An Investigation of Lower Wilcox Group Coals in Portions of Avoyelles, Catahoula, Concordia, Grant, Lasalle, and Rapides Parishes, Louisiana

A Thesis

Presented to the

Graduate Faculty of the

University of Louisiana at Lafayette

In Partial Fulfillment of the

Requirements for the Degree

Master of Science

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Summer 2014

An Investigation of Lower Wilcox Group Coals in Portions of Avoyelles, Catahoula, Concordia, Grant, Lasalle, and Rapides Parishes, Louisiana

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Major: Geology
Title of Thesis: An Investigation of Lower Wilcox Group Coals in Portions of Avoyelles, Catahoula, Concordia, Grant, LaSalle, and Rapides Parishes.
Thesis Director: Dr. Gary L. Kinsland
Pages in Thesis: 156; Words in Abstract: 133

ABSTRACT

Significant accumulations of lower Wilcox Group coals have previously been reported throughout regional reconnaissance studies in north-central Louisiana. The present study is part of a series of contiguous sub-regional studies that incorporate much higher well densities, evaluate each well log individually for coal presence, and map the structures and thicknesses of the Reynolds and the Russell coal. The thickest coal accumulations are found in paralic lagoon deposits in the northern portions of the study area within Lasalle and Rapides Parishes just south of the Angelina-Caldwell Flexure and ontop of the LaSalle Arch. No lower Wilcox Group coals were found south of Township 2N (latitude 31.100° N) in this study. Lower Wilcox Group strata south of Township 2N are interpreted as a shoreline with marine conditions to the south, not suitable for coal accumulation.

ACKNOWLEDGMENTS

I would first like to thank my thesis advisor, Dr. Gary Kinsland, for giving me the opportunity to work on this project and be a part of the coalbed methane research group at the University of Louisiana at Lafayette. Dr. Kinsland's support and leadership throughout this thesis project has been crucial in developing this work. Dr. Kinsland's approach and ability to visualize geology and depositional systems has given me an invaluable way at looking at geological regimes which I have used in this project and will continue to use in the industry. I not only consider him a thesis advisor or professor but also a friend.

I would also like to extend my gratitude to Doug Cristina of Covington Exploration. I have been working for Mr. Cristina for over four years; many of the skills he has taught me have been utilized in this project. Mr. Cristina has been a valuable person to bounce ideas and concepts off of. I truly appreciate his support and dedication throughout this project.

I would like to thank the University of Louisiana at Lafayette Geology Program, which provided an excellent education and a greater understanding of geology as a whole. The professors have a real enthusiasm for teaching and hold students to high expectations.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF ABBREVIATIONS

BCF	Billion cubic feet
BTU	British thermal unit
DOE	Department of Energy
EIA	Energy Information Administration
GR	Gamma Ray
LDWR	Louisiana Desktop Well Reference
LSU	Louisiana State University and Agricultural and Mechanical College in Baton Rouge
MCF	Thousand cubic feet
MCFD	Million cubic feet per day
MMCF	Million cubic feet
SONRIS	Strategic Online Natural Resources Information System
SP	Spontaneous potential
TCF	Trillion cubic feet
TD	Total Depth
U.S.	The United States of America

INTRODUCTION

Background

The U.S. Energy Information Administration (EIA) recently released the International Energy Outlook 2013 (IEO2013) Figure 1 that projects world energy consumption will grow by 56% between 2010 and 2040, from 524 quadrillion British thermal units (Btu) to 820 quadrillion Btu (EIA, 2013). Most of this growth will come from non-Organization for Economic Cooperation and Development (non-OECD) countries, where demand is driven by strong economic growth (EIA, 2013). Renewable energy and nuclear power are the world's fastest-growing energy sources, each increasing 2.5% per year. However, fossil fuels were predicted to continue to supply nearly 80% of world energy use through 2040 (EIA, 2013). Natural gas is the fastest-growing fossil fuel, as global supplies of tight gas, shale gas, and coalbed methane (CBM) increase.

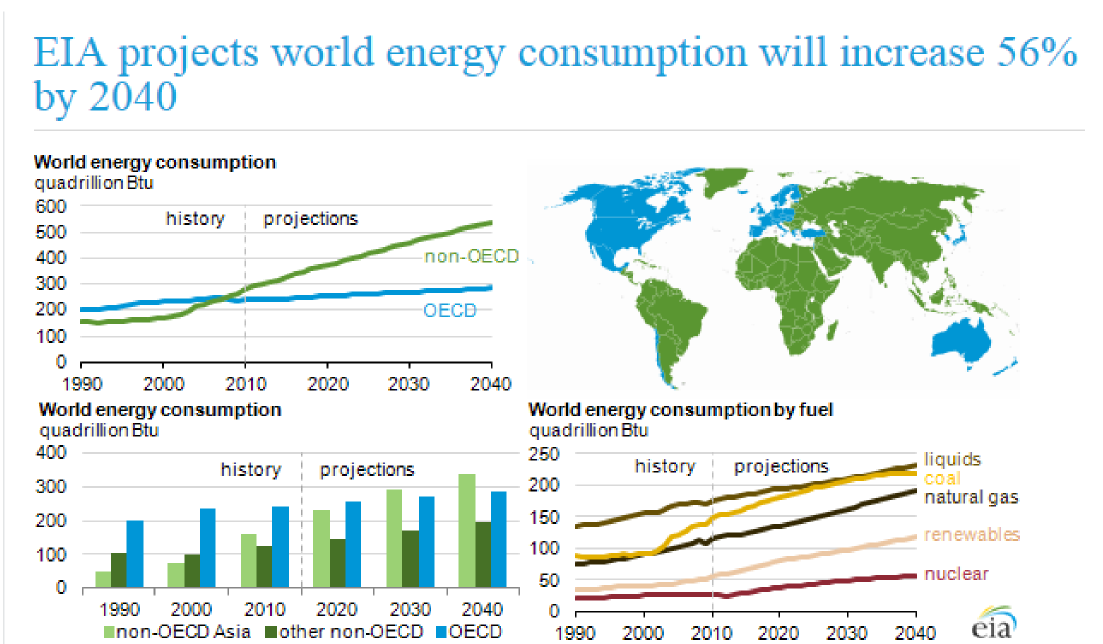

Figure 1: Model of world consumption of energy to 2040 (EIA, 2013).

Production of coalbed methane in Louisiana is minimal compared with that of other comparable basins throughout the U.S. Other basins such as the San Juan basin of New Mexico and Colorado, Black Warrior basin of Alabama, and the Powder River Basin of Wyoming and Montana account for 7.3% of the U.S natural gas production in 2011 (EIA, 2013). Natural gas from coal-rich basins such as those found in the United States, is comprised mainly of methane (CH_4) and is one of the cleanest burning fossil fuels. This readily accessible resource is significant, particularly because the country is persistently searching for alternative energy resources to assist in decreasing dependency on foreign energies.

Coalbed methane production has been established in a number of basins in the U.S. since the late 1980s, the graph in Figure 2 shows the increase in coalbed methane production from 1990-2012.

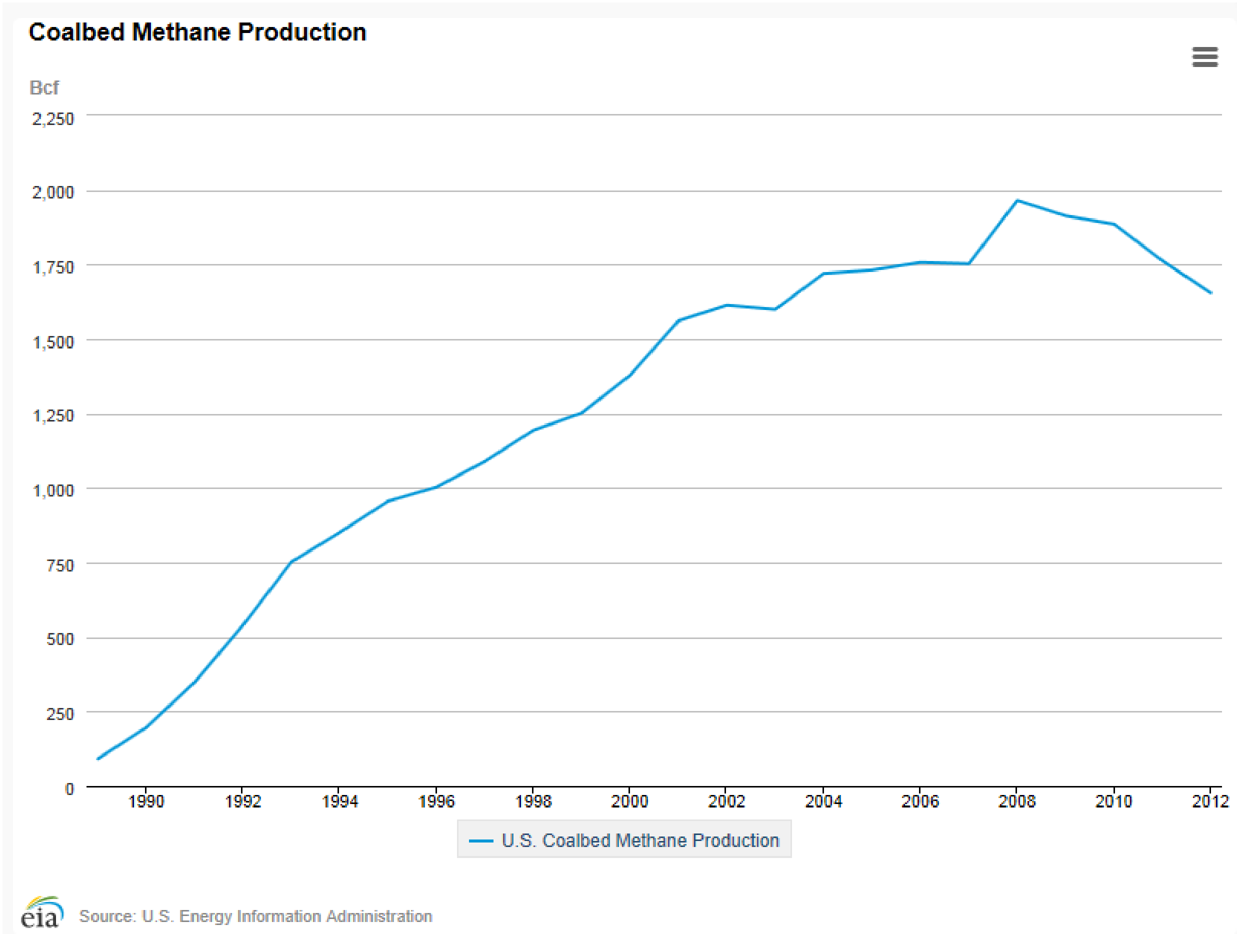

Figure 2: U.S. coalbed methane production from 1990-2012 (U.S. Energy Information Administration, 2013).

The bulk of CBM production has been from Paleozoic coals in the east and from younger, thicker coals in the west; however, very limited drilling activity has been conducted in the Gulf Coast Tertiary basin to define the coalbed methane resource specifically (Breland, 2004). The quality, burial depth, and age of the Gulf Coast coals have generally been considered negative contributing factors in the possible development of this resource. Likely estimates of coalbed methane resources within the U.S. are broken down by basin in Figure 3 by basin.

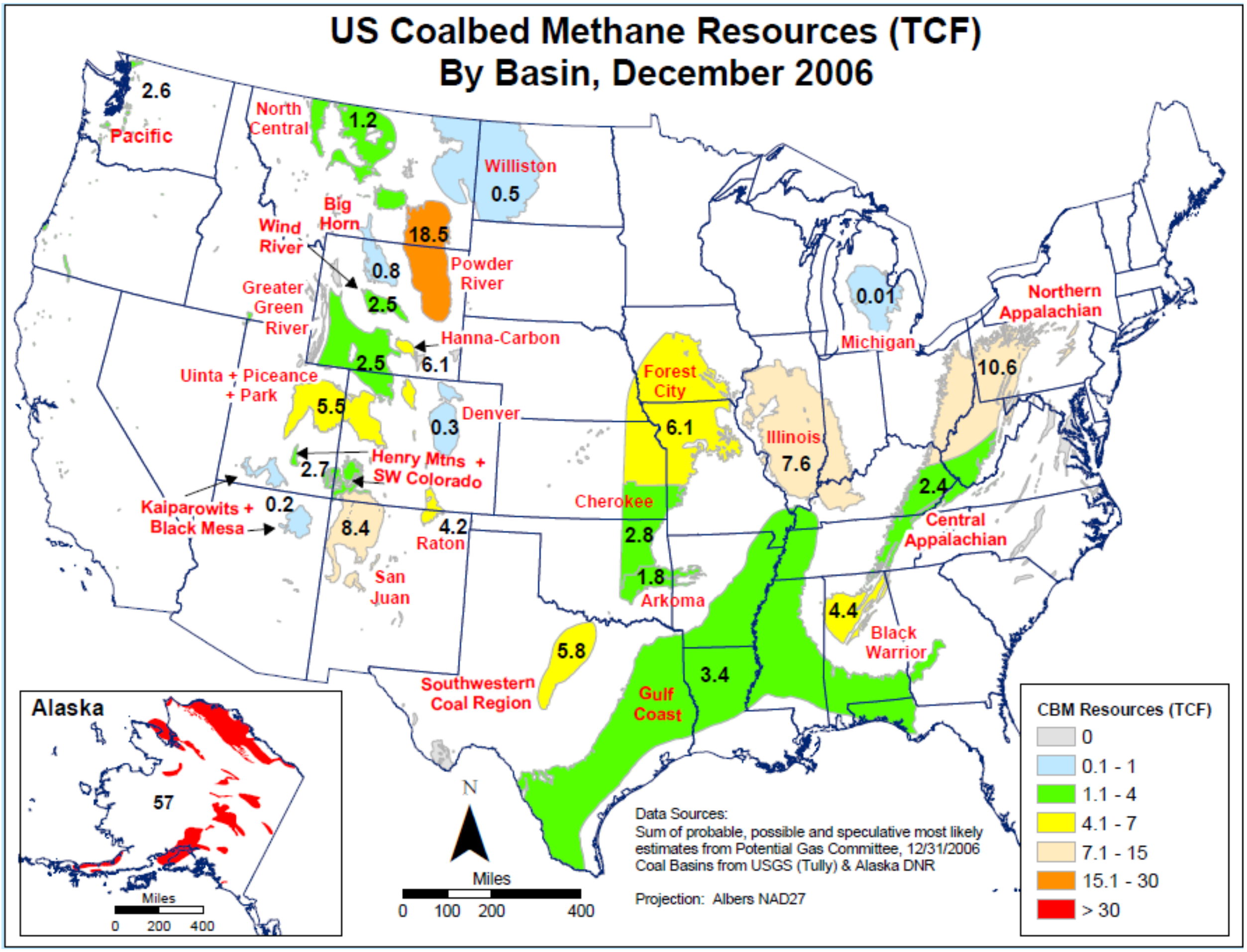

Figure 3: U.S. coalbed methane resources (U.S. Energy Information Administration, 2007).

The first coalbed methane well drilled in Louisiana was completed by Torch Operating Company in 1989. The #3 Greer well was producing 50 million cubic feet per day (MCFD), and it was later plugged and abandoned (Breland, 2004). Data available from several wells completed in Wilcox Group coals in the north-central part of the state have production rates ranging from 7 to 122 MCFD and associated water production of up to 550 barrels of water per day (BWPD)

(Warwick et al., 2004b). By far the best examples of coalbed methane production in Louisiana are in Riverton and Woolen Lake Fields. These two fields are located in parts of Ouachita, Richland, Franklin, and Caldwell Parishes. Southwestern Energy Company began drilling in June of 2005, by May of 2008 there was a total of 31 producing wells, and over 70,000 MCF per month in the majority of 2008 as seen in (Fig.4). Maximum production rates for Riverton Field were 2500 MCFD before the wells started depleting. Cumulative production from Riverton Field as of December of 2011 was 2,262 MMCF with 10,000,000 barrels of water out of 31 wells.

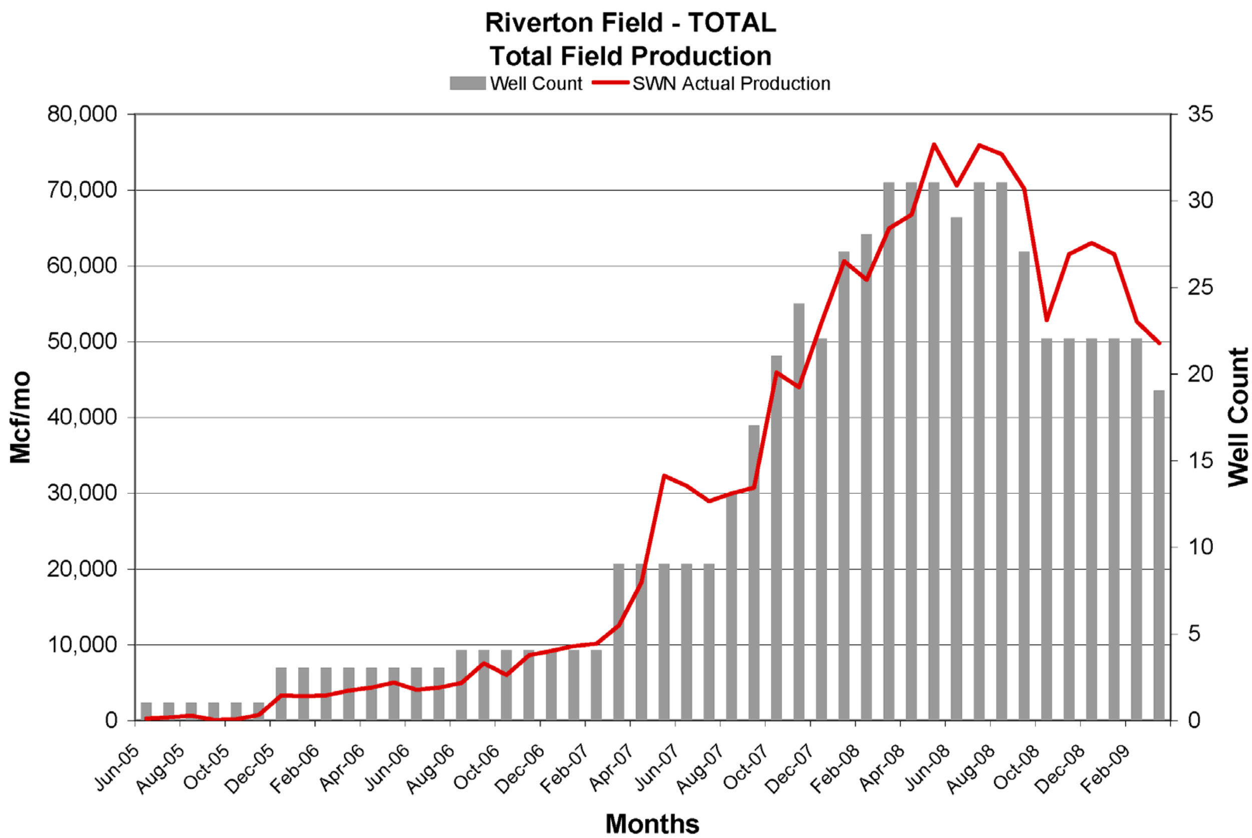

Figure 4: Riverton Field production rates with Southwestern Energy Company (SWN) production rates with well counts per month from 6/2005-2/2009 (Foss, 2009).

The best well in the field is the Southwestern Energy Youngblood #1 (Fig. 5) which has produced 268 MMCF in 3.8 years, averaging 193 MCFD, without a decline in gas rate (Foss, 2009).

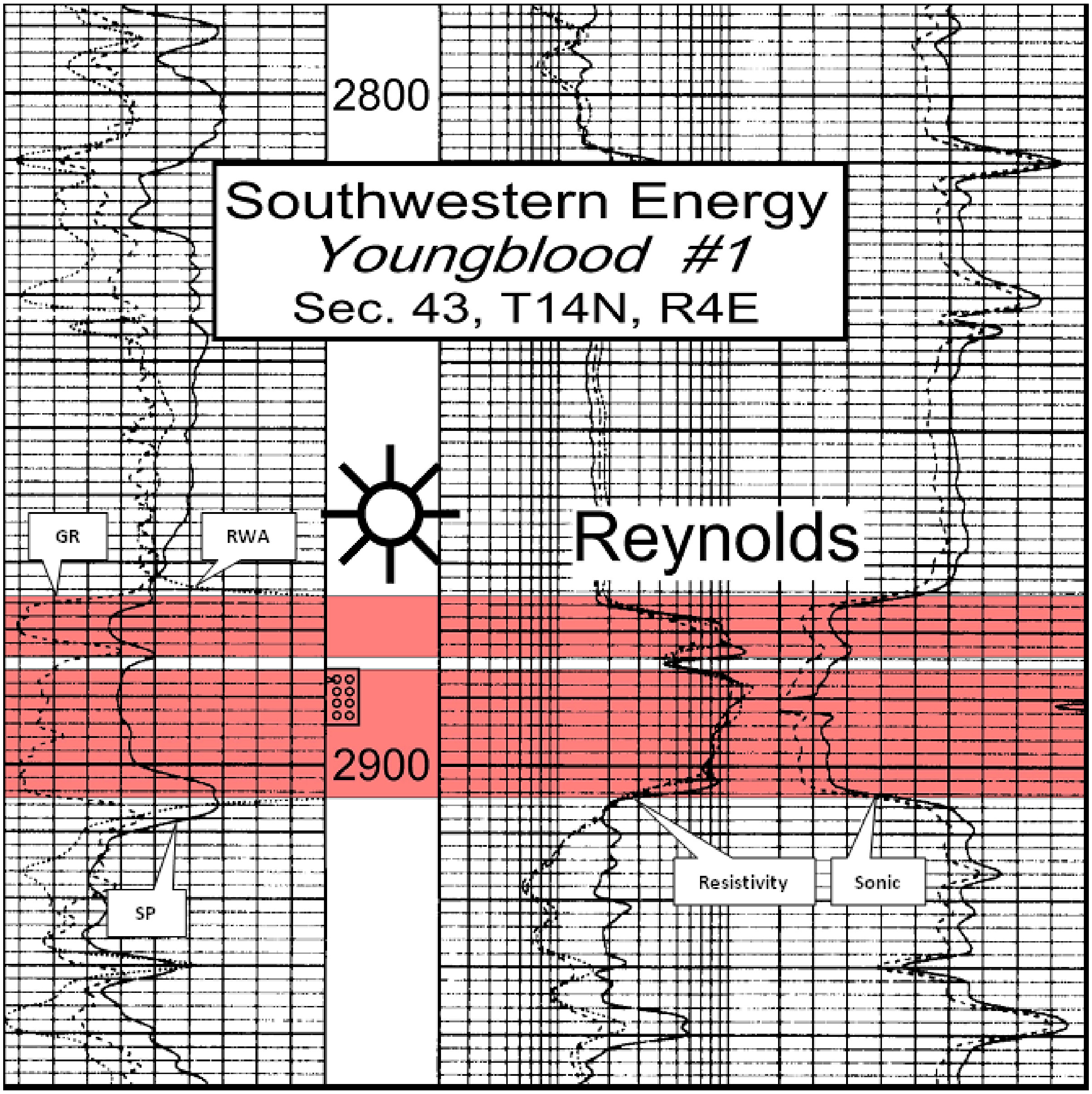

Figure 5: Reynolds coal type log. Southwestern Energy #1 Youngblood well is located in section 43, T14N, R4E, in Caldwell Parish, Louisiana (Modified after Foss, 2009).

Woolen Lake Field is located seven miles east of Riverton Field. In Woolen Lake Field, the Reynolds coal isopach map Figure 6 shows the Reynolds coal reaching a maximum of 32 ft thick in the CHC #1 Lelon Kenney well (SE NE, section 15, T14N, R5E) (Fig. 7). Coal thickness in the 21 wells drilled in the field to date ranges from 4 to 32 ft (Foss, 2009).

