Etouffee productive sand in it and can be difficult to see in the cross-section. The CL&F #6 well log displays three separate sections of Etouffee productive sand: Etouffee 1, Etouffee 2 and the Etouffee 3 Sands. Although there are 3 separate Etouffee Sands, Etouffee 1 contains the highest amount of Etouffee productive sand.

The second cross-section represents the Etouffee Sands in all the well logs (Figure 72). Every well log contains the Etouffee Sands, except for CL&F #5. The amounts for the Etouffee Sands in the wells are all fairly close, with the exception of CL&F #2. CL&F #4 contains the greatest amount of Etouffee Sands with CL&F #6 not far behind.

A major depositional episode during the Middle Miocene was the evolution of the Miocene deltaic coastal plain, which resulted from prograding deltas (Curtis, 1970). Well log signatures associated with a progradational parasequence were able to be identified
Figure 71. Etouffee productive sand cross-section of the main six wells located within the Etouffee Sands producing zone. The red highlighted within the well logs represents the Etouffee productive sand for the Etouffee Sands. The easternmost well log, CL&F #5, is the only well without any Etouffee productive sand found within it. Although hard to identify, CL&F #2 does contain a small amount of Etouffee productive sand. The numbers at the bottom of the figure correspond to the numbers on the locator map, which shows the order of the wells for the cross-section.
Figure 72. Etouffee Sands cross-section of the main six wells located within the Etouffee Sands producing zone. The yellow highlighted within the well logs represents the Etouffee Sands. The easternmost well log, CL&F #5, is the only well without any Etouffee Sand found within it. The numbers at the bottom of the figure correspond to the numbers on the locator map, which shows the order of the wells for the cross-section.
from electric logs. These signatures were located in the Textularia W zone throughout the main six wells (Figure 73) (Figure 74) (Figure 75). The Textularia W unit was deposited during the Upper Middle Miocene about 12 million years ago. Although other major depositional episodes may have occurred, they were not able to be identified.
Figure 73. Progradation signature from the Textularia W sand in the CL&F #1 well log. The shaded green section corresponds to coastal plain sandstones and shales, the shaded yellow section represents shallow marine sandstones, and the shaded brown section correlates to shelf shales. The horizontal red lines represent 50 foot depth intervals for easier interpretation. This sand is located approximately 400 feet below the Robulus 5 sand. Figure 22 was used as a guide for interpreting the well log signatures.
Figure 74. Progradation signature from the Textularia W sand in the CL&F #5 well log. The shaded green section corresponds to coastal plain sandstones and shales, the shaded yellow section represents shallow marine sandstones, and the shaded brown section correlates to shelf shales. The horizontal red lines represent 50 foot depth intervals for easier interpretation. This sand is located approximately 400 feet below the Robulus 5 sand. Figure 22 was used as a guide for interpreting the well log signatures.
Figure 75. Progradation signature from the Textularia W sand in the CL&F #6 well log. The shaded green section corresponds to coastal plain sandstones and shales, the shaded yellow section represents shallow marine sandstones, and the shaded brown section correlates to shelf shales. The horizontal red lines represent 50 foot depth intervals for easier interpretation. This sand is located approximately 400 feet below the Robulus 5 sand. Figure 22 was used as a guide for interpreting the well log signatures.
DISCUSSION

Identifying the differences of faulting between the shallower horizon, Tex L, and the deeper horizon, Rob L, was only possible with the use of 3D seismic data. Without this dataset, one cannot fully classify the faults within the study area. The 3D seismic data allowed for an interpretation and analysis of the faulting for both horizons throughout the study area. The faulting associated with the Tex L sand was generally smaller in size and contained reduced normal growth faulting (Figure 76) although, there are several normal growth faults that extend through both horizons. On the other hand, the faulting related to the Rob L sands is significantly larger and contains increased normal growth faulting. Rollover features and a greater displacement of the beds on the downthrown block of these faults are easily recognizable. This significant displacement of beds is likely due to overlying sediment loading and the process of salt withdrawal (Peel, 2014).

The high quality of the 3D data used for this study allowed for an interpretation of the faults and horizons in the area. The presence of deep salt is a good indication that the salt withdrawal or salt reduction process caused the massive displacement of the Etouffee Fault. Along with deep salt, deep marine shales are also present in the area. The salt withdrawal process is responsible for the deep location of the Rob L horizon on the downthrown side of the Etouffee Fault.