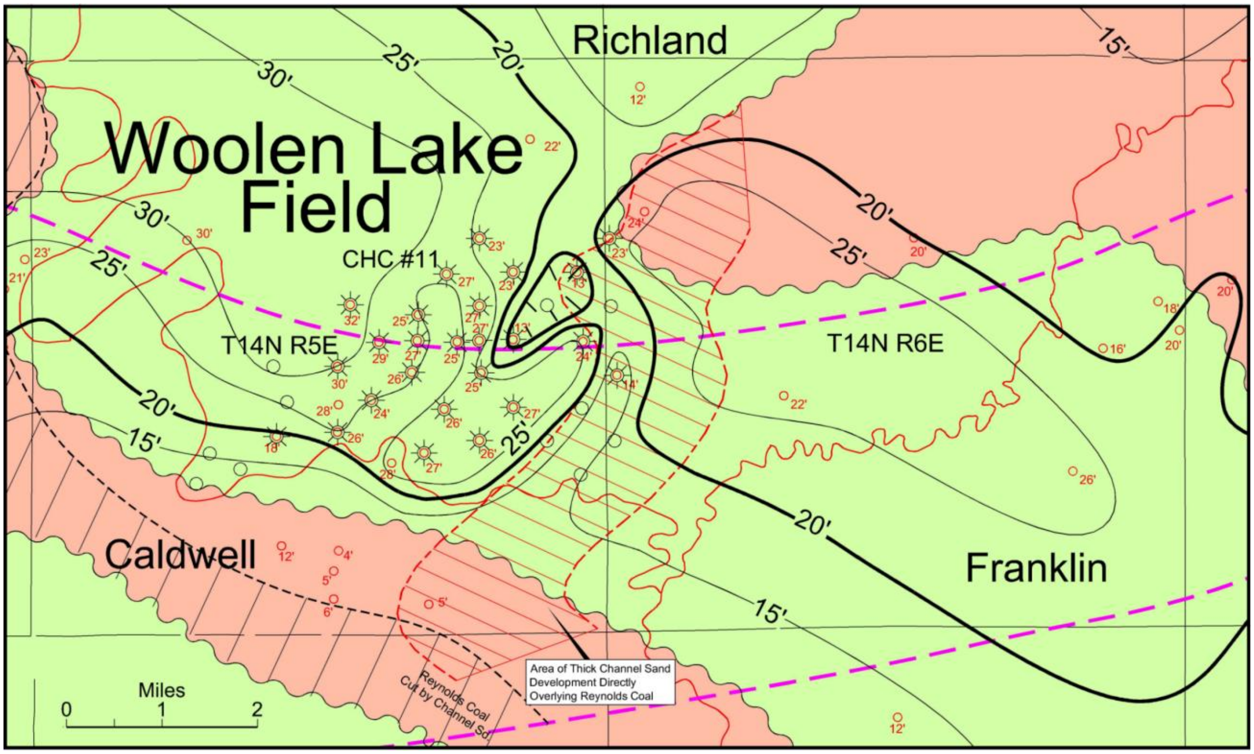

Figure 6: Reynolds coal isopach, Woolen Lake Field. Areas of shale-isolated (shale bounds the coal above and below) Reynolds coal are indicated by lighter shading, whereas areas of no isolation are indicated by darker shading (Foss, 2009).

Cumulative production from Woolen Lake Field as of December of 2011 was 208 MMCF and 536 MBW from 21 wells.

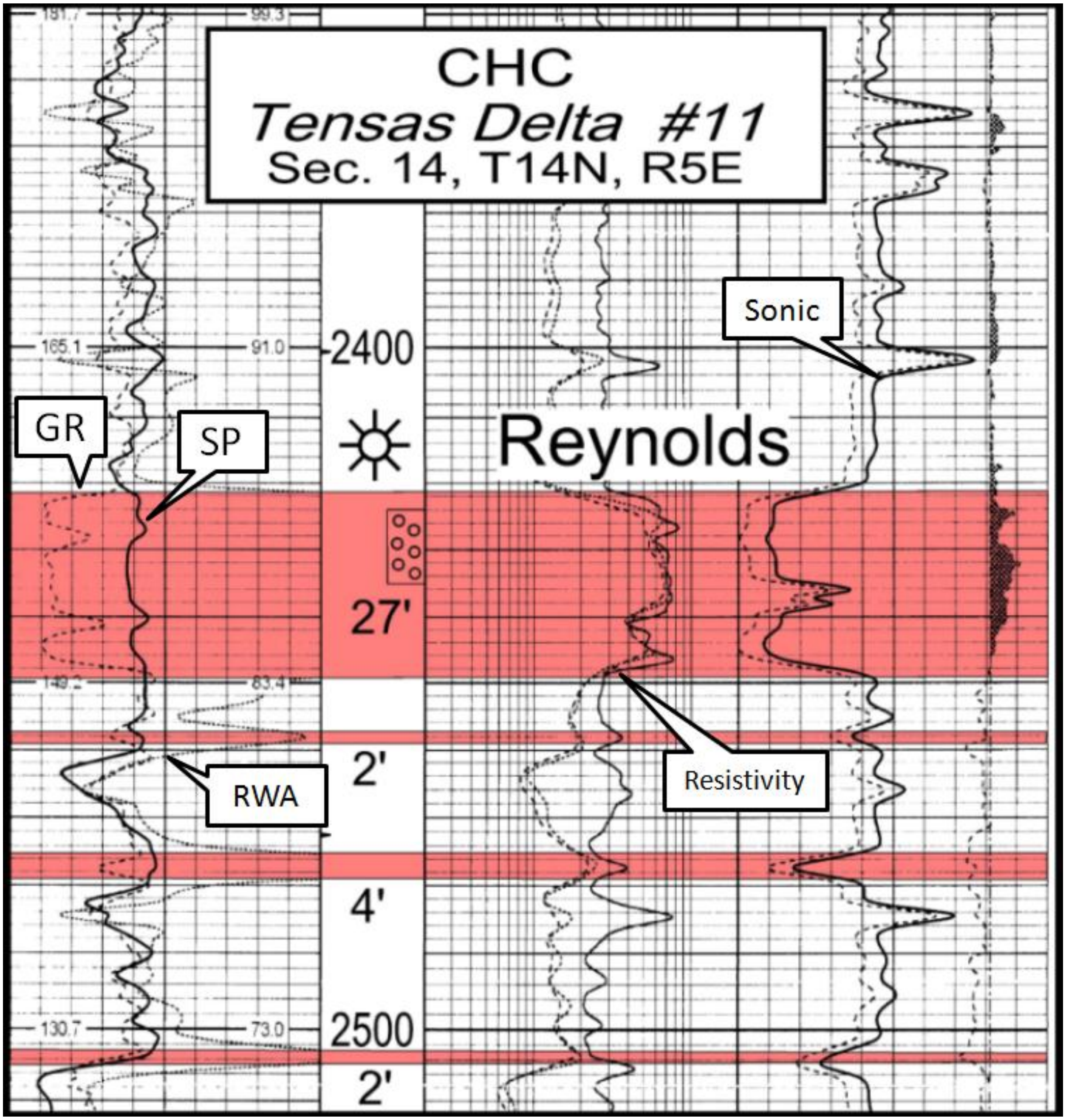

Figure 7: Woolen Lake Field type log. CHC #11 Tensas Delta Exploration well is located in section 14, T14N, R5E, in Richland Parish, Louisiana (Foss, 2009).

PREVIOUS WORK

The first advances in understanding the stratigraphy of the Wilcox Group (Fig. 8) were by Echols and Malkins (1948). They were the first to identify the Holly Springs Delta and its general extent throughout the Wilcox Group in the Gulf Coast. Depositional systems of the lower Wilcox Group of Texas were later described by Fisher and Mcgowan (1967). Their studies led to the division of facies into shelf, delta, barrier bar, lagoon, strandplain, and fluvial systems.

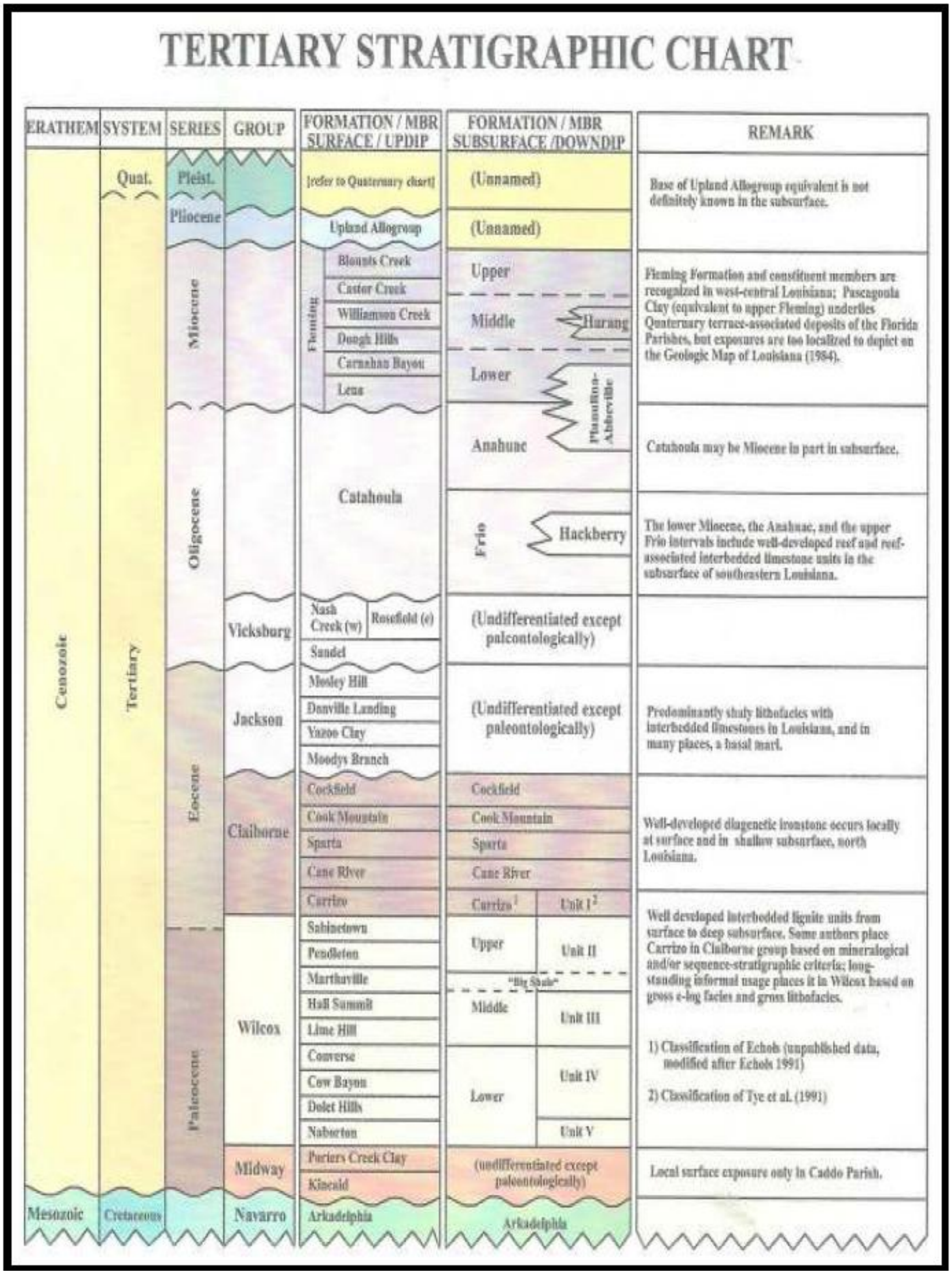

Figure 8. Stratigraphic chart for the Cenozoic of Louisiana, indicating the position of the Wilcox Group (Johnston et al., 2000).

Galloway (1968) postulated that the lower Wilcox Group of Louisiana, Mississippi, and Alabama consists of deposits of four major depositional systems; the Holly Springs Delta System which is volumetrically the largest system, the Pendleton Bay-Lagoon System which is located in eastern Texas, a restricted shelf system which lies to the east of the Holly Springs delta system, and an unnamed fluvial system which crops out along the flanks of the northward trending Mississippi trough. Galloway (1968) also determined, through detailed facies maps, that "two principal types of delta lobes differentiated by their areal geometry, internal facies relationships, and distributary channel development can be recognized in the Holly Springs Delta System." Using electric logs, Galloway (1968) constructed detailed depositional cross sections as seen in Figure 9 to depict the provenance of prodelta muds, bar-finger sands, shoal water distributary mouth bars, delta front sands, interdistributary muds, and deltaic plain distributary channel sands. In addition, Galloway (1968) made the association between depositional environment and hydrocarbon production within the lower Wilcox Group.

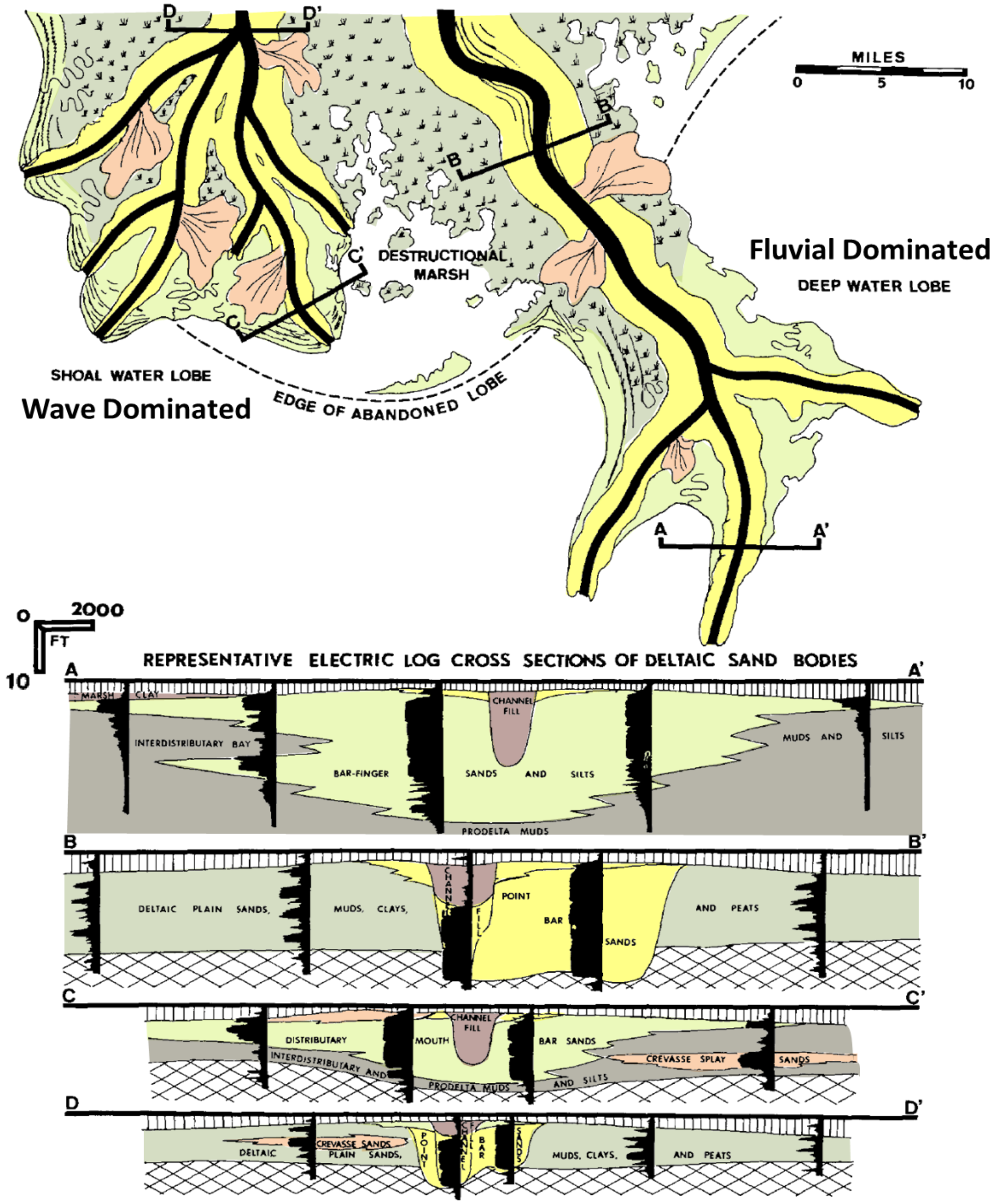

Figure 9: Modeled log cross-sections depicting facies trends within the deltaic environment (Galloway, 1968).

Coates (1979) as part of his master’s thesis at Louisiana State University mapped and identified coals within the lower Wilcox Group of Louisiana. His greatest contribution to this study was his implementation of subdivisions in the lower Wilcox Group that divided the lower Wilcox into four regional lithologic units, informally known as intervals 1, 2, 3, and 4 (Fig. 10). These same divisions are used in this study but are identified utilizing different nomenclature as interval the top of the Midway Shale to Horizon 1 (Interval TopMS-H1), Horizon 1 to Horizon 2 (Interval H1-H2), Horizon 2 to Horizon 3 (Interval H2-H3), Horizon 3 to the Bottom of the Big Shale (Interval H3-BBS) respectively.

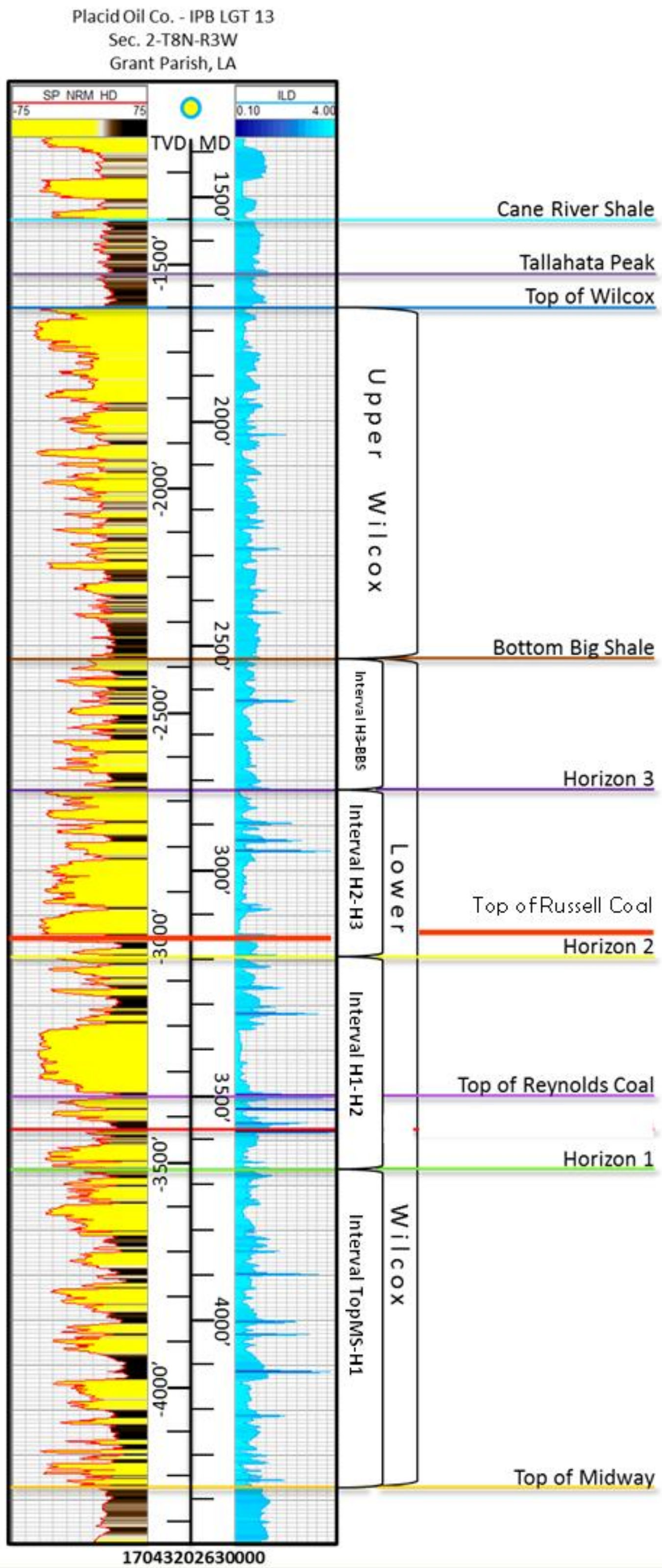

Figure 10. Wilcox Group type log which depicts the intervals of the Wilcox Group and the related horizons (Modified after Han, 2010).

Rogers (1983) thesis also documented lignite development and depositional environments of the lower Wilcox. Rogers (1983) analyzed sand body geometry, petrophysical properties of lignites, and developed electric log resistivity cutoff values to help define coals when only SP and resistivity log curves are available. Tye (1991) focused on regional geology, eustatic sealevel, and lithostratigraphic units.

Since the late 1990's coalbed methane has gained much more attention and the University of Louisiana at Lafayette has been very active in mapping and explaining the Wilcox Group. The earliest of these studies was completed by Kinsland et al. (2003); gravity and magnetic surveys were analyzed to connect basement structure with depositional trends throughout the Wilcox Group. This prompted many subsequent studies to be done in north/central Louisiana on the Wilcox Group. Initial studies utilizing a subset of the available wells in each study area were completed by Kull (2005), Comegys (2006), Guidry (2006), Dew (2007), and Ball (2007) at a regional scale to gather reconnaissance level information on coal concentrations and structural/stratigraphic settings (Fig. 11).

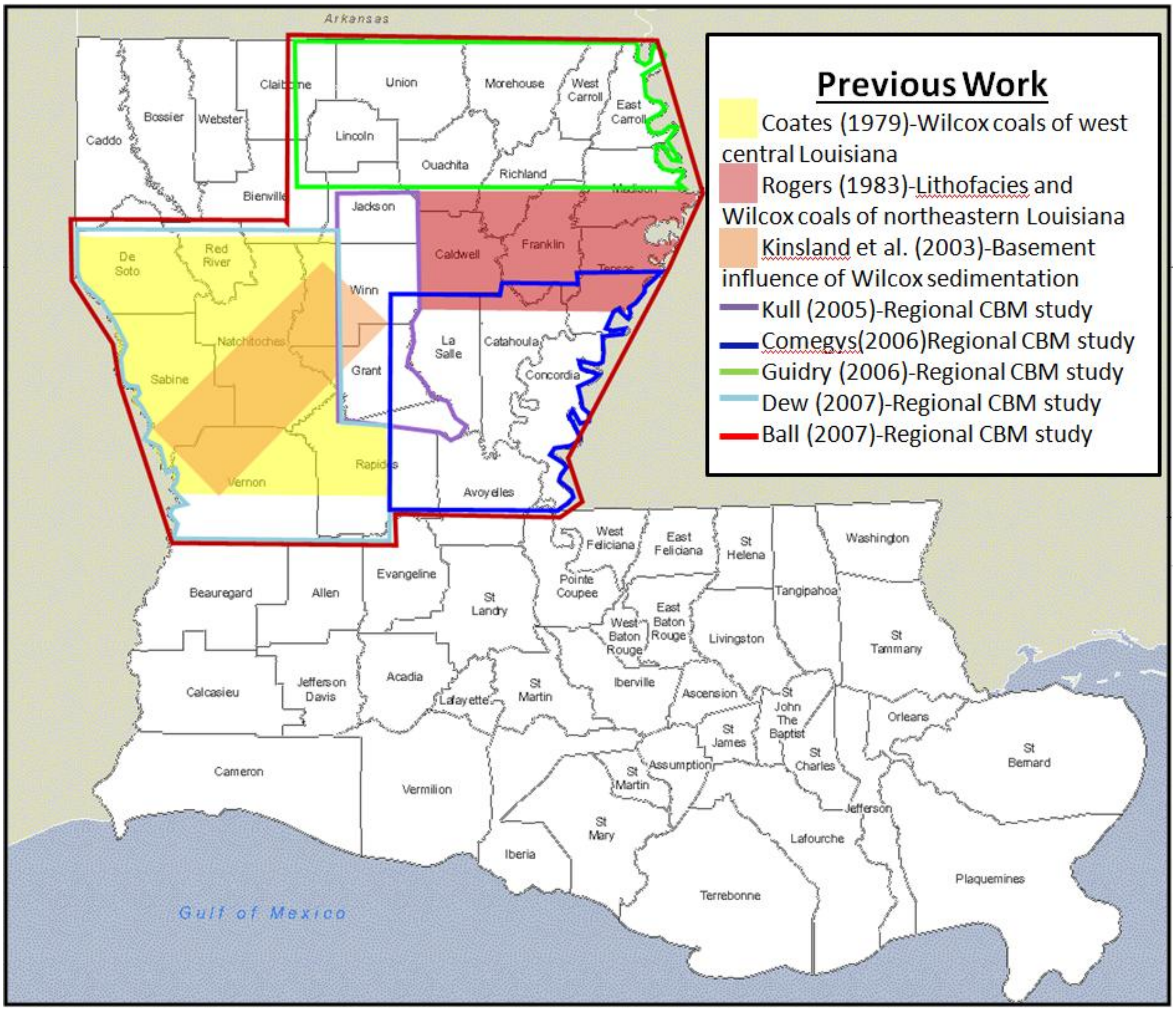

Figure 11. Previous Regional Coalbed Methane Studies.

Later more detailed studies, by Sheahan (2008), Copeland (2009), Han (2010), and Kruse (2011), were conducted within the boundaries of the previous regional studies and are considered sub-regional. These sub-regional studies dealt with smaller mapping areas within which all wells that penetrate the studied horizons were utilized thus providing denser well control, and individual coals were mapped, whereas in the reconnaissance studies only the cumulative thickness of coals in the individual intervals were mapped.

GOALS AND OBJECTIVES

Coalbed Methane Research Group Goals

There are four main reasons for conducting this research. The first objective is to improve knowledge regarding the location and distribution of lower Wilcox Group coals throughout northern Louisiana. The second is to understand regional structural settings in northern Louisiana and their roles in lower Wilcox deposition and structure. The third is, through mapping the subsurface, to better understand the depositional systems that controlled sedimentation and produced the dynamic depositional environment of the lower Wilcox Group. The fourth is to support the efforts of the coalbed methane group at the University of Louisiana at Lafayette to compile a database of well information, digitized well logs, 3-D seismic, gravity data, magnetic data, structural maps, and stratigraphic maps that can be referenced or used by both academia and industry.

Study Area

The study area comprises parts of Grant, Rapides, Avoyelles, Concordia, Evangeline, Point Coupee, West Feliciana, Catahoula, and LaSalle Parishes (Fig. 12). The study area encompasses 4,214 square miles which is equivalent to 2,700,000 acres. From the most northern point of the study area to the southermost point is approximately 66 miles. From the most western point to the most eastern point is approximately 75 miles. Its northern most latitude is 31.795982° N and its most southern latitude is 30.852032° S. Its most western longitude is -92.620465° W and its eastern most longitude is -91.3738° E.

The study utilizes approximately 130 wells. The majority of wells drilled in this part of Louisiana targeted upper Wilcox Group oil sands. Many of these wells are very shallow and only penetrate the upper portions of the lower Wilcox Group. Thousands of wells were drilled within the study area, but only wells meeting specific criteria could be used for this study. Wells were targeted that, at minimum, reached the anticipated depth of the Reynolds Coal Horizon. Wells that penetrate the entire lower Wilcox were ideal for this study. Prospective wells that reach the required depths must also have an accompanying well log. Some potential well log suites did not have the correct logs reported or the appropriate curves visible. Finding well logs that fit all of the requirements of this study was difficult and left only a small percentage of usable well logs available from the total wells that have been drilled in this region of Louisiana.

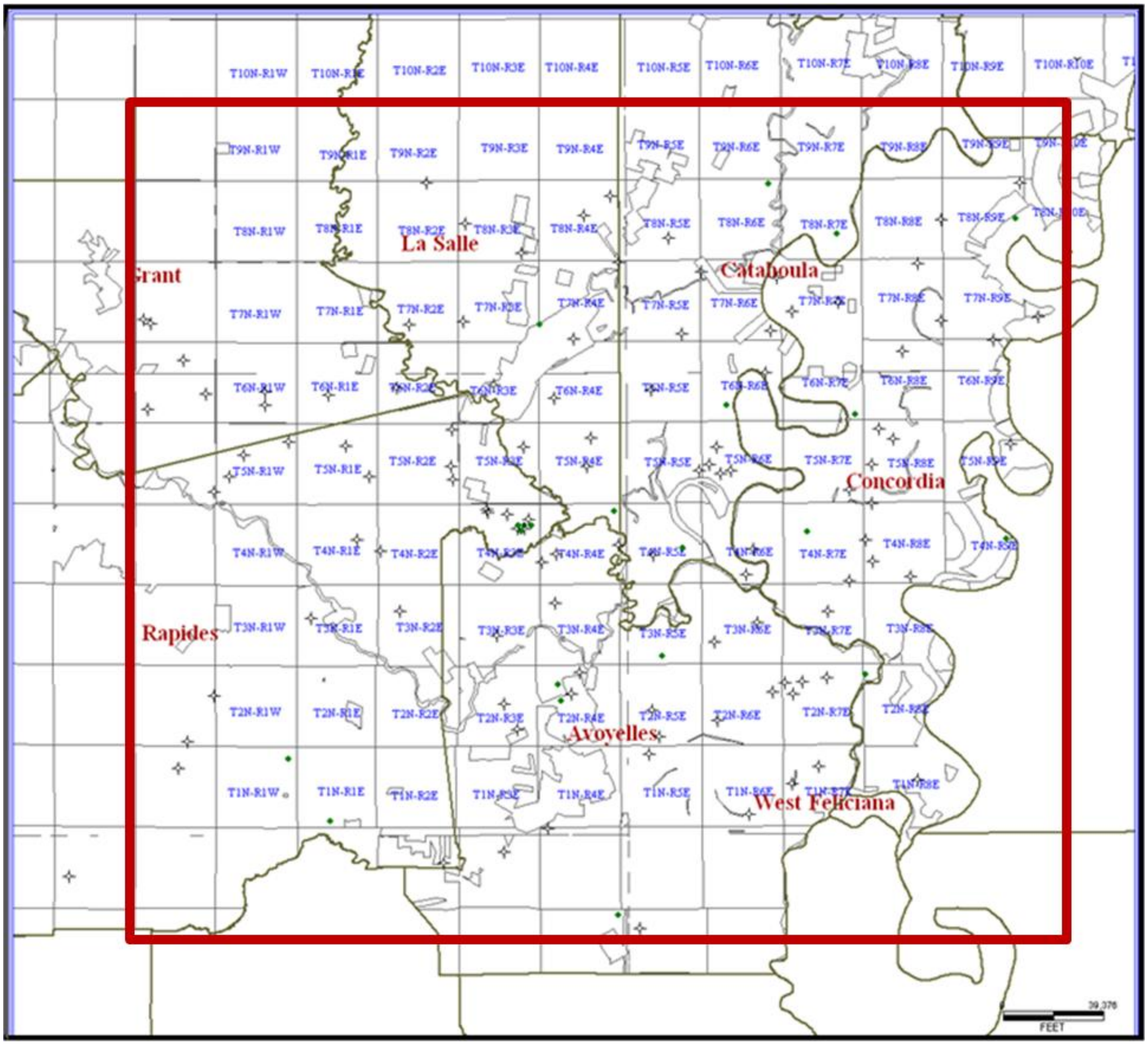

Figure 12: Boundaries of current sub-regional study.

The study area was chosen for two reasons. First, the current study area had previously been investigated in a bigger project on a regional scale by Comegys (2006) and Ball (2007). These studies were for reconnaissance level information on coal concentration and used a general resistivity cutoff for defining coals. This investigation utilizies a greater variety of logs which more precisely define which instances of high resistivity are in fact indicative of coals.

Secondly, this current study area depicted in Figure 13 borders previous sub-regional studies completed by Sheahan (2010) and Han (2010). The completion of this current investigation will produce a seamless transition to previous sub-regional studies. This investigation will charcterize lower Wilcox Group coals in the southern limits of expected coal deposition.

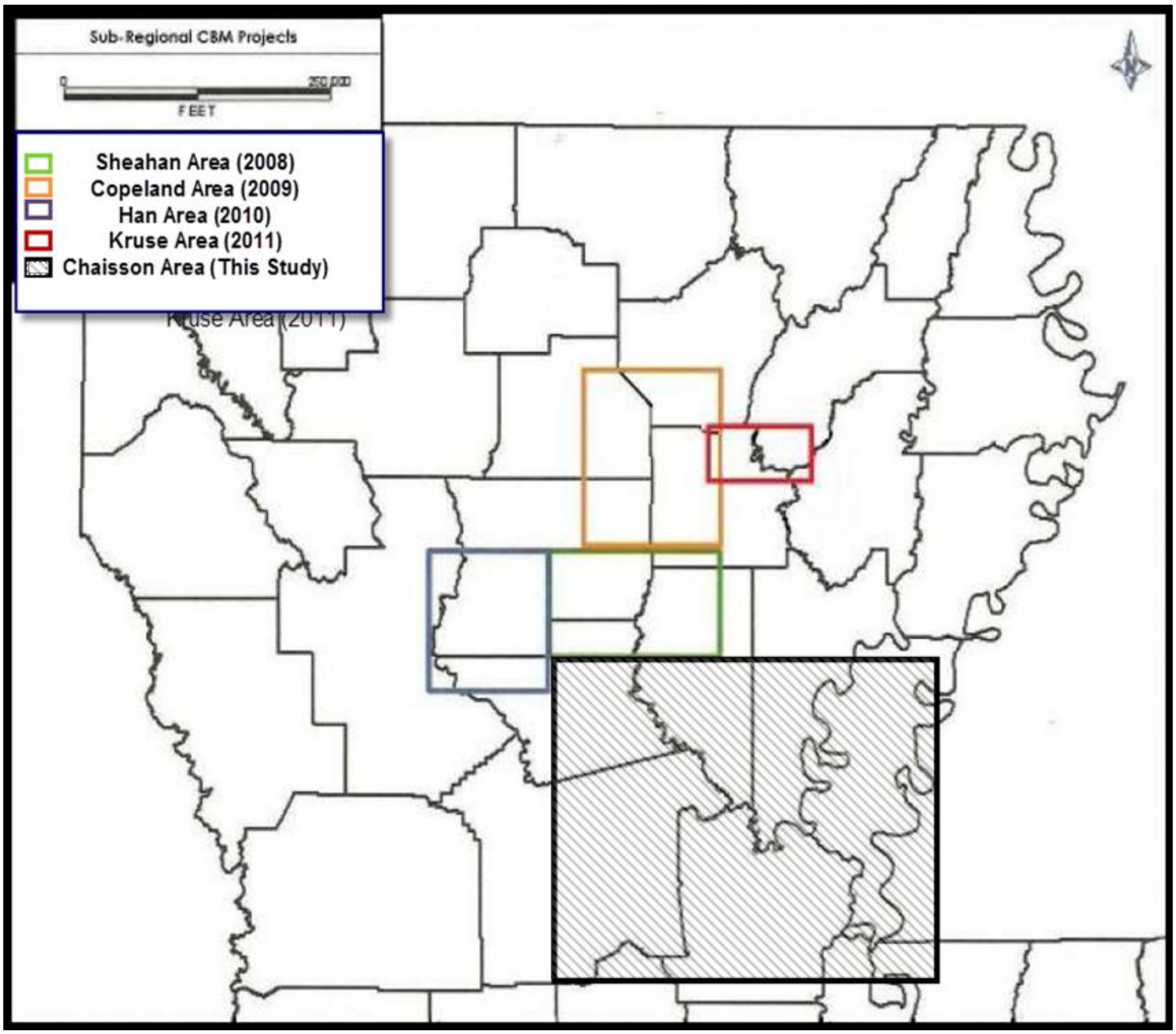

Figure 13: Previous and current sub-regional CBM projects (Modified after Kruse, 2011).

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Nature of the Study

The purpose of this study is to produce detailed structure maps at stratigraphic boundaries within the lower Wilcox Group (Fig. 14). Structure maps were constructed on the top of the Midway Shale, Horizon 1, Horizon 2, Horizon 3, Bottom of the Big Shale, and the Carrizo Sand.

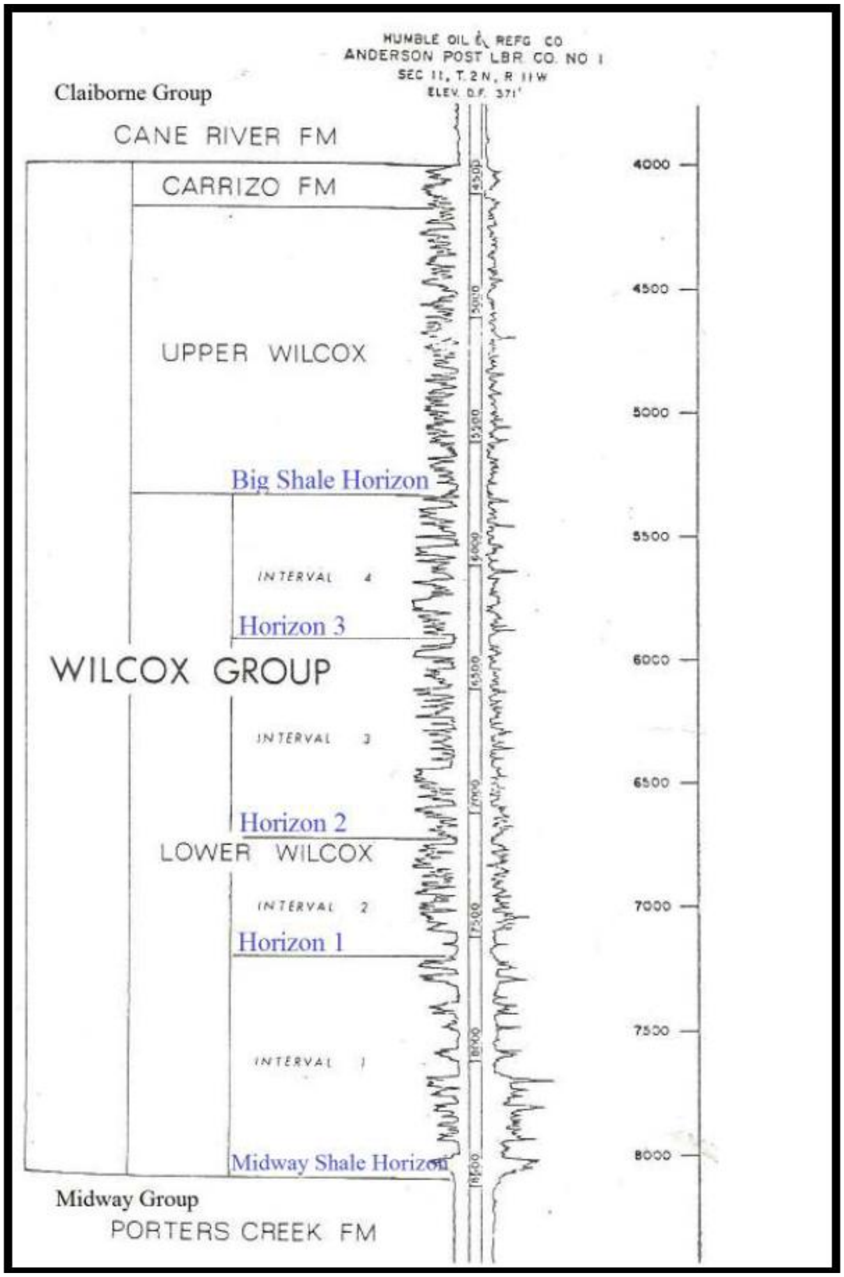

Figure 14. Wilcox Group type log and stratigraphic chart with intervals defined by Coates (1979) (Modified after Coates, 1979).

Additionally, detailed isochore maps were generated on intervals within the lower Wilcox Group: Interval TopMS-H1, Interval H1-H2, Interval H2-H3, Interval H3-BBS. The Reynolds and Russell coals are mapped individually for both areal extent and thickness.

This study utilized well logs that were obtained from the Strategic Online Natural Resources Information system (SONRIS) of the Lousiana Department of Natural Resources (LDNR) and/or already in the database of the coalbed methane project at the University of Louisiana at Lafayette. Logs were digitized in Neuralog, imported into Petra and correlated on stratigraphic boundaries.

GEOLOGICAL SETTING

Regional Geology

The Wilcox Group is a large clastic wedge that is Paleocene to early Eocene in age. A large flux of terrigenous sediment was fed into the ancestral Mississippi and Red Rivers during the time of the Laramide Orogeny (Rainwater, 1968). These sediments were derived from the Western Cordilleran Mountains, and deposited in east Texas as the Rockdale Delta System, with reactivation of the Sabine uplift, sediments were diverted eastward into north/central Louisiana forming the Holly Springs Deltaic System (Galloway, 1968). One of the most influential features on the area is the Mississippi Trough. The Mississippi Trough acted as a funnel to feed clastic rich sediments from the continental interior to the Gulf Coast Basin (Fig. 15).

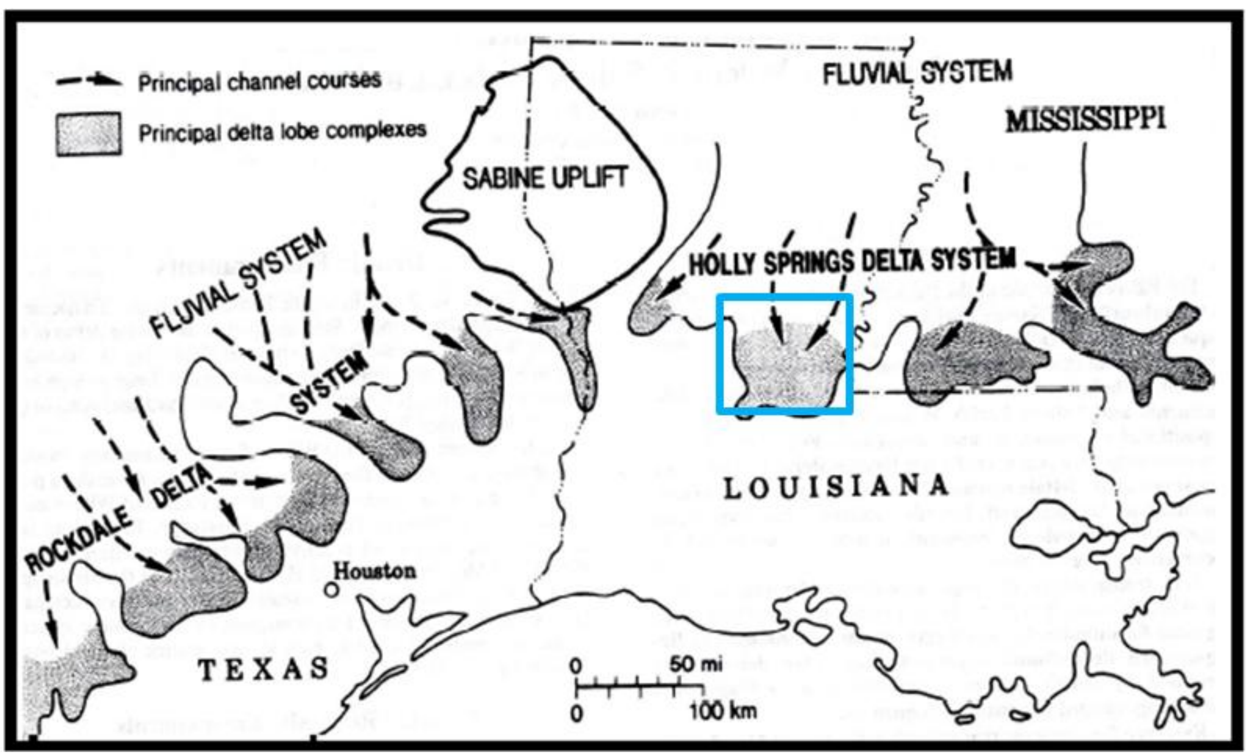

Figure 15: Texas and Louisiana depositional systems (Galloway, 1968).

There is an abundance of structural features in the Gulf Coast Basin that affect the regional geology of northern Louisiana. The most influential on sedimentation in northern Louisiana have been the Sabine Uplift, Monroe Uplift, the LaSalle Arch, Angelina Caldwell Flexure, Mississippi Salt Basin, and the Mississippi Trough (Fig. 16). The two structural features that have the most significant influence on the study area are the LaSalle Arch and the Angelina Caldwell flexure.

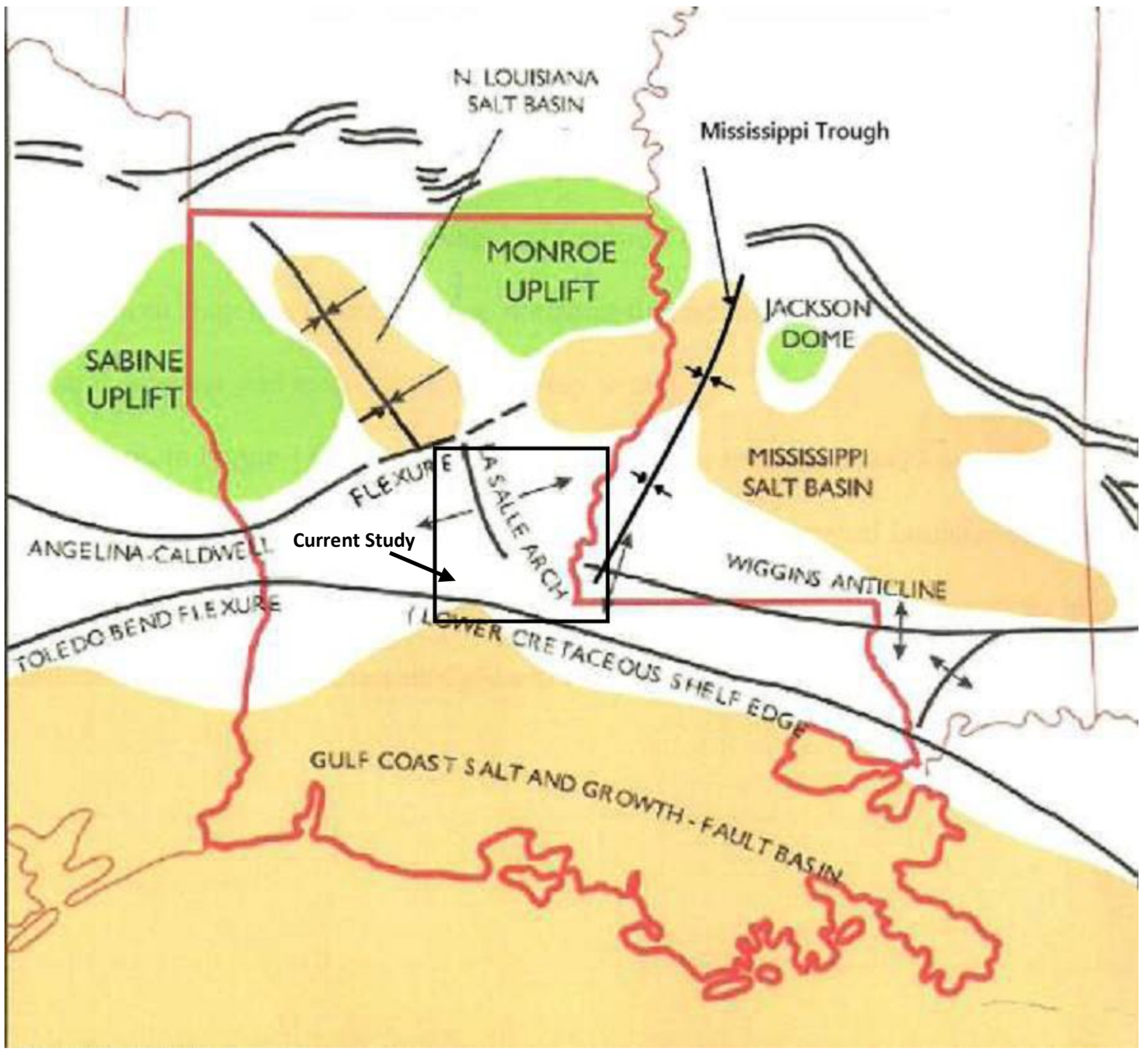

Figure 16: Regional structures along the Gulf Coast with study area shown (Modified after McCulloh and Heinrich, 2002; Mississippi trough data from Galloway, 1968).