The Etouffee Fault is a combination of two growth faults joining together to form one big fault. This fault cuts through the center portion of the rollover anticline and is one
Figure 76. South-North seismic line showing the Tex L sand and showing faulting associated with it. The light blue line represents the top of the Tex L horizon, whereas the dark green line corresponds to the top of the Rob L horizon. The faults are represented by the same color to identify them easily. The Etouffee Fault corresponds to the pink and magenta lines linking together. The red and red/white vertical lines represent wellbores from different wells.
of the trapping structures for the Etouffee Sands. Careful observation of the fault at the Tex L horizon reveals the thicknesses of the upthrown and downthrown sides are the same. This is highly indicative of stress occurring within the rocks and no growth of the Etouffee Fault during this time. Deposition and faulting related to the Tex L horizon does not consist of certain geologic processes that are associated with the Rob L horizon including: compaction, slumping and salt related processes. The Tex L horizon was deposited during the Upper Miocene, which shows little sign of any major geologic activity or processes occurring.

The thickness of the downthrown side of the Etouffee Fault is significantly greater than the upthrown side during Rob L time. This shows that the fault was growing during the Middle Miocene, which is when the Rob L sands were deposited. The Etouffee Fault dies out in an area primarily consisting of deep salt, but deep marine shales are also present. The anticline is the other structure that helps trap the sands (Figure 77). This structural feature is associated with the Etouffee Fault and hydrocarbon migration (Figure 78). Migration likely took place as the rollover anticline was forming.

The deposition and subsidence of the overlying sediments probably assisted with the rotation of the Etouffee Sands. These sediments also helped with the formation of a wedge of sands and shales that exist in between the horizons. Additional rotation and faulting shaped the structure of the Etouffee area. Interpreting well log signatures helped identify a progradation occurring during the Middle Miocene. The progradation of deltaic sediments proves that a regressive sequence also took place during this time.

The modern depositional environment of the Etouffee Sands is considered to be a
Figure 77. South-North seismic line displaying an outline of the rollover anticline. The Etouffee Fault can be seen running through the center of the anticline. The shaded blue area represents where hydrocarbon accumulation for the Etouffee Sands is located at. The top of the Tex L horizon is represented by the light blue line, whereas the top of the Rob L horizon corresponds to the dark green line.
Figure 78. Interpretation of south-north cross-section (Figure 77). The yellow region represents the extent of the anticlinal features present in the area. The blue region corresponds to the projected location of the Etouffee Reservoir. The Etouffee Fault is labeled and all the faults are displayed in different colors for an easier interpretation. Black arrows are shown to illustrate the downthrown and upthrown sides of each fault. Horst and graben features are displayed and are associated with the Tex L horizon.
paludal environment. Marsh units make up the majority of this environment and are highly contained within southeast Louisiana. Of these marsh units, the Etouffee Sands are believed to be located within a freshwater marsh. Analyzing the paleobathymetry of the sands helped determine the paleoenvironment to reside within the outer neritic or deep neritic zone. This zone is located on the outer shelf and at the beginning of the shelf edge. This helps confirm that the sands were deposited on a shelf-edge delta in a shallow marine environment.
CONCLUSIONS AND FUTURE WORK

The Etouffee Sands were deposited in the Turtle Bayou-Kent Bayou-North Turtle Bayou Complex. This complex lies within a significant hydrocarbon-producing trend of mainly Middle Miocene age. An overall progradation during the Middle Miocene was able to be interpreted from the use of electric logs. This confirms that the rate of deposition was greater than the rate of subsidence and that regressive sediments filled in the basins. This study concludes that the Etouffee Sands were developed from the Etouffee Fault and a rollover anticline associated with it. These structural features acted as the main hydrocarbon traps for the sands. The presence of deep salt indicates that the salt withdrawal process helped create the massive thickness of the downthrown block of the Etouffee Fault. Migration of the hydrocarbons likely occurred as the rollover anticline was forming. Well log analyses and seismic interpretation helped identify the depositional environment for the Etouffee Sands. The sands were deposited in a shallow marine environment with shales along the shelf-edge of a delta. The age of deposition for the sands is no later than the beginning of the Middle Miocene.

Future studies may include targeting the Rob L unit in a nearby area and conducting a structural and/or stratigraphic interpretation based study on it. An important question to ask for the future is if this type of production has the possibility of occurring again? If so, where would be the best place to start looking? The best location for this would be south of the Etouffee Prospect near the edge of the study area boundary line. This location lies on a structural high, which significantly increases the chances in
finding hydrocarbon accumulation. A large down-to-the-coast normal growth fault runs just southeast of this area and is the primary structural feature. Only one well deep enough to reach the Rob L horizon is currently available in this area. Although well data may be limited, a structural and stratigraphic study for this location should be done.
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