The Angelina Caldwell Flexure is located just north of the study area with a small portion located in the study area in the north-eastern quadrant of Grant parish. It extends from Angelina County, Texas through west Louisiana through portions of Grant, Winn, LaSalle, and Caldwell Parishes. The Angelina Caldwell flexure is a monocline that was most prominent as a feature influencing deposition during the Late Cretaceous and Paleogene (Ambrose et al., 2009). North of the flexure there is very gentle south dip. South of the flexure dip is more toward the south and increases by a factor of almost 10 compared with dip north of the flexure (Echols, 2001).

The LaSalle Arch is located in the north central portion of the study area. Its extent is limited to parts of Grant, LaSalle, Catahoula, and Avoyelles Parishes. The arch can be seen throughout all Wilcox Group horizons mapped. It's effect on structure is a locally higher region with gentler dip than adjacent areas. The LaSalle Arch axis is oriented northwest to southeast with a significantly exagerated nose to the southeast. Strata on top of the LaSalle Arch are much thinner than strata on the flanks that have a much thicker vertical section. Lawless and Hart (1990) postulated that the LaSalle Arch basement complex consists of Paleozoic continental crust which caused overlying strata to become uplifted, forming an anticline. The western limb formed by differential subsidence during the early Paleogene and the eastern limb formed due to regional tilting sometime during deposition of the Sparta Formation of the Claiborne Group during the middle Eocene (Lawless and Hart, 1990).

Eustatic sea level rise during the Late Paleocene and Early Eocene played a big role in the regional geology of coastal areas. The lower Wilcox is dominated by transgressive sequences, high stand systems tracts, and low stand systems tracts. The resulting parasequences of the lower Wilcox Group are progradational, aggradational, and retrogradational. This is illustrated in Figure 17 in which Tye et al. (1991) compared lower Wilcox sequence stratigraphy to a eustatic sea level curve adopted from Haq et al. (1987).

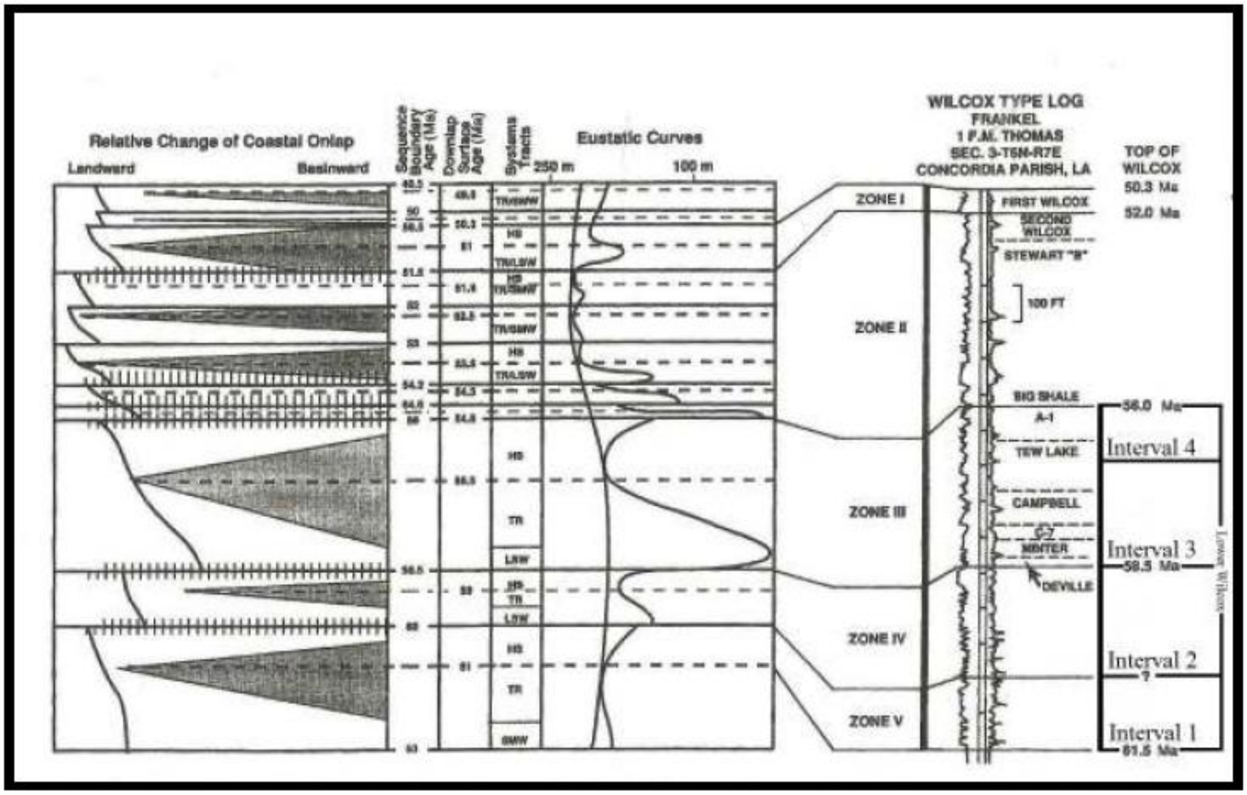

Figure 17. Correlation of global eustatic sea level from Haq et al., (1987) to the Lower Wilcox Group intervals derived from Coates (1979) and the adopted zones of Tye et al. (1991) (Modified after Tye et al., 1991).

Coal Development

Coal is derived from peat that has been changed chemically and physically. A specific set of environmental conditions are required to develop the vegetation necessary to form peat and a delicate equilibrium must exist to accumulate adequate quantities to eventually develop coalbeds (Flores, 1993). The process of coalification occurs when peat undergoes multiple changes as a result of bacterial decay, compaction, heat, and time (Kentucky Geological Survey, 2012). Peat deposits are quite diverse and include everything from pristine plant parts (bark, roots spores, etc.) to decayed plants, decay products, and even charcoal if the peat caught fire during accumulation (Kentucky Geological Survey, 2012). Peat can form into coal when peat has undergone rigorous compaction in burial, water loss, increased pressure, and increased temperature (Kentucky Geological Survey, 2012). As peat undergoes these changes it transforms through peat, lignite, sub-bituminous coal, bituminous coal, anthracite coal, to graphite (Kentucky Geological Survey, 2012). Coal rank Figure 18 is based on burial depth, temperature experienced, and time under these conditions. This is similar to conventional petroleum source rock maturation; coal is the source rock and reservoir rock for the majority of coalbed methane production (Moore, 2007). The rank affects the coals overall permeability, cleating orientation, absorption, and generally the producibility of hydrocarbons (Moore, 2007).

For detailed discussion of the depositional environments in which coals form, the following literature should be sought Coates (1979), Coleman et al. (1983), Farre et al. (1983), Fisher et al. (1967), Flores (1993), Frazier et al. (1969), and Galloway (1968). Their discussion was focused on peat deposition in the fluvial and deltaic environment, related to channel avulsion, channel abandonment or reclamation, and other conditions prone to accumulate peat. Studies by Flores (1968) and Frazier (1967) should be referenced for information regarding fluvial depositional environments of coal. Additionally, the article by Horne et al. (1978) should be consulted for discussion of lower delta plain reconstruction and lithologic characteristics of coal bearing environments.

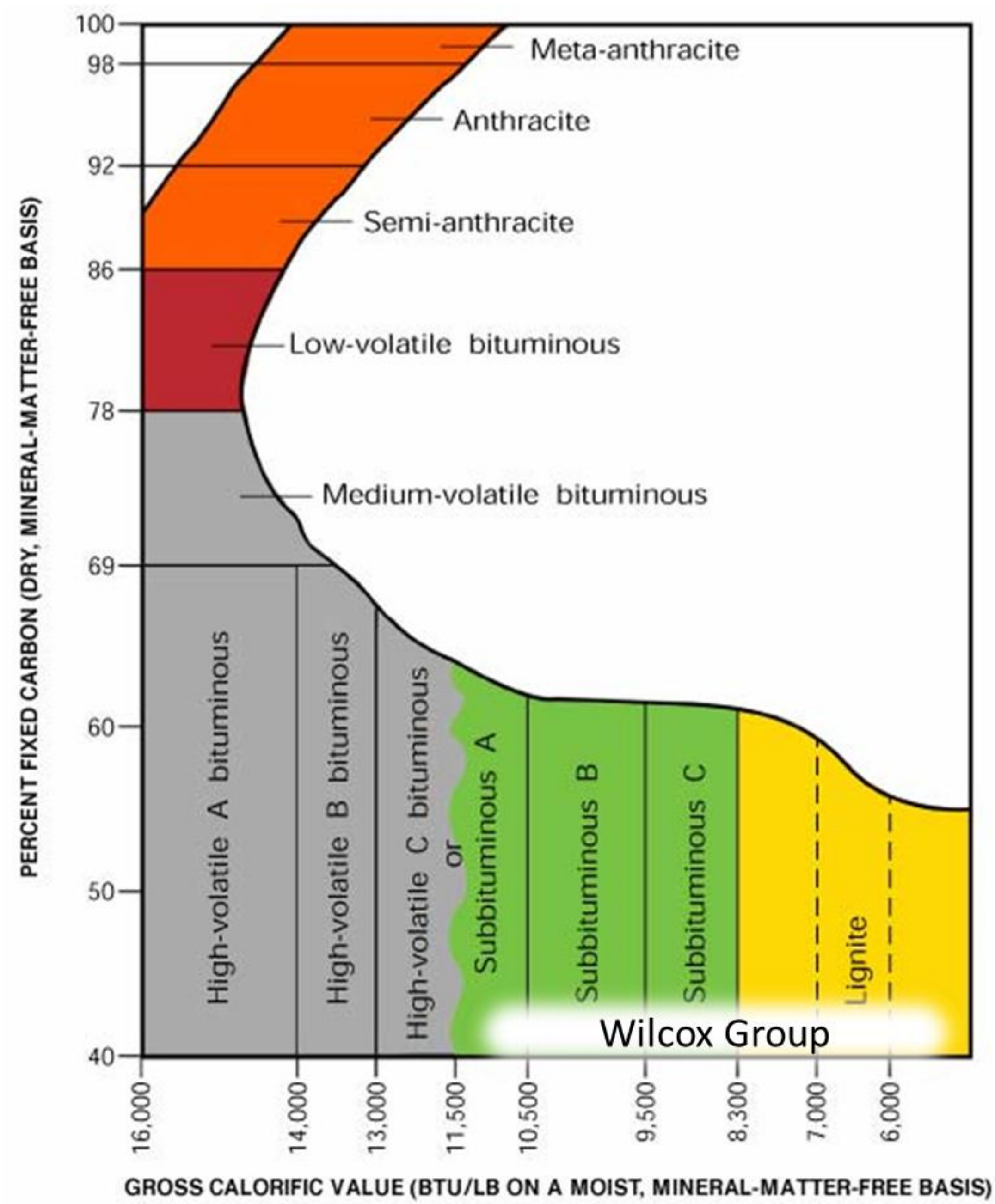

Figure 18. Coal Rank with corresponding BTU values and with the Wilcox Group range highlighted (Modified after Schweinfurth, 2004).

METHODS AND PROCEDURES

Well Log Analysis - Sand

Evaluation of well logs was the primary technique used in this project. In the state of Louisiana, it is required by the Louisiana Deparment of Natural Resources (LDNR) Office of Conservation, that all one inch scale electric logs be made public. Operators of wells shallower than fifteen thousand feet are allowed a period of one year before being released to the public, plus one additional year if evidence is submitted that the well is part of a leasehold interest; operators of wells deeper than fifteen thousand feet are allowed two years before the log has to be released. Unfortunately the spontaneous potential (SP) log is not ideal for determining coals. Deep resistivity logs are also not conclusive for determining coals as calcareous shale yields a combination of SP and deep resistivity signatures very similar to a coal. With this study being sub-regional and therefore more detailed in nature, special care was taken in acquiring well logs with additional logging suites. This is more time consuming as you have more files to sift through and more log curves to evaluate. However, being able to accurately discern coals from calcareous shales (tight streaks) makes the resulting maps more accurate and the project that much more valuable. The most diagnostic logging tools for recognizing coals but which are not required to be made public are Gamma Ray (GR) logs, Density logs, Neutron logs, and Sonic logs. The GR tool measures bulk gamma rays emitted from the radioactive minerals in the immediate vicinity of the well bore; coals usually have a low GR response because the concentration of clay minerals are low (Halliburton, 2007). The bulk-density log is a high-energy gamma ray tool, that is an excellent coal indicator, the density and neutron log are typically run in combination to most accurately identify coals (Halliburton, 2007). The neutron porosity tool responds to the hydrogen index of the matrix rock; coal has one of the highest hydrogen index values of common minerals encountered in sedimentary depositis (Halliburton, 2007). Thus, in coal, the neutron porosity tool is a good indicator of coals. Sonic logs can aid in recognition of coals by their long transit times, which typically is longer than most any other formation in the well (Halliburton, 2007). With the aid of these additional logs most lithologies in this area can be characterized as either sandstone, shale, limestone, or coal. One problem that arises when dealing with a large number of well logs is the varying ranges in measured voltage used for measuring SP. Petra software can account for this problem by normalization, which calibrates the curves of various logs to a common scale. The base line shift method was used in this project to correct for this problem. The base line shift method adjusts the log curves in scale to match other log curves based on the computed average of all curves being analyzed. This method revises the scales of the logs while conserving the original geometry of the curves. Petra was used to compute log statistics as shown in Figure 19. Throughout this study the 5^{th} percentile, 95^{th} percentile, and 50^{th} mean percentile SP value for all wells were computed in the histogram module in Petra. A SP cutoff value was derived from these computations and applied to all logs in the project. This cutoff is used to compute net footages for the gross interval isochore maps, net sand maps, and net sand to gross interval ratio maps.

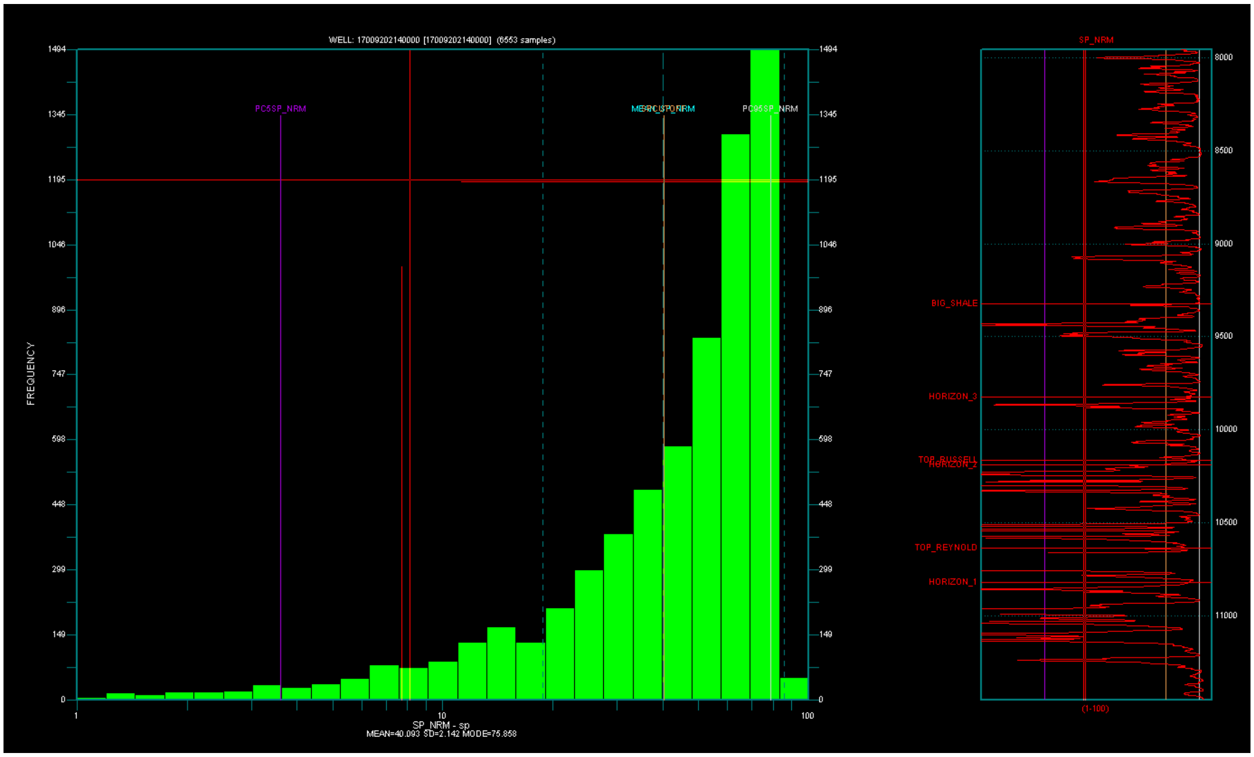

Figure 19. Log Statistics for computing sand cutoffs and footages using the 5th, 95th, and 50th mean percentile SP value.

Well Log Analysis - Coal

Previous regional studies conducted by Kull (2005), Comegys (2006), Guidry (2006), Dew (2007), and Ball (2007) employed a "Quick Look" technique which attempted to identify coals based solely on resistivity cutoffs. Kull (2005) used a cuttoff value of 2.5 ohm-meters to delineate coals, higher than 2.5 ohm-meters was considered a coal, and lower than 2.5 ohm-meters was not considered a coal. Subsequent regional studies tried to develop this technique by assigning small changes in resistivity cutoff values to specific geographic areas based on log response. These techniques can give erroneous results when searching for coals because of the vast size of data sets, large numbers of well logs to be normalized under the same log scale, resistivity changes with deeper logs, and digitizing errors as well as the ability to distinguish coals from calcareous shales.

In this study, coals were first picked with the assistance of additional log curves other than spontaneous potential and resistivity. Gamma Ray was the third most prevalent log available amongst the wells in the study area. Just 19 well logs within this study contained one or more of the following curves: GR, Neutron Porosity, Density Porosity and/or Sonic. Depicted in Figure 20 are wells with logs in addition to the usual SP and resistivity curves required by the state. In this study, each individual log curve was evaluated alone and in combination rather than relying on a general coal resistivity cutoff. Advanced logging suites were first sought for identifing coals. These advanced logs were then compared with basic logging tools to better recognize coals with just SP and deep resistivity logs.

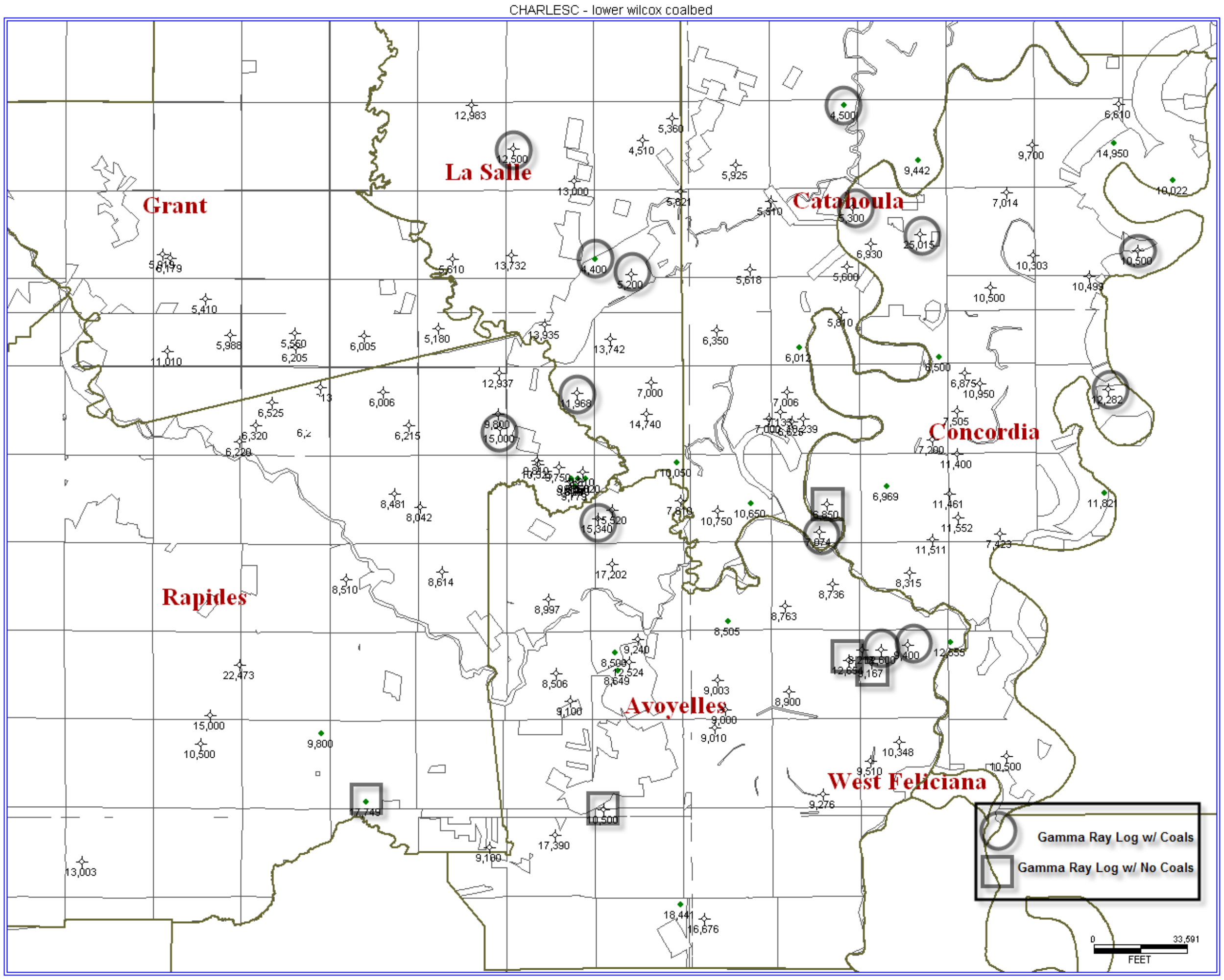

Figure 20. Wells with advanced logging suites in the study area.

Generally, newer vintage 5-in logs contain all of the above mentioned logging tool data and were the first logs interpreted for coal occurrence. Once the coals were picked using 5 inch logs, then logs containing just Gamma Ray logs (in addition to the deep resistivity) were utilized. Well logs with just SP and deep resistivity logs were used to pick coals where a generally high SP response was combined with a high deep resistivity response. Resistivity values for determining coals vary quite a bit throughout the study area due to the large size and large variation in depth of burial, but most coals picked had resistivity values over 3 Ohms-meters. The Justiss Oil Company #1 5 in log seen in Figure 21 shows the presence of coal seams with a combination of SP, GR, RWA, deep resistivity, and Sonic logs.

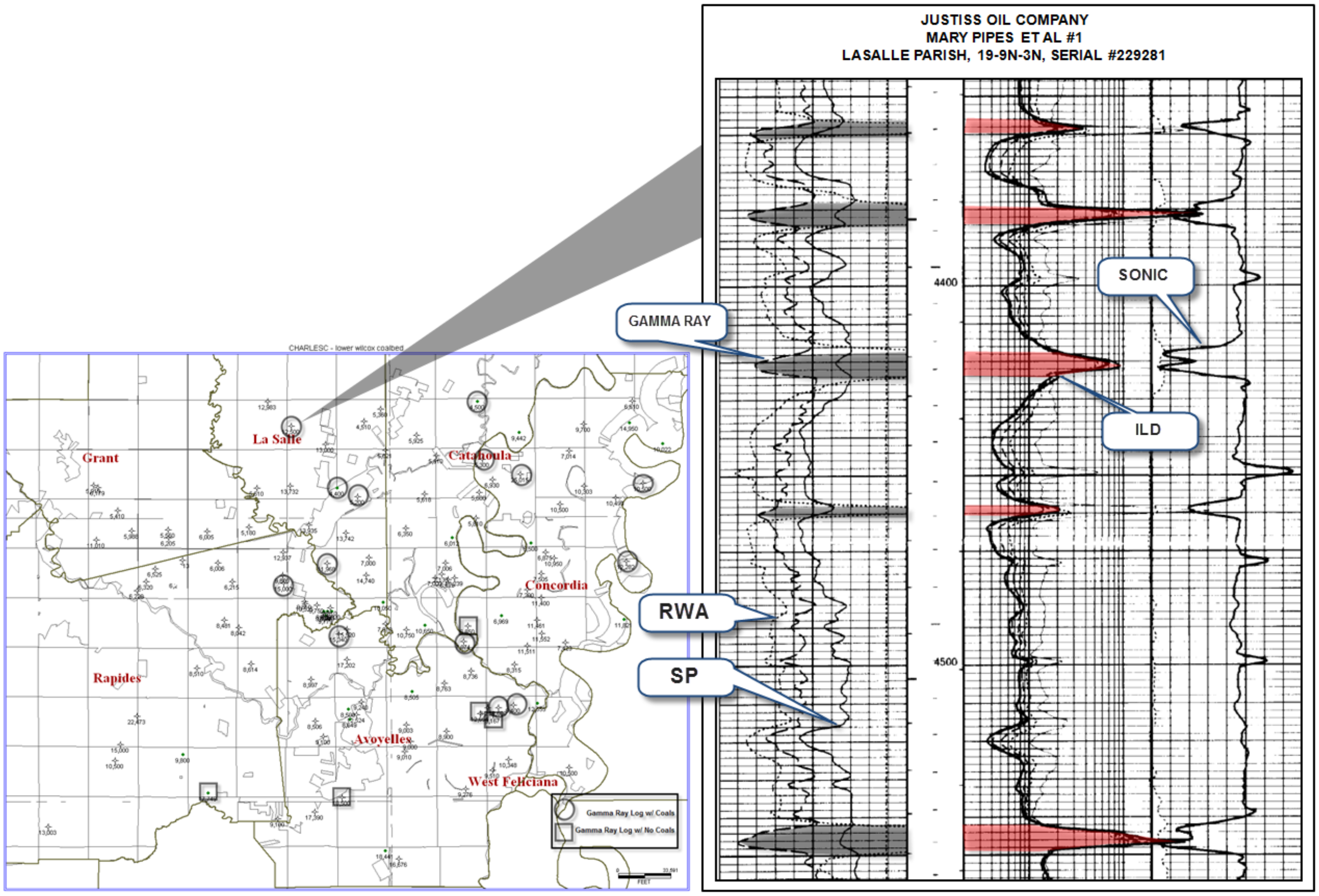

Figure 21. Example of numerous coal seams that are identified in the Justiss Mary Pipes et al. #1 with the use of a 5 in log.

General cutoffs for identifying coals through well logs are Bulk Density < 2gm/cm^3, Gamma Ray < 60 API, Neutron Porosity > 50%, Sonic Transit Time > 80µs/ft, Shear Transit Time > 180µs/ft, and Resistivity > 0.5 ohm-meters (Rogers et al., 2007). Coals can occur outside of these parameters, as these are general cutoff values; the typical well log response can be seen in Figure 22.

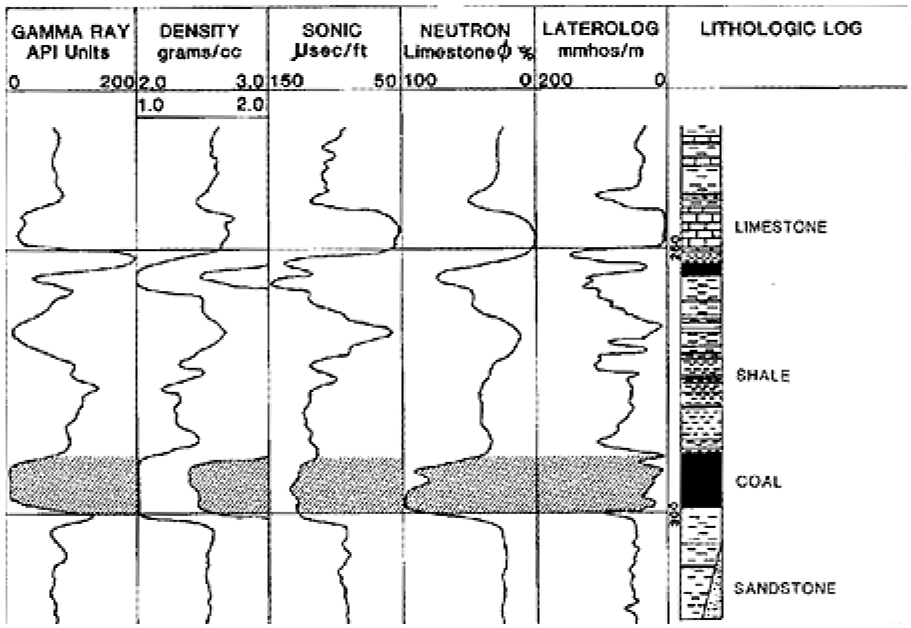

Figure 22. Typical well log responses to coal (Wood et al., 2003).

Coals were identified in Petra using the "Pay Intervals" function and marked as "pay" within each mapped interval. This function made it easy to pick coals and map them because the software allows you to assign a top and base to the coal of choice. You can then simply select top of coal for all of your picks for the selected coal and quickly produce a structure map on that surface. Petra also allows you the ability to color code the coals in each interval for easier identification. All coal picks in Interval TopMS-H1 are colored black. All coal picks in Interval H1-H2 are colored blue. All coal picks in Interval H2-H3 are colored red. All coal picks in Interval H3-BBS are colored green. Once all coals had been selected, the Petra software categorized them in the database as "Zones". These "Zones" were then used to produce isochore maps of coal thickness for each interval. A type log of the lower Wilcox showing the color scheme for coals within the lower Wilcox can be seen in Figure 23. Coals were then summed from all intervals picked to create a coal thickness map for the entire lower Wilcox.

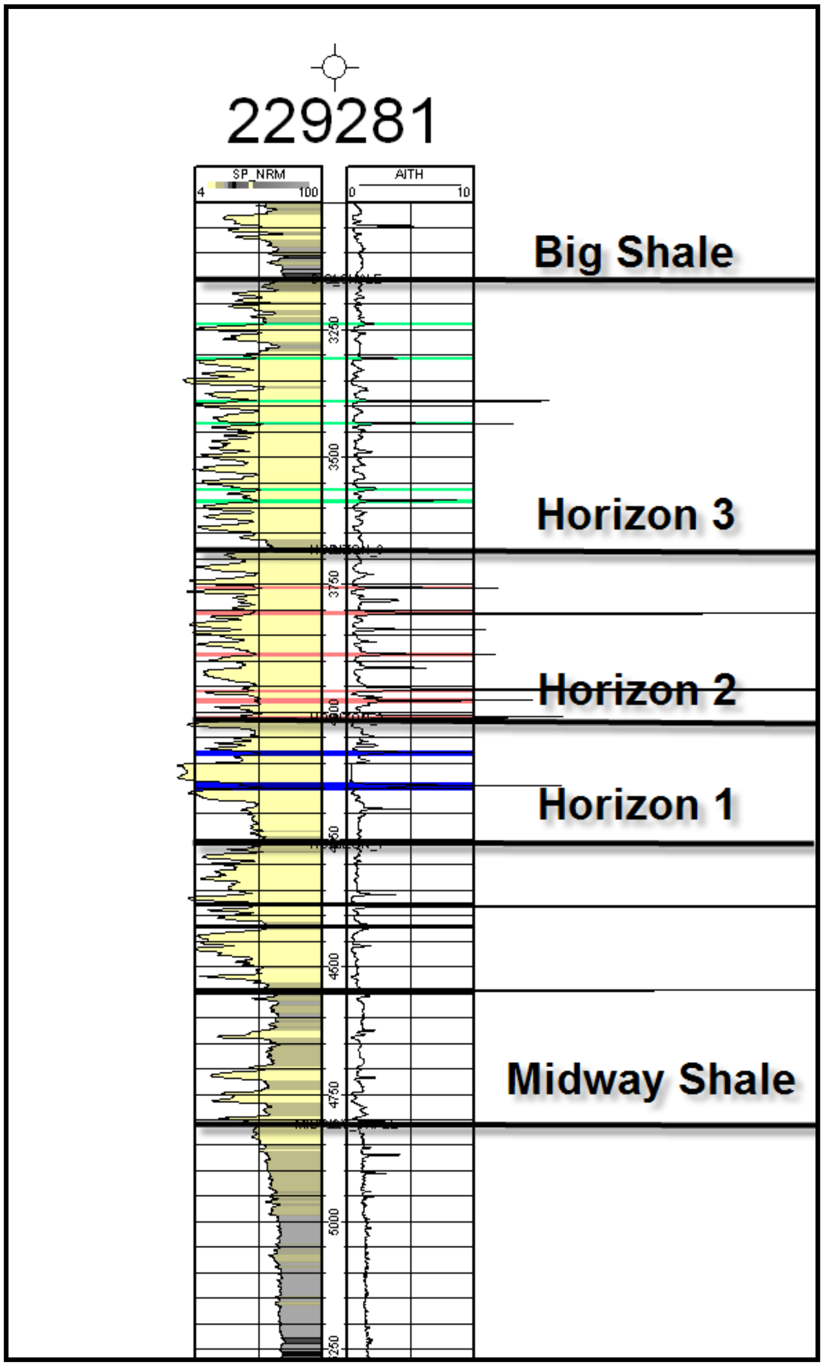

Figure 23. Type log showing color coded coal intervals.

Data Acquisition

The study area was chosen as a continuation of sub-regional studies in the area that had previously been mapped on a regional scale for reconnaissance level information. These sub-regional studies utilized all available well logs and the areas were evaluated in much more detail including mapping of individual coals. The northern boundaries of the study area were chosen to abut against the previous sub-regional studies of Han (2010) and Sheahan (2008) so there could be a seamless transition in correlations. The eastern boundary of the study area is the Louisiana-Mississippi border; no wells were to be utilized from Mississippi. The western boundary abuts against the southeast corner of the Han (2010) area and forms a linear border south of this interface. The southern boundary was selected so as to include several deeper wells that penetrate the entire section of the lower Wilcox.

The initial step for seeking potential wells in the study area was to reference the past regional studies conducted by the Univeristy of Louisiana at Lafayette coalbed methane group. A number of regional studies have been done within and around the outlined study area. The database, which is managed by the coalbed methane group was carefully investigated for wells that are inside the study area. 55 wells were available that had been previously digitized and utilized in regional studies. Once this phase was complete, the Strategic Online Natural Resource Information System (SONRIS) was utilized. SONRIS has a very useful GIS application that lets you view wells within Louisiana. This application allows you to view these wells in multiple map forms and also gives you the ability to activate multiple layers (Fig. 24). All wells in the study area were evaluated to select those with the required curves and which reach the depth of the Reynolds coal, the deepest coal of likely commercial interest.

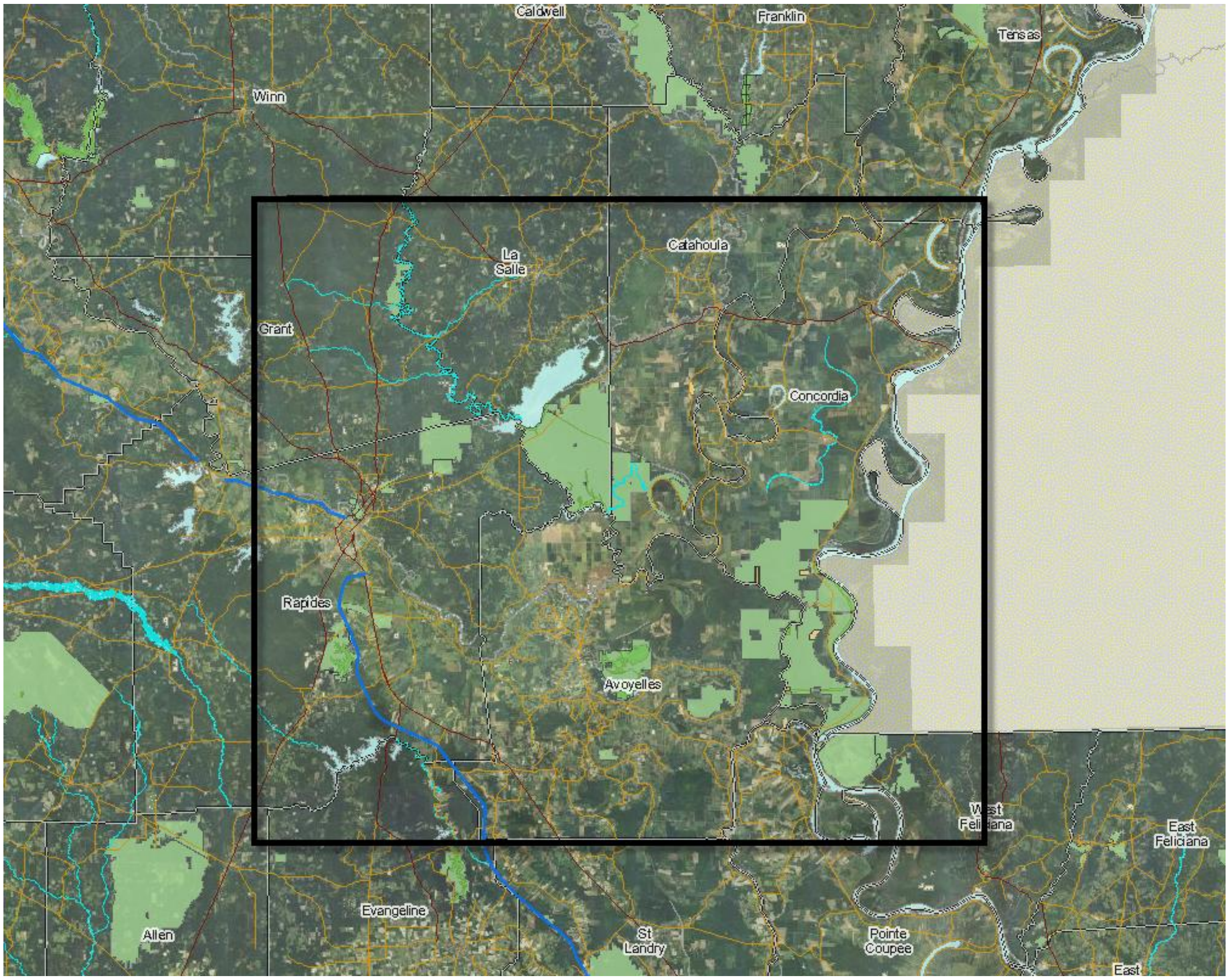

Figure 24. Detailed map generated in the GIS application of SONRIS over study area (SONRIS, 2014).

Once all of the wells in the study were found that meet the above requirements, the raster logs from the Louisiana Department of Natural Resources (LDNR) were downloaded. The raster logs were then imported into Neuralog software. Neuralog was used to digitize, straighten, and adjust raster images in a manner to best show log characteristics for additional interpretation software. These raster images were then exported from Neuralog and imported into the Petra project. The log header and other relevant information relating to each well log were entered into the Petra project. This made accessing information about each well during the interpretation portion of this study very easy because all of the location and log data were in the project. Many of the older wells did not include Kelly Bushing (KB) or elevation information. Regional topographic maps and Goggle Earth were utilized to determine proper elevation for designated wells. Kelly Bushing values were estimated using nearby wells or wells with similar depths of penetration (which relies on an assumption of similar drilling rigs being used to drill to similar depths). Once all well data were incorporated in the project the wells could then be evaluated. The previously digitized regional wells were first correlated for proper correlation points. New wells were incorporated with known correlative horizons. The logs in Petra were used to produce cross-sections, correlate formation tops and coals, produce various isochore maps, evaluate log statistics, and determine lithology cutoffs.

MAPPING RESULTS AND DISCUSSION

Order Of Discussion

The structure of the Wilcox Group is discussed first. In this discussion, all horizons mapped are presented from oldest to youngest. The horizons include the top of the Midway Shale, Horizon 1, Horizon 2, Horizon 3, the Bottom of the Big Shale, and the top of the Carrizo Sand. Following the discussion of the Wilcox structure, the major stratigraphic intervals of the lower and upper Wilcox are discussed. As with the structure, the intervals are discussed in order from oldest to youngest. These intervals include: Interval TopMS-H1, Interval H1-H2, Interval H2-H3, Interval H3- BBS, and Interval BBS-TopW. The analysis of each interval includes a gross interval isochore map, a net sand thickness map, a net sand to gross interval ratio map, and a net coal isochore map. The Reynolds and Russell coal are discussed individually, with a structure map and net coal isochore map for each. Additionally, the entire lower Wilcox group as a whole is disucssed. The discussion of this interval includes a gross interval thickness map, a net sand map, a net sand to gross interval ratio map, and a net coal isochore map.

Top of the Midway Shale Structure

The top of the Midway Shale is the lowermost boundary of the lower Wilcox Group (Fig. 25). It is an excellent correlative marker that lies above the Cretaceous. The top of the Midway Shale is characterized by an extensive shale sequence with interspersed sandstone occurrences. The mapping surface for the top of the Midway Shale in this study is consistently an abrupt change in SP response above a thick shale interval at the base of the lower Wilcox Group. The shallowest penetration of the top of the Midway Shale is by the Placid Oil #2 in section 3-8N-2E at a depth of -4018’ (Fig. 32). The top of the Midway Shale exhibits 7,945' of structural relief from the Placid Oil #2 to the southernmost well in the study the Moncrief Ducote #1. South to southeast dip is clearly defined over the entire portion of north-central Louisiana at the top of the Midway Shale horizon. In the northern half of the study there is a considerable amount of east dip (Fig. 31) compared with the southern portion where it starts to trend more toward the south. Many of the wells in the study area do not reach the top of the Midway Shale. With the decrease in well control, important structural features are not seen and/or their characteristics less well defined. The relief of the LaSalle Arch is almost unrecognizable due to the low number of penetrations at this horizon and their distribution such that there is almost no control to the west of the LaSalle Arch in the study. Approximately 70 wells reached the top of the Midway Shale in this study.

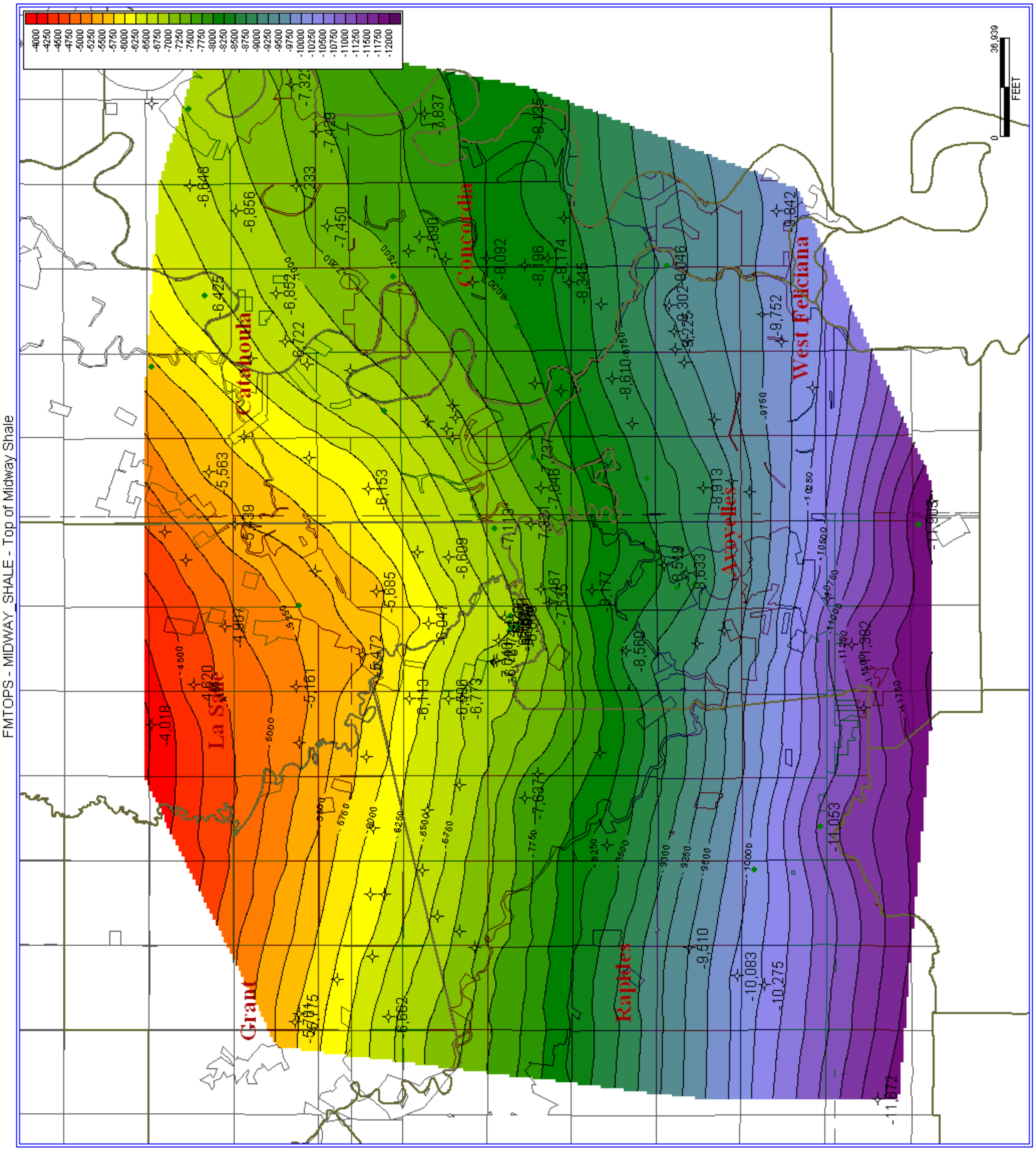

Figure 25. Top of the Midway Shale Structure Map.

Horizon 1 Structure

The mapped horizon next above the top of the Midway Shale is Horizon 1 (Fig. 26). The shallowest penetration of Horizon 1 in this study is by the Placid Oil #2 in section 3-8N-2E at a depth of -3,396’. Horizon 1 exhibits 7,844’ of structural relief from the Placid #2 to the southernmost well in the study. Horizon 1 is consistently found in 88 wells throughout the study area. Horizon 1 is defined as a Type 2 sequence boundary that occurred 60Ma (Kinsland, 2013). The increase in well penetrations compared with the top of the Midway Shale horizon is most apparent in the central and east portions of the study (Fig. 33). Slight east and west dip around the arch accentuates the structural feature. General dip is similar to the top of the Midway Shale, south /southeast.

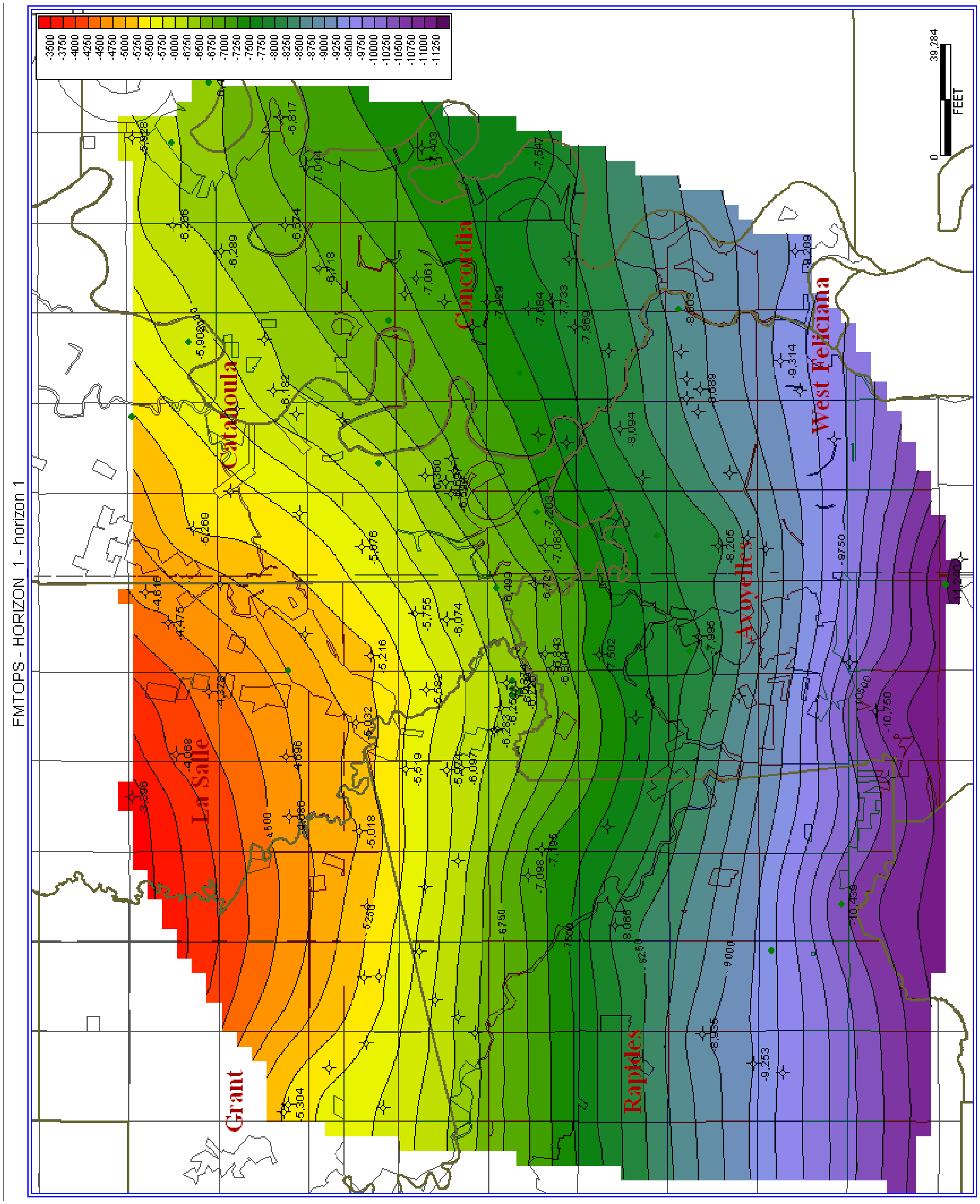

Figure 26. Horizon 1 structure map.

Horizon 2 Structure

The next mapped horizon above Horizon 1 is Horizon 2 (Fig. 27). The shallowest penetration of Horizon 2 in this study is by the Placid Oil #2 in at a depth of -3,109’. Horizon 2 exhibits 7,645’ of structural relief from the Placid #2 to the southernmost point of the study. Approximately 106 wells penetrate Horizon 2 in this study. Horizon 2 is interpreted as a Type 2 sequence boundary with an overlying shelf margin within which the Russell coal accumulated (Kinsland, 2013). The Horizon 2 sequence boundary occurred 58.5 Ma (Kinsland, 2013). More well control is apparent at this horizon compared with deeper horizons. The structural features in Horizon 1 generally carry over to Horizon 2. These two horizons are virtually identical and exhibit no real change in structure. Correlations are not always consistent at this horizon; some wells have notable shale breaks for the surface of Horizon 2. However, some wells, have large box car sand sequences that completely cover the anticipated correlative surface. These wells which are difficult to correlate have likely penetrated a channel which has cut through the mapping horizon. When this situation occurs, the anticipated surface is picked that best fits the geology, log response, and nearby wells.

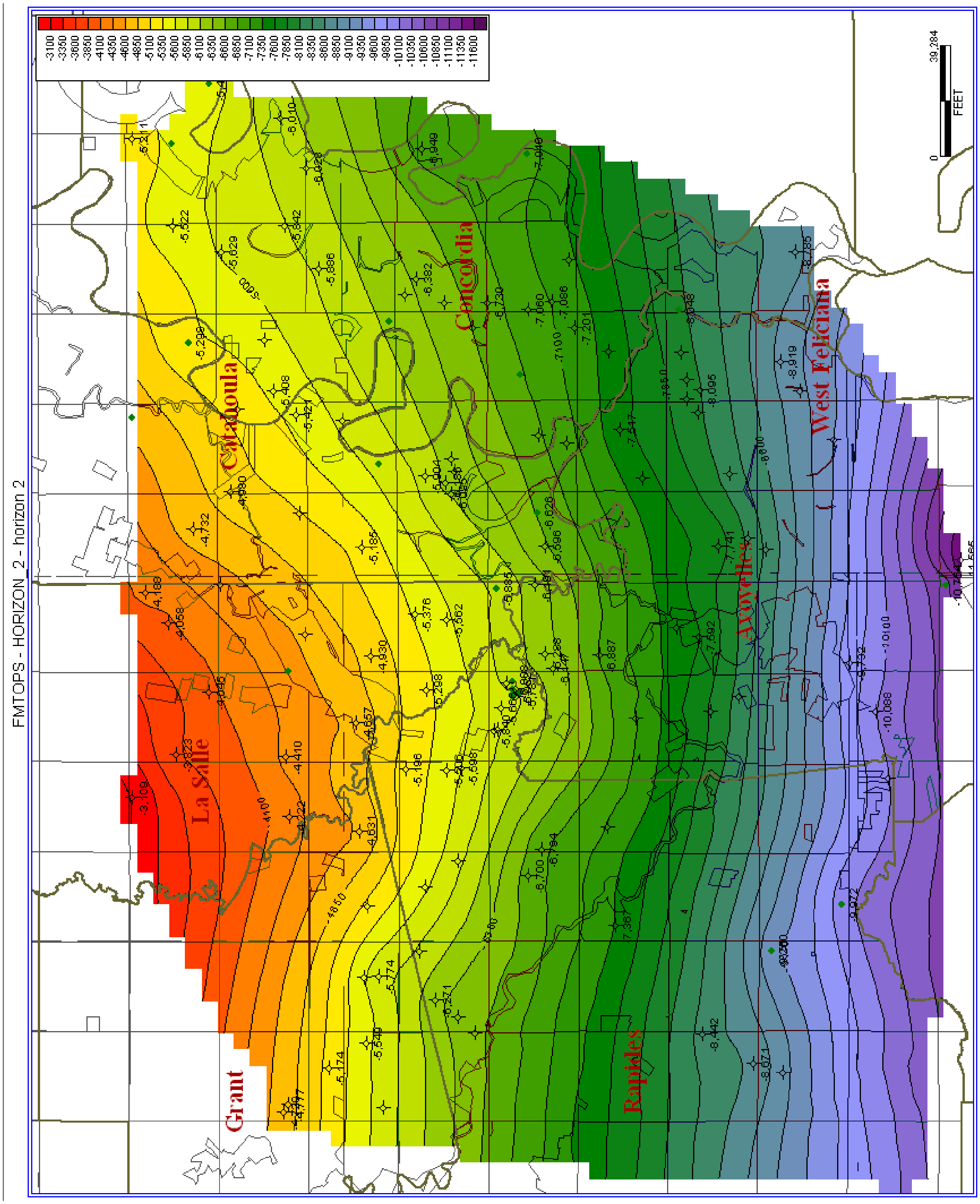

Figure 27. Horizon 2 structure map.

Horizon 3 Structure

The next mapped horizon above Horizon 2 is Horizon 3 (Fig. 28). The shallowest penetration of Horizon 3 in this study is by the Placid Oil #2 at a depth of -2,678'. Horizon 3 exhibits 7,770' of structural relief from the northernmost well to the southernmost well in the study. Horizon 3 is penetrated in 126 wells throughout this study. The increase in well density significantly alters the mapped structure compared with deeper mapped horizons with less well density. The LaSalle Arch really stands out in this horizon. The arch has gone from a flatter, less exaggerated feature at older horizons to more of an elongated nose at shallower horizons where well control is better. This nose is greatly exaggerated with east and west dip on the flanks of the arch (Fig. 34). The boundary at Horizon 3 is difficult to define with well logs as this horizon is located within a dynamic time period where sequence boundaries shifted between lowstand, transgressive, and highstand systems tracts (Tye et al., 1991).

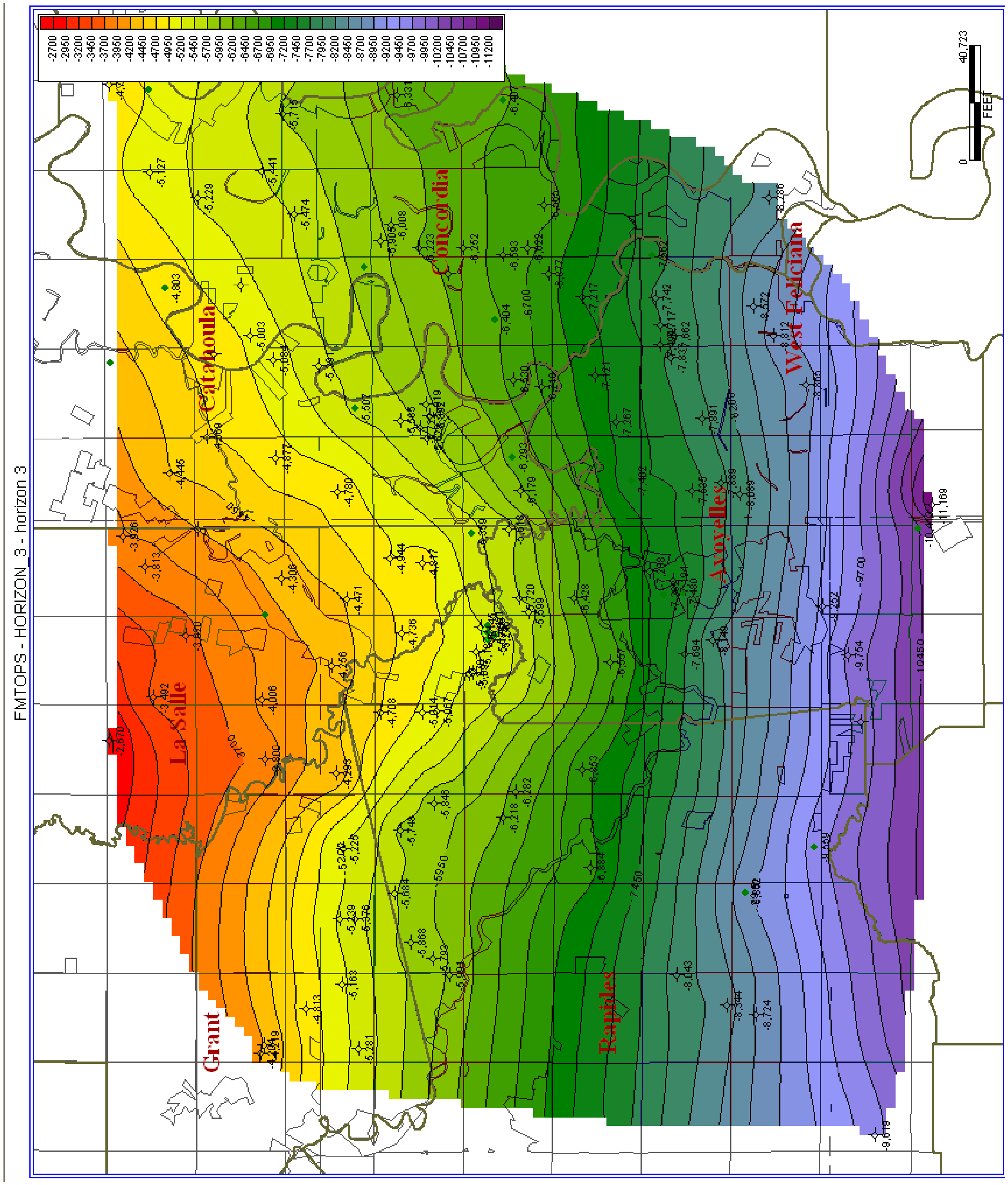

Figure 28. Horizon 3 structure map.

Bottom of the Big Shale Structure

The horizon above Horizon 3 is the Bottom of the Big Shale (Fig. 29). The Bottom of the Big Shale is the upper boundary of Interval H3-BBS and the lower boundary of Interval BBS-TopW. The Bottom of the Big Shale is the upper boundary of the lower Wilcox Group and the lower boundary of the upper Wilcox Group. Similar to other mapped horizons the shallowest penetration of the Big Shale is seen in the Placid Oil #2 well at a depth of -2,349'. The Big Shale exhibits 7,647' of structural relief from the Placid #2 to the southernmost well the Moncrief Ducote #1. Approximately 130 wells penetrate the Bottom of the Big Shale in this study. The Big Shale is a marine transgressive shale of sub-regional extent that separates the upper and lower Wilcox Group (Galloway, 1968). The abrupt lithologic contact at the Bottom of the Big Shale corresponds to sea level fall at 56 Ma, the degree of which would have been adequate to expose the continental shelf to subaerial exposure (Tye et al., 1991). Correlations at the Bottom of the Big Shale are excellent within the confines of this study. The result of the improvement in precision of correlations can be seen in comparisons between the older horizons and the Bottom of the Big Shale where contour spacing is much better and contours are smoother, producing a much cleaner map.

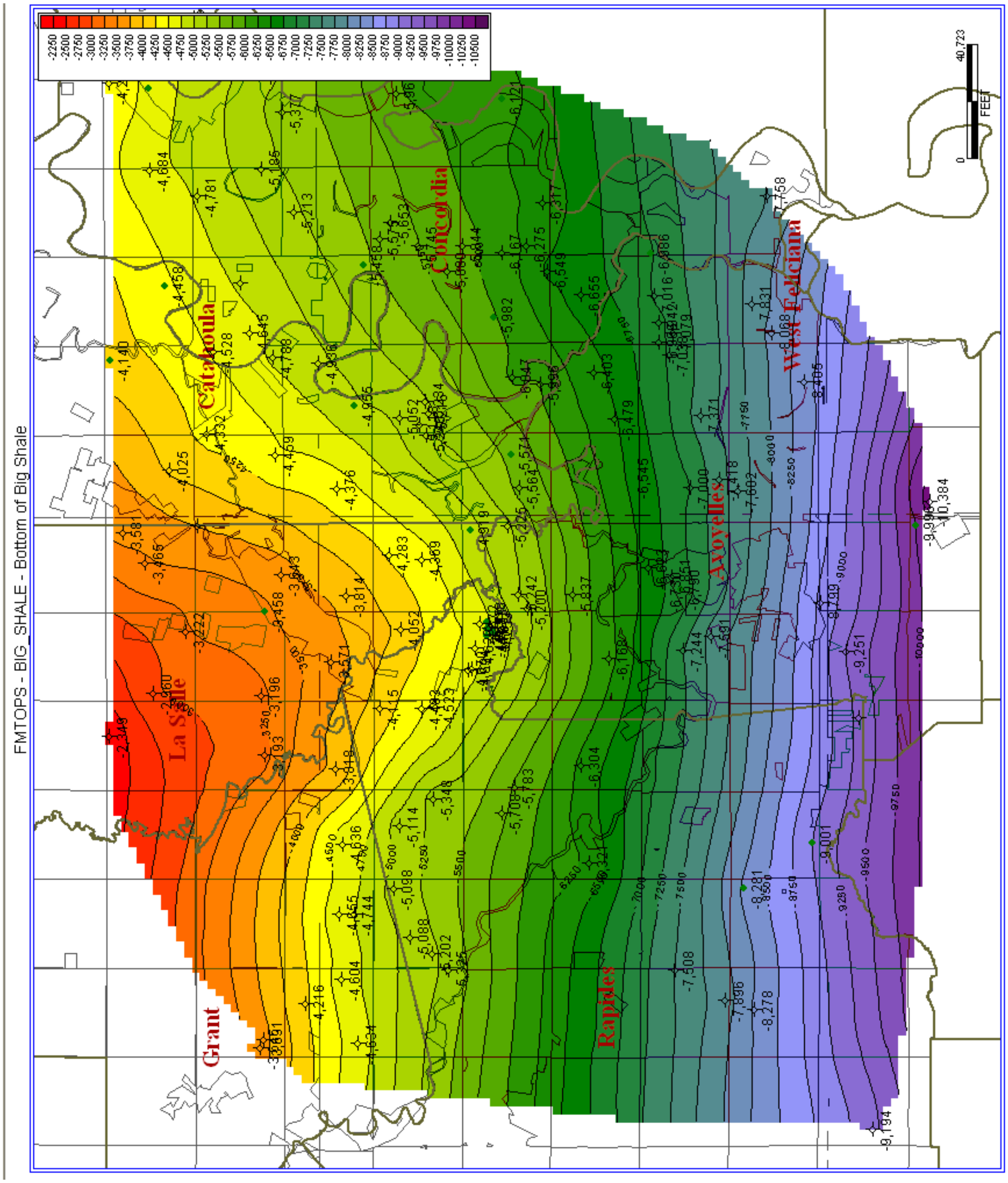

Figure 29. Bottom of Big Shale structure map.

Top of Wilcox (Carrizo Sand) Structure

The uppermost and final horizon of this study is the Top of the Carrizo Sand (Fig. 30). The Top of the Carrizo Sand is the upper boundary of Interval BBS-TopW. The Top of the Carrizo Sand is also the upper boundary of the Upper Wilcox Group. The shallowest penetration of the Carrizo Sand is by the Placid Oil #2 at a depth of -1,835'. The Carrizo sand exhibits 6,666' of structural relief from the northernmost well the Placid #2 to the southernmost well the Moncrief Ducote #1 in North Bayou Jack Field. Approximately 130 wells penetrate the Carrizo Sand in this study. Additionally this horizon is an excellent correlation point throughout all of the wells in the study. The Carrizo sand can be characterized by a coarsening upward sequence followed by the thick shale section of the Cane River Shale before encountering younger sandstone packages. This horizon can be easily and accurately correlated in cross-sections for over 50 miles, proving its excellent correlatibility (Fig. 35).

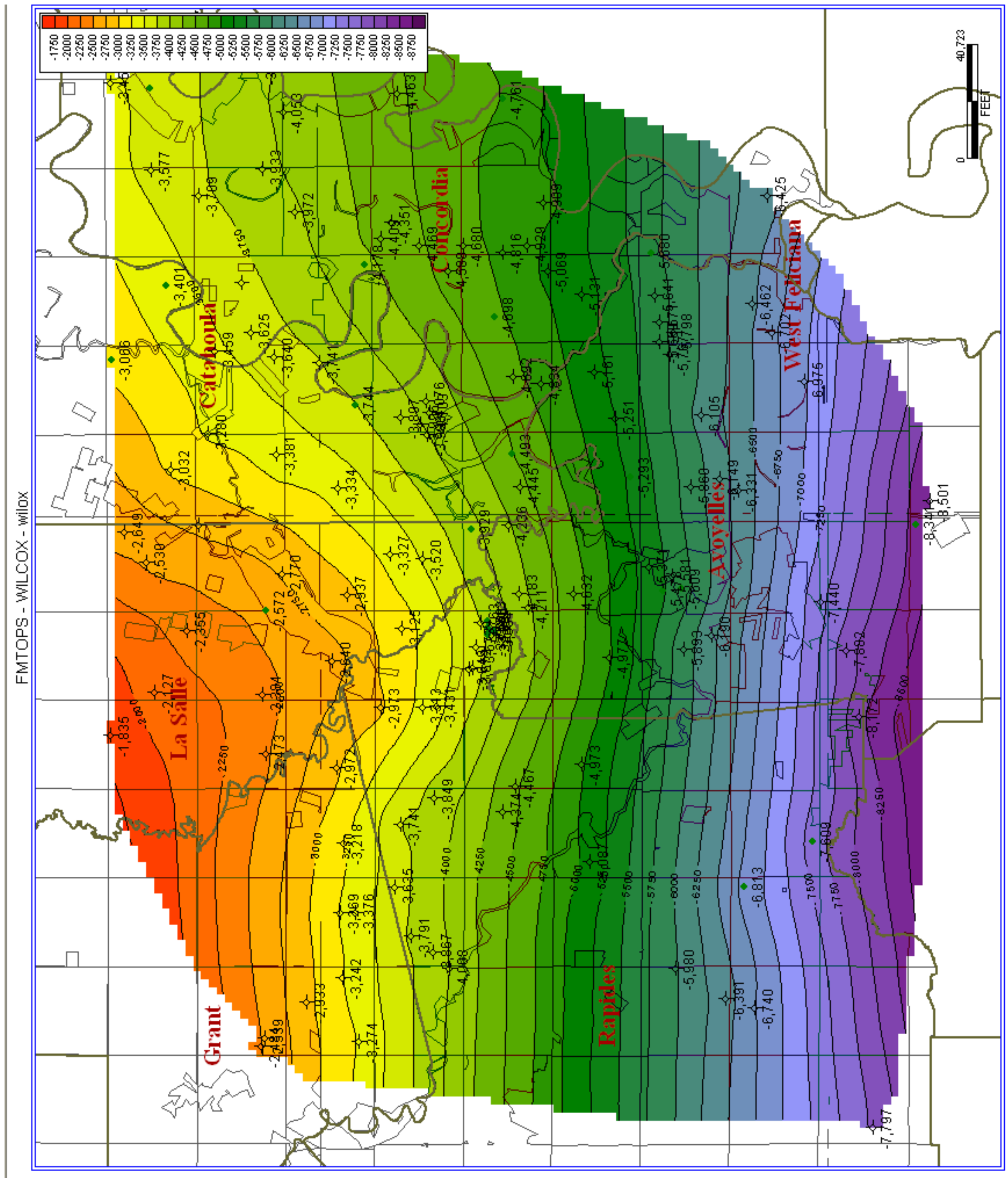

Figure 30. Top of Carrizo Sand structure map.

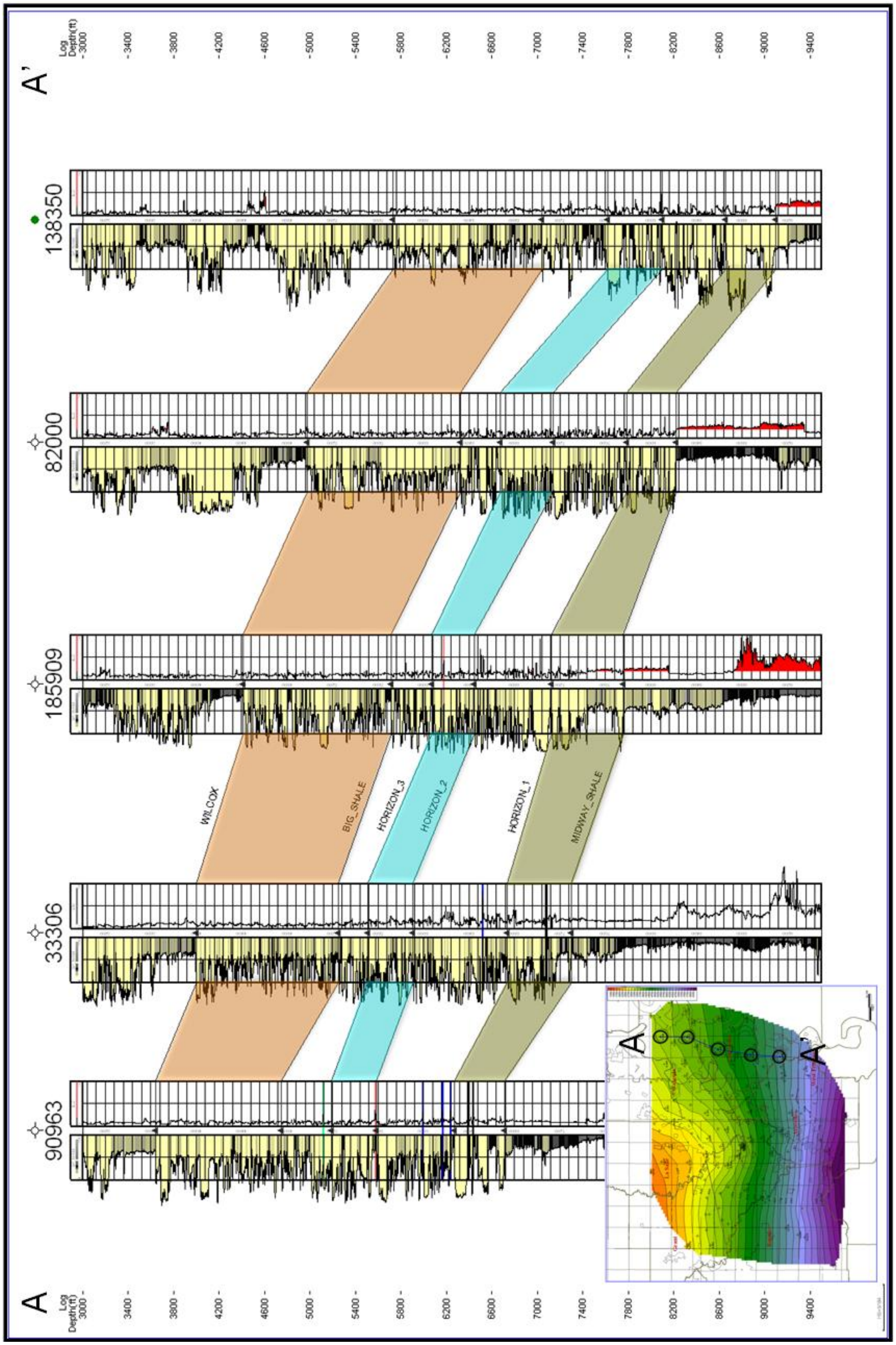

Figure 31. North-South line A-A’ through eastern portion of study area.

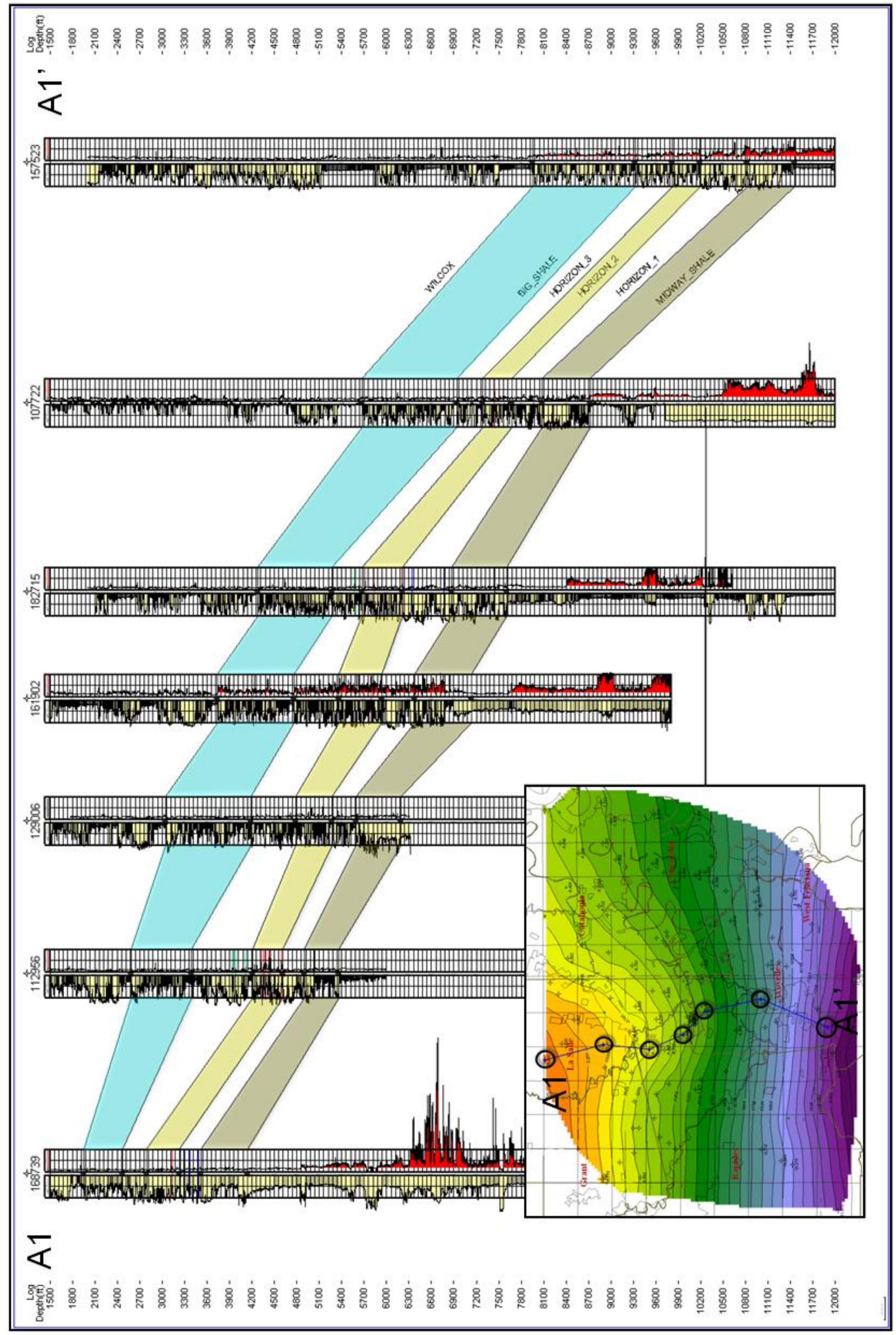

Figure 32. Cross section A1-A1'.

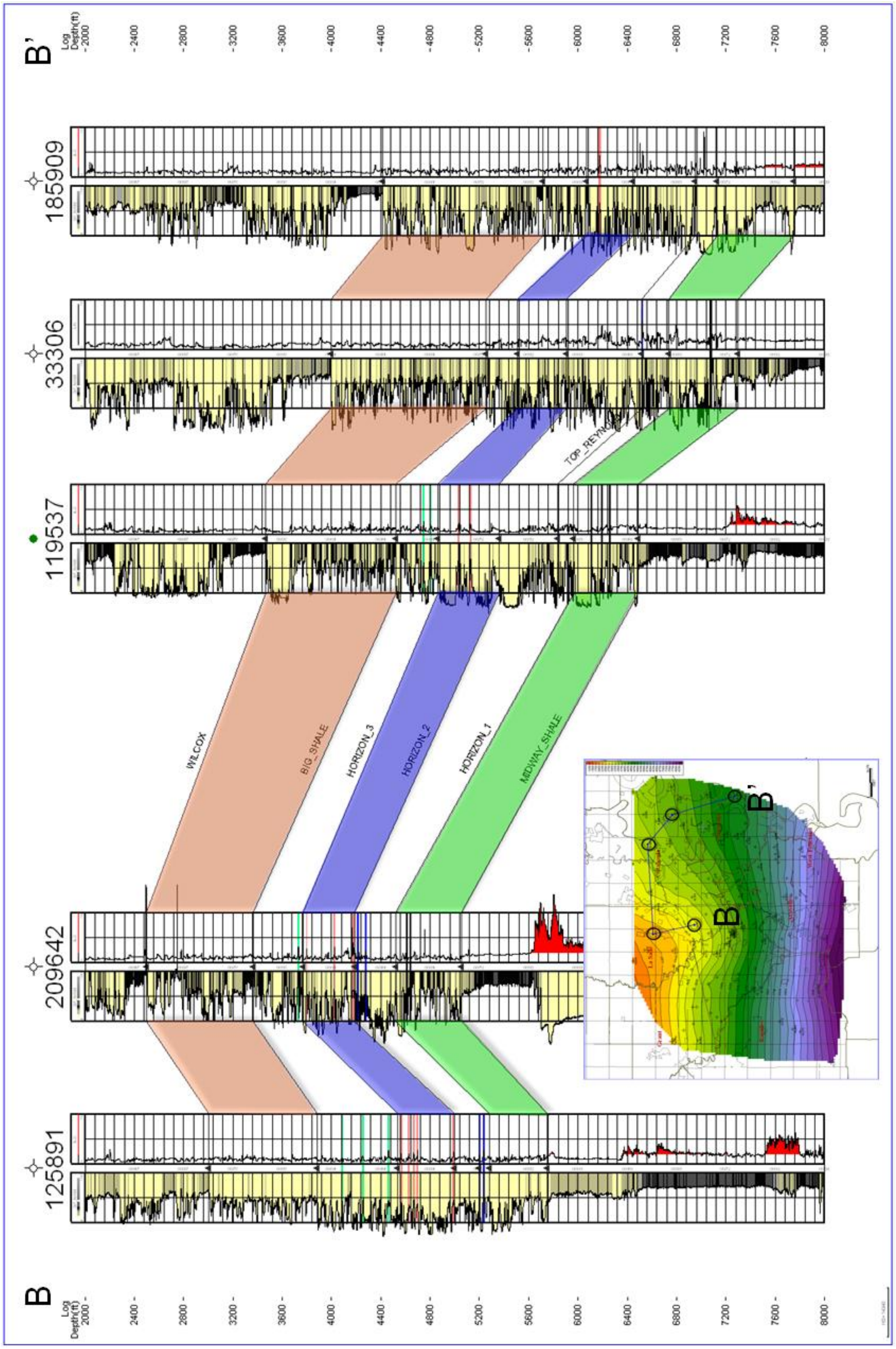

Figure 33. Cross section B-B' through study area.

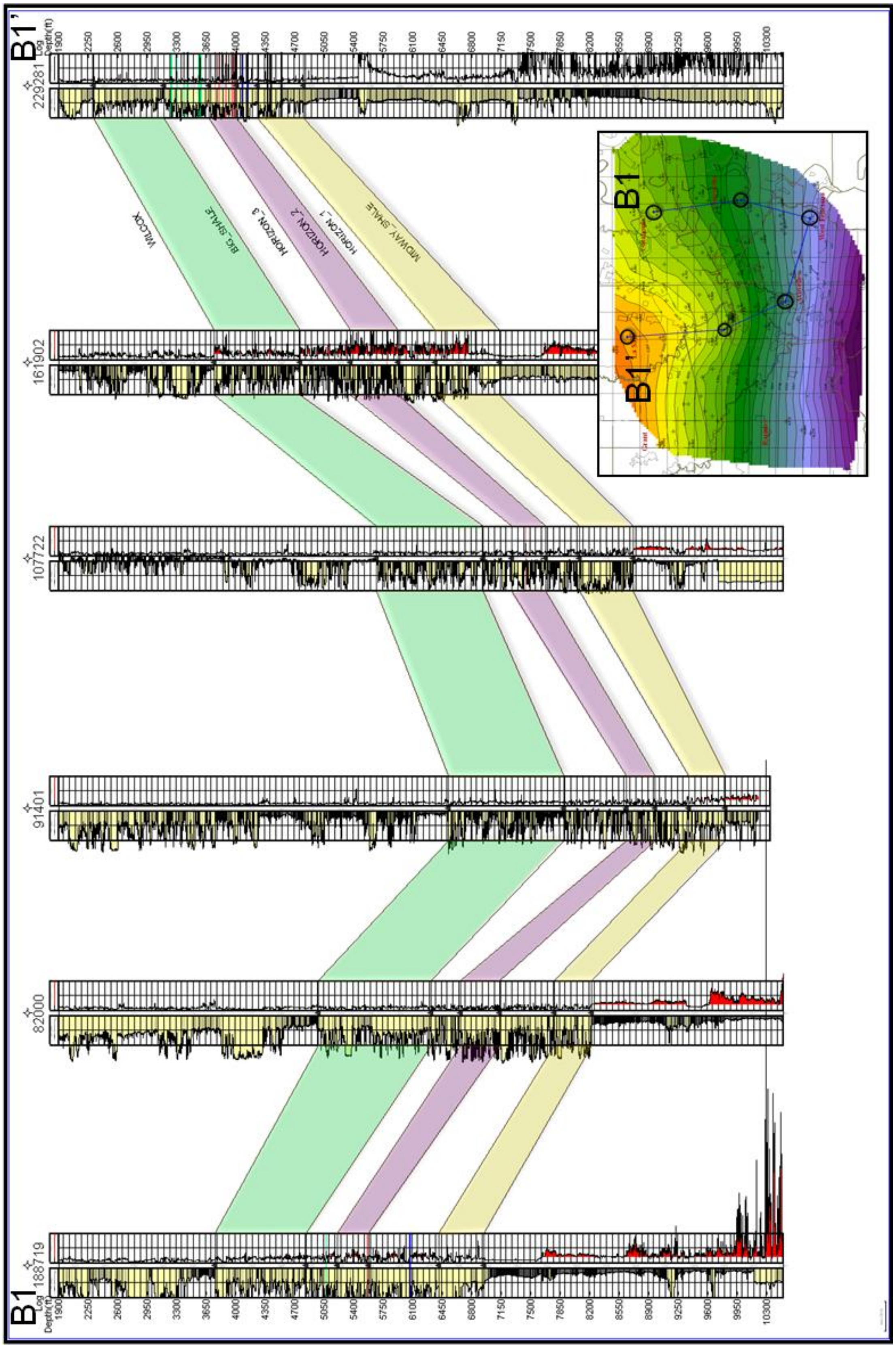

Figure 34. Cross section B1-B1'.

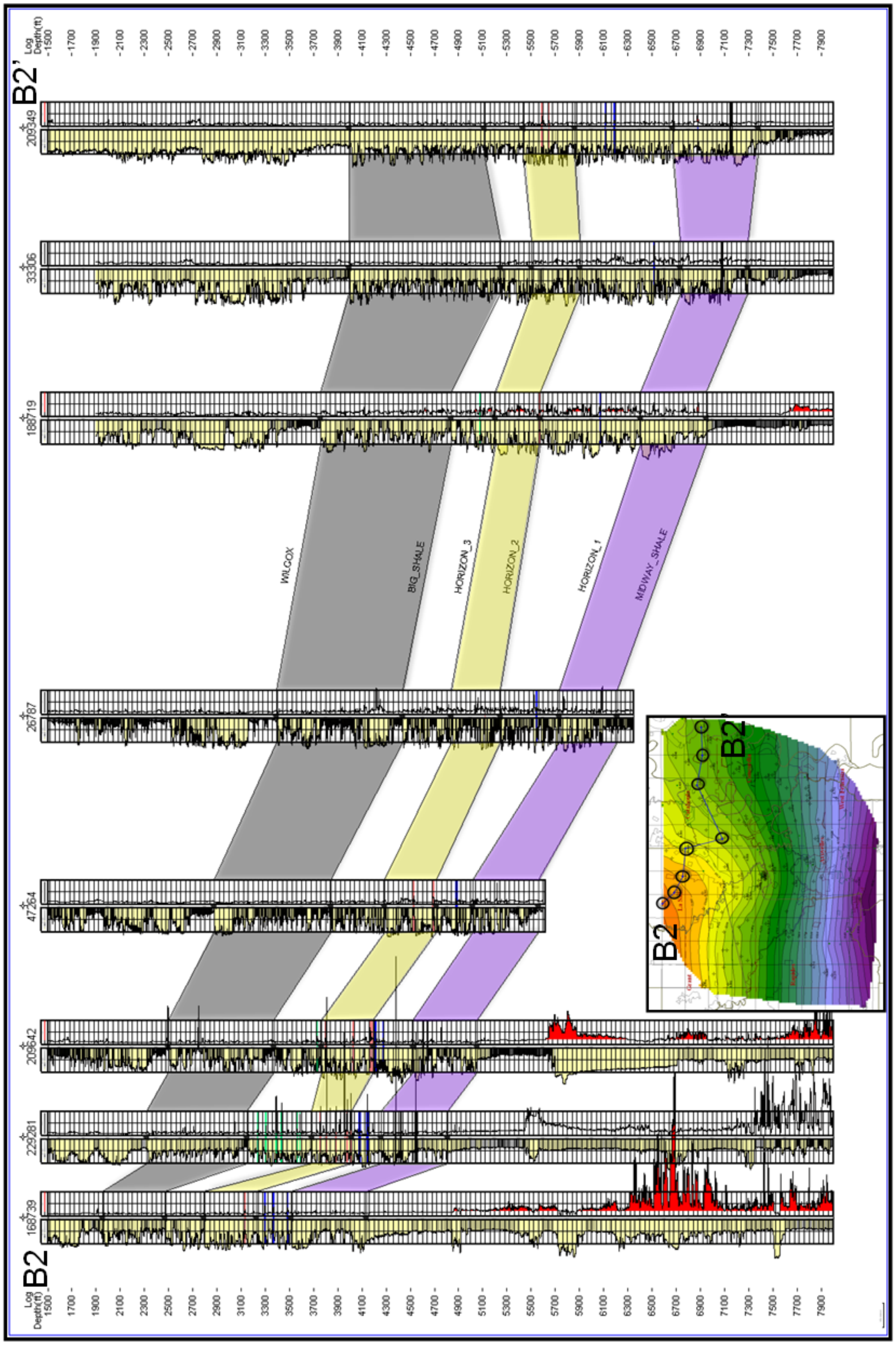

Figure 35. Cross section B2-B2'.

Interval TopMS-H1

Interval TopMS-H1 is bound at its base by the top of the Midway Shale and at its top by Horizon 1. This interval represents the lowest interval of the lower Wilcox Group. Interval TopMS-H1 can be recognized on well logs as consisting of coarsening upwards packages indicative of a progradational delta system. Approximately 70 wells in the study area penetrate this interval. The wells that penetrate this interval were used to create interval isochore, net sand thickness, net sand thickness to gross interval ratio, and net coal thickness maps.

The interval isochore map shows the gross thickness of the Interval TopMS-H1 (Fig. 36). The Tensas Delta Land Company #1 in LaSalle Parish has only 294’ of gross interval thickness. This well is located at the north boundary of the study just east of the LaSalle Arch. This interval greatly thickens toward the south and east, the John T. Palmer #1 has 751’ of gross interval thickness toward the south-central portion of the study. Interval thickness greatly increases to the southwest where many wells have in excess of 500’ of gross section. The western side of the study is poorly defined at this interval by the low number of well penetrations.

The net sand map shows the amount of sand that each well contains in Interval TopMS-H1 (Fig. 37). The lowest net sand area is in the most northern portion of the study in parts of LaSalle and Catahoula Parishes. This low net sand area spans about 10 Townships with sand values less than 250’. South of the thin area the sand footages increase; some wells have net sand thicknesses in excess of 500’. The orientation of the higher net sand thickness pattern suggests a meandering delta system. The delta system stretches from Catahoula and Concordia Parishes all the way to Avoyelles Parish. The north-central portion of the delta complex is roughly 10 miles wide and increases to over 25 miles in the southern limits of the study. The delta system is adjacent to the north and west to areas of low net sand which helps define the higher net sand delta system.

The net to gross interval ratio map is similar to the net sand map (Fig. 38). The lowest net to gross ratio values are around 0.37 with values as high as 0.94. The thickest accumulations on the gross interval isochore map are present in the central and southwestern portions of the study area. These thicknesses conform to the net sand map with high sand content, likely deposited by a delta. The delta complex seen in the net sand map isn't as clearly visible in the net to gross ratio map. Noticeable features of the delta are subtle.

The net coal map for this interval shows a high concentration of coals toward the north portion of the study area (Fig. 39). 7N-3E, 8N-3E, and 8N-4E contain the thickest coal deposits. Nine wells in parts of LaSalle and Catahoula Parishes have over 10' of net coal in this interval. The IPB LLS #125 in section 12-8N-4E in LaSalle Parish has a total of 27' of net coal which is the highest coal footage documented in this interval. A total of 28 wells in Interval TopMS-H1 have occurrences of coal out of 70 wells that penetrate the Midway Shale. All wells south of Township 3N have 0' of coal. This interval should have significant coal development north of the study area due to the location of the shoreline and there being good coal deposits at the northern boundaries of the study area.

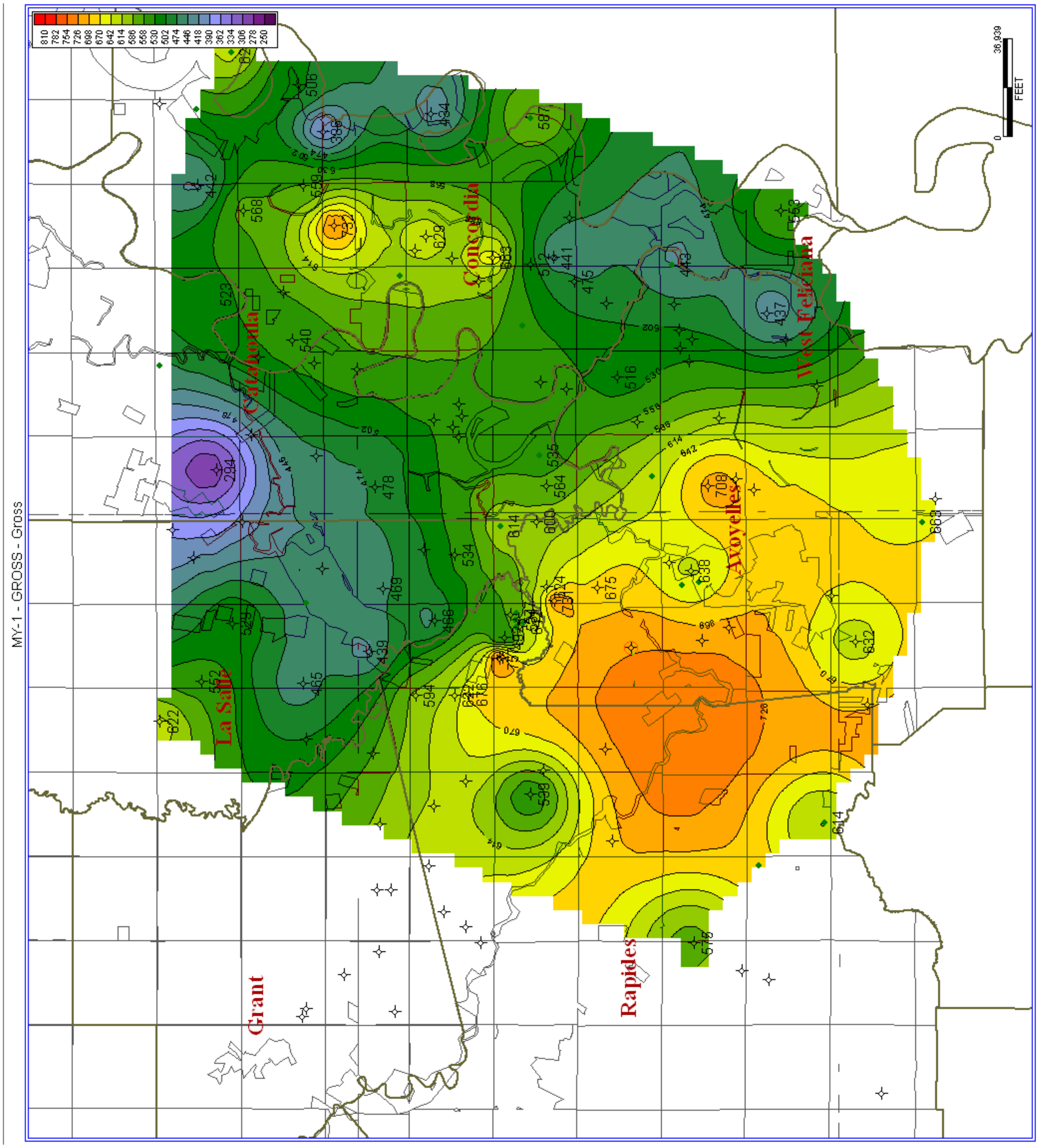

Figure 36. Interval Midway Shale – Horizon 1 gross interval map.

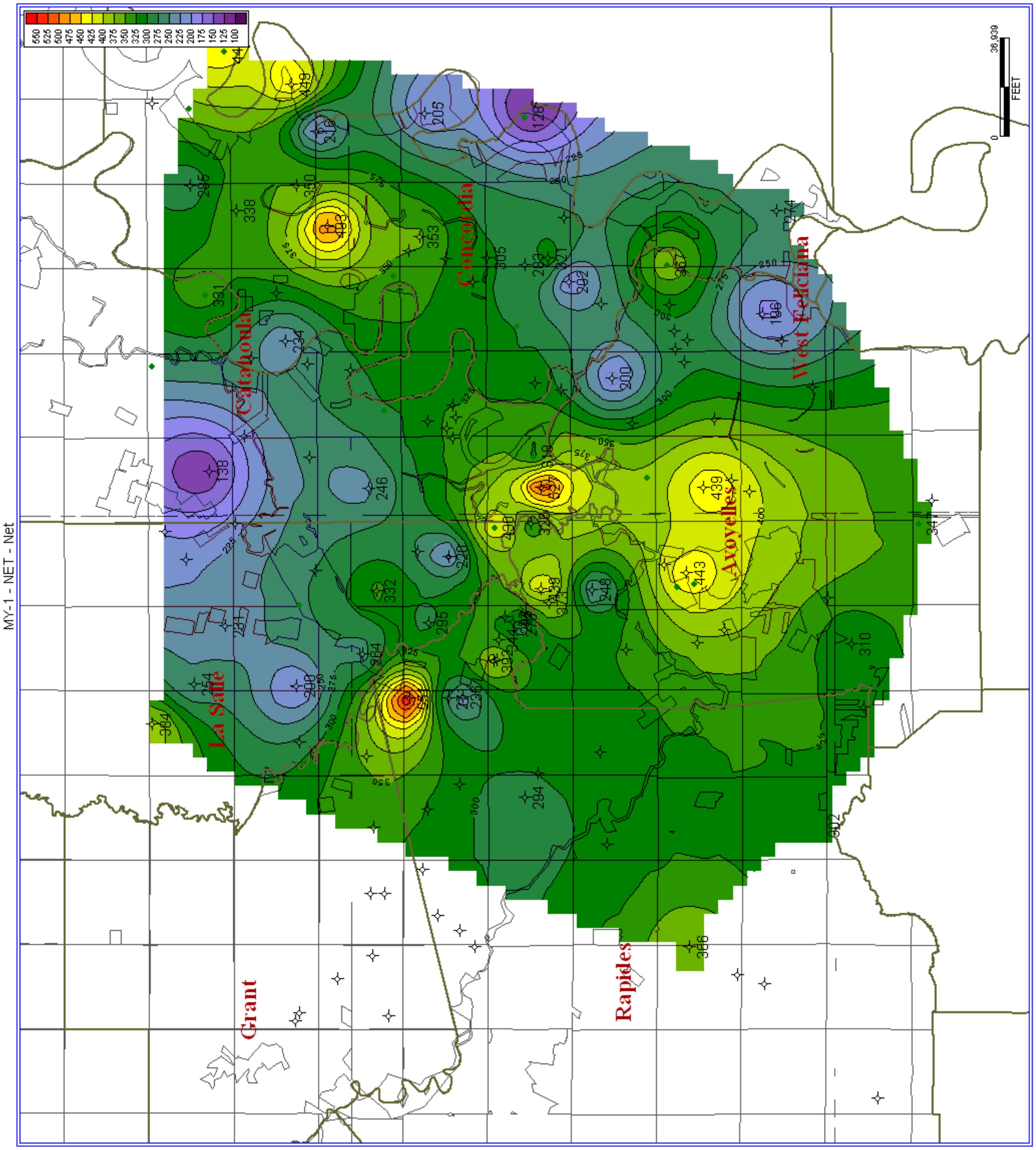

Figure 37. Interval Midway Shale – Horizon 1 net sand map.

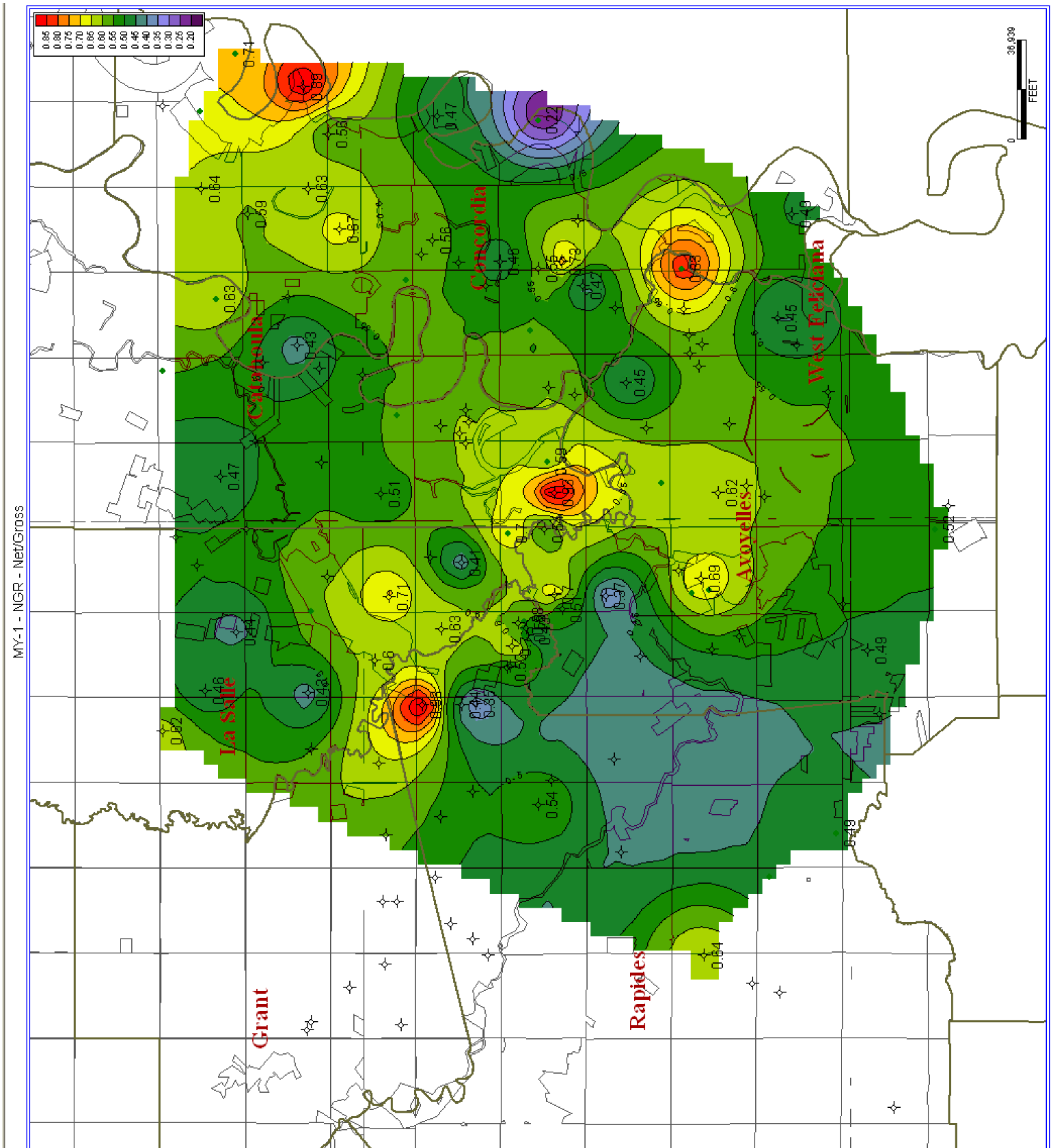

Figure 38. Interval Midway Shale – Horizon 1 net sand to gross interval ratio map.

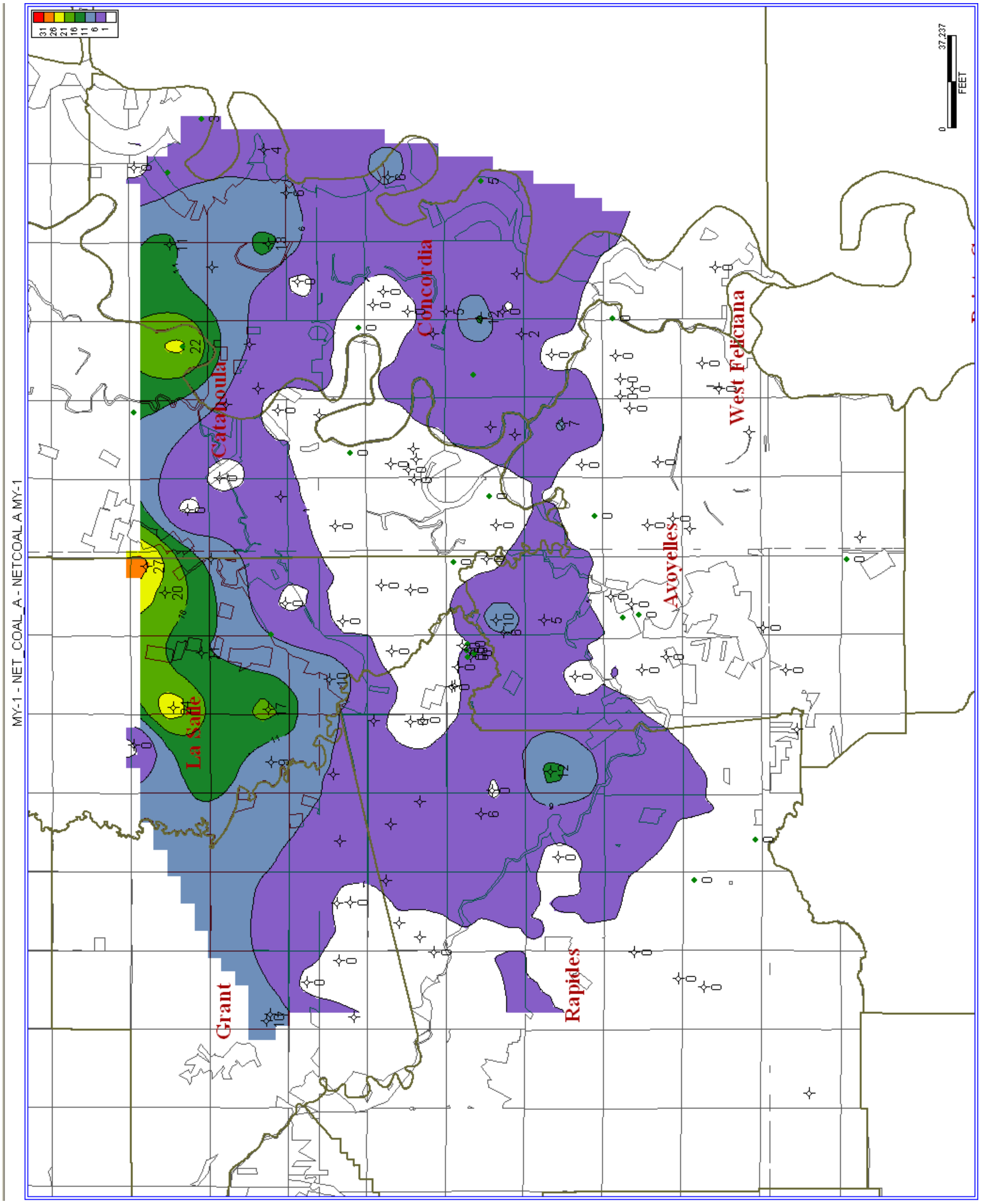

Figure 39. Interval Midway Shale – Horizon 1 net coal isochore map.

Interval H1-H2

Interval H1-H2 is bound at its base by Horizon 1 and at its top by Horizon 2. This interval represents the second deepest interval of the lower Wilcox Group. Interval H1-H2 can also be recognized on well logs as a coarsening upwards package with intermittent shale breaks, indicative of a progradational and aggradational delta system. Out of 130 wells that were selected for this study, 88 wells penetrate this interval.

Interval H1-H2 is very similar to the Interval TopMS-H1 where there is a thin interval toward the north (Fig. 40). However, at Interval H1-H2 the thin gross interval section is located further to the west, directly overlying the LaSalle Arch. Some wells like the Mary Pipes #1 in Trout Creek Field have as little as 246' of gross interval in this thin area. The interval gradually thickens to the east to over 1000' in the California Time & R.C. Bertolet #1 in section 26-6N-9E of Concordia Parish. Wells with greater than 600' of gross interval are present in the southwest of the study area and majority of the eastern portion of the study area. They are connected by a thicker swath of wells that abut to the north and south wells with 400' of gross section.

The net sand map is very similar to the gross interval map at Interval H1-H2 (Fig. 41). Many of the same features carry over, such as the thin area on top of the LaSalle Arch and the gradual thickening to the east. The Atlantic Logan & Mckeever #1 in Rapides Parish has only 91' of sand with wells around it averaging 200'. Due east the sand thickness greatly increases to 768' in the Fife Oil & Gas #1 in section 20-7N-10E of Concordia Parish. Many of the wells on the eastern portion of the study area are relatively thick. The Mississippi Embayment is likely the reason for the greater thicknesses in this part of the study area.

The net to gross ratio map shows the same high value section in the eastern portion of the study area as did the net sand and gross interval maps (Fig. 42). The net to gross ratio map also depicts a high value trend of over 0.6 oriented north to south in the center of the study and extending 40 miles. Net to gross ratio values are as low as 0.3, with values as high as 0.95 present. As mentioned before, many wells didn't reach this interval so well control isn't as good as compared with shallower intervals.

The net coal map of Interval H1-H2 contains many more occurrences of coal than the deeper Interval TopMS-H1(Fig. 43). Similar to the deeper interval, the coals are most concentrated in the northern portion of the study area in LaSalle and Catahoula Parishes. The Interval H1-H2 contains the Reynolds coal. The Reynolds coal is the thickest most extensive regional coal found throughout northern Louisiana. The northern concentration of coals range from around 15' to 28'of net coal. The J Balfour Miller et al. #1 in section 1-8N-9E of Concordia Parish has the highest accumulation of net coal in this interval with 28' of coal. Three separate trends emerge when looking at the orientation of coal footages at this interval. In LaSalle Parish multiple wells have 15' to 25' of coal, the net footages decrease to the south, and increase to 16' of net coal in 4N-1E. Similarly this same situation occurs south of thick net coal wells in Catahoula Parish and south of thick net coal wells in Concordia Parish. There seems to be no development of coal south of Township 2N.

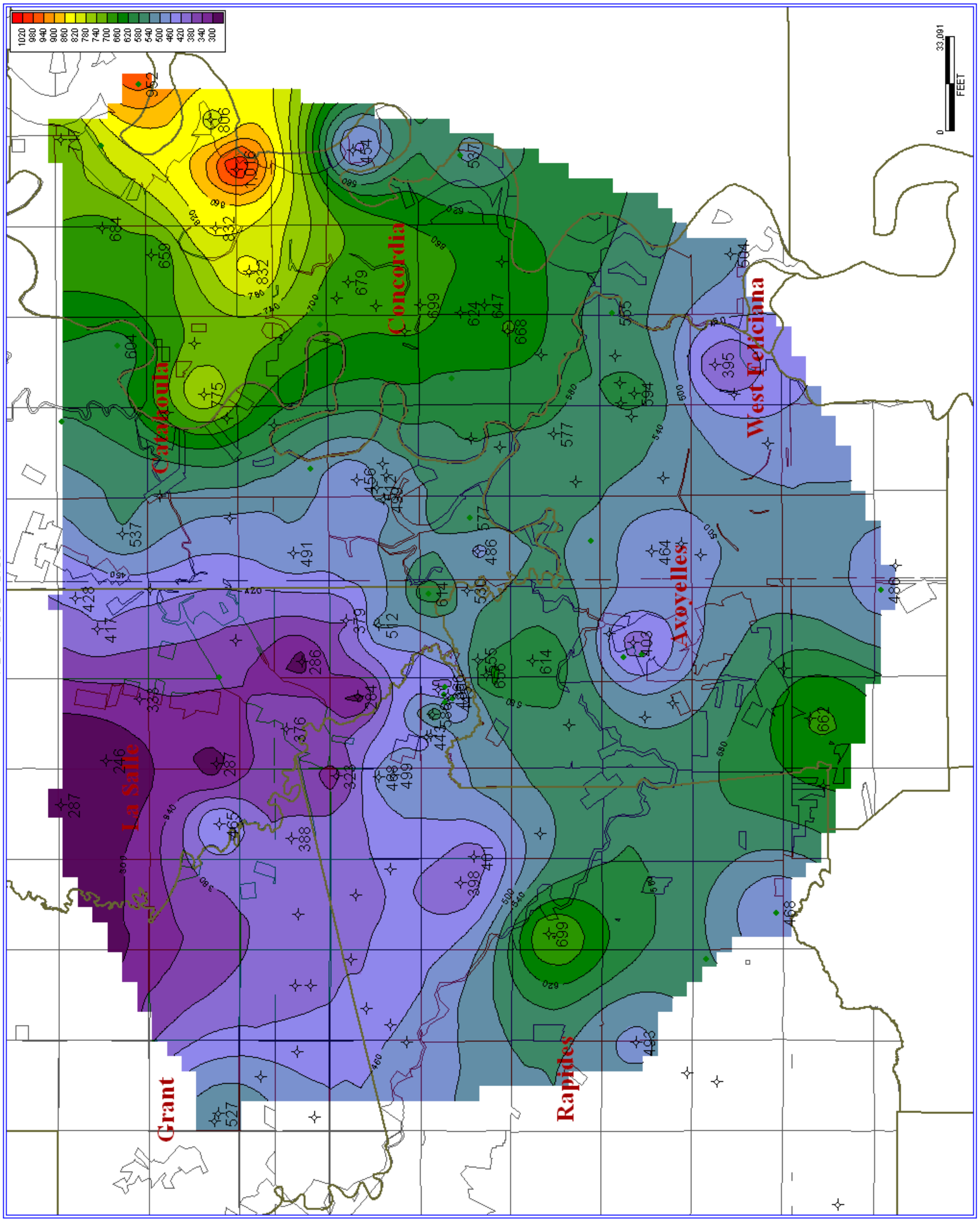

Figure 40. Interval Horizon 1 – Horizon 2 gross interval map.

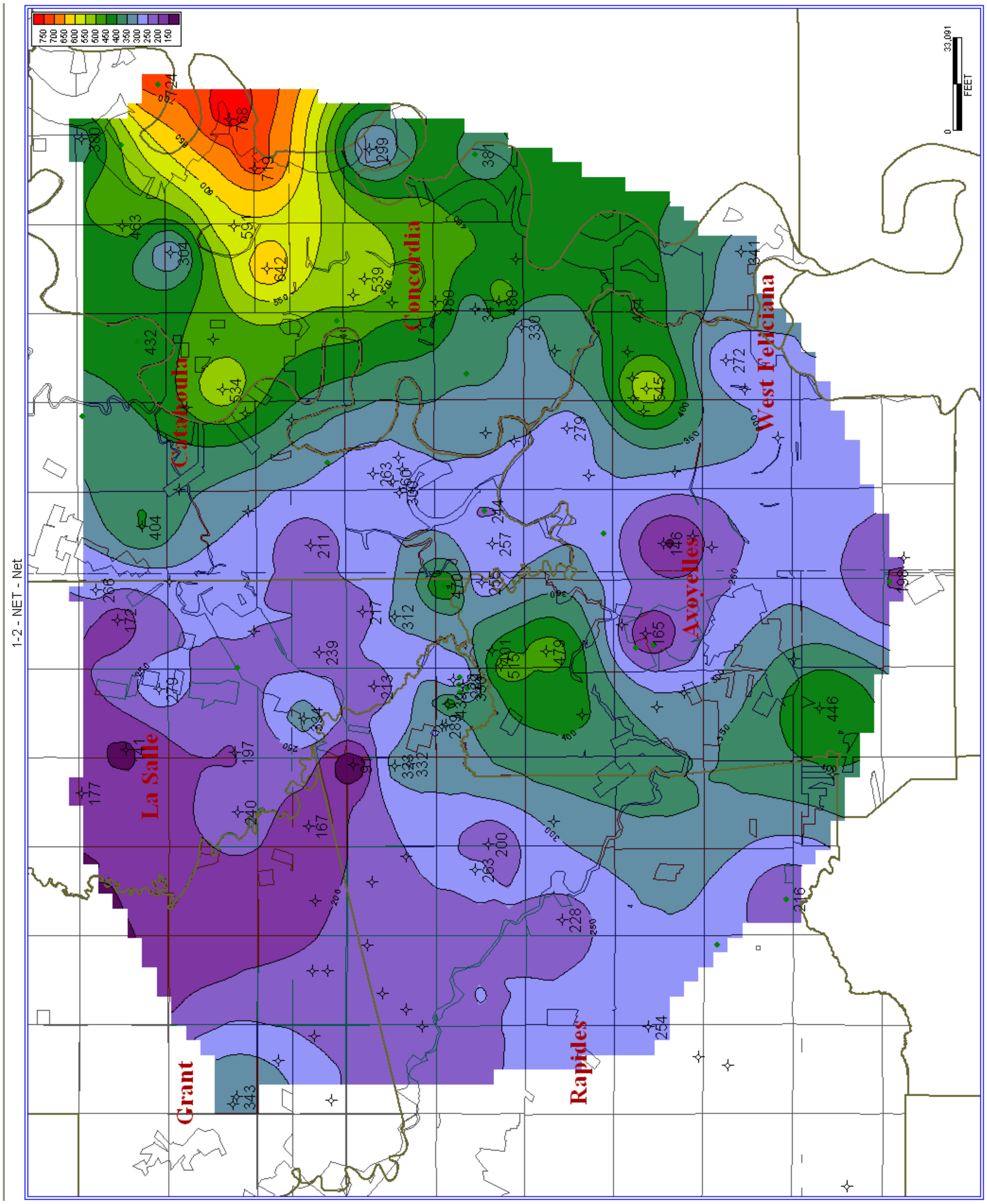

Figure 41. Interval Horizon 1 – Horizon 2 net sand map.

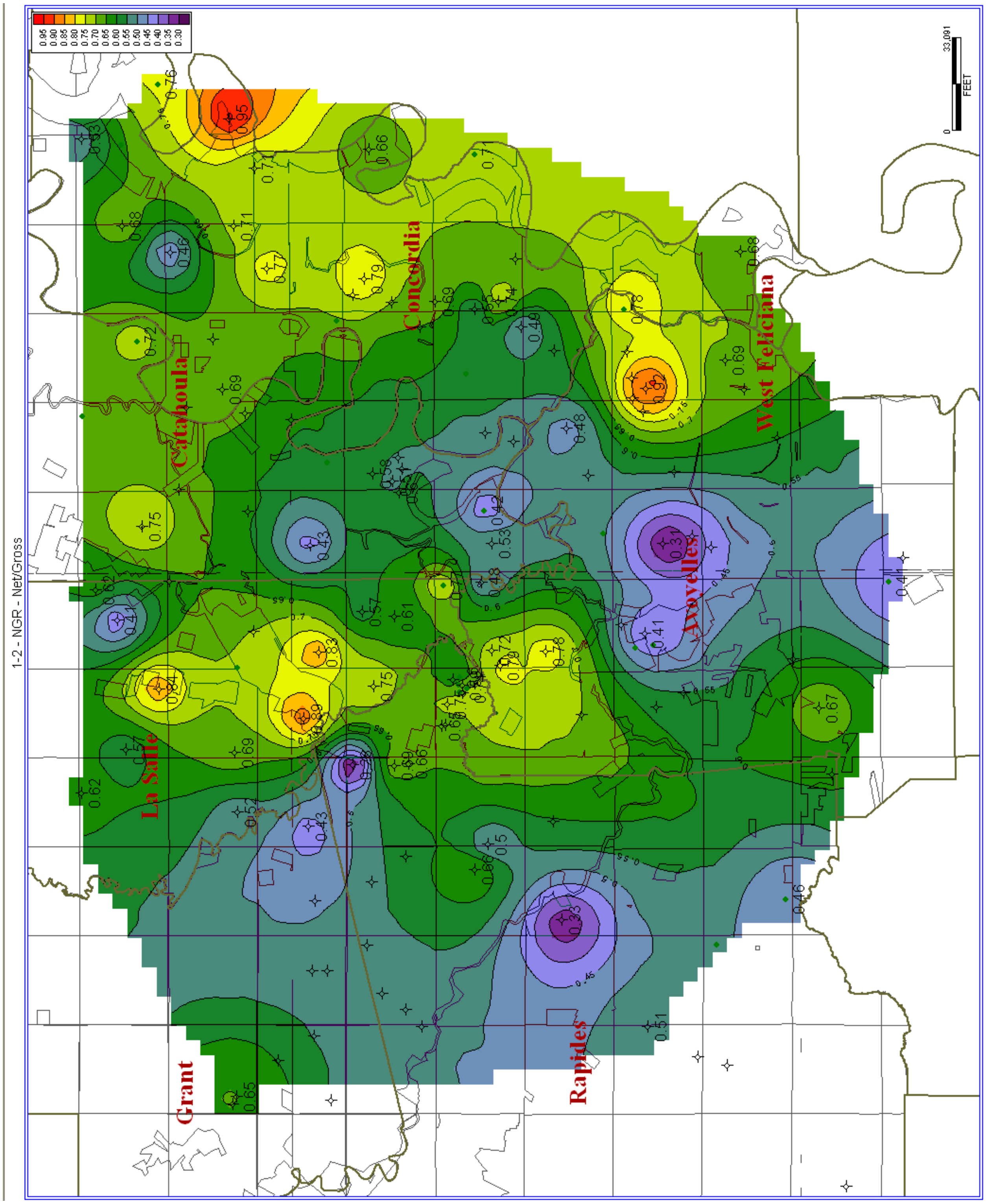

Figure 42. Interval Horizon 1 – Horizon 2 net sand to gross interval map.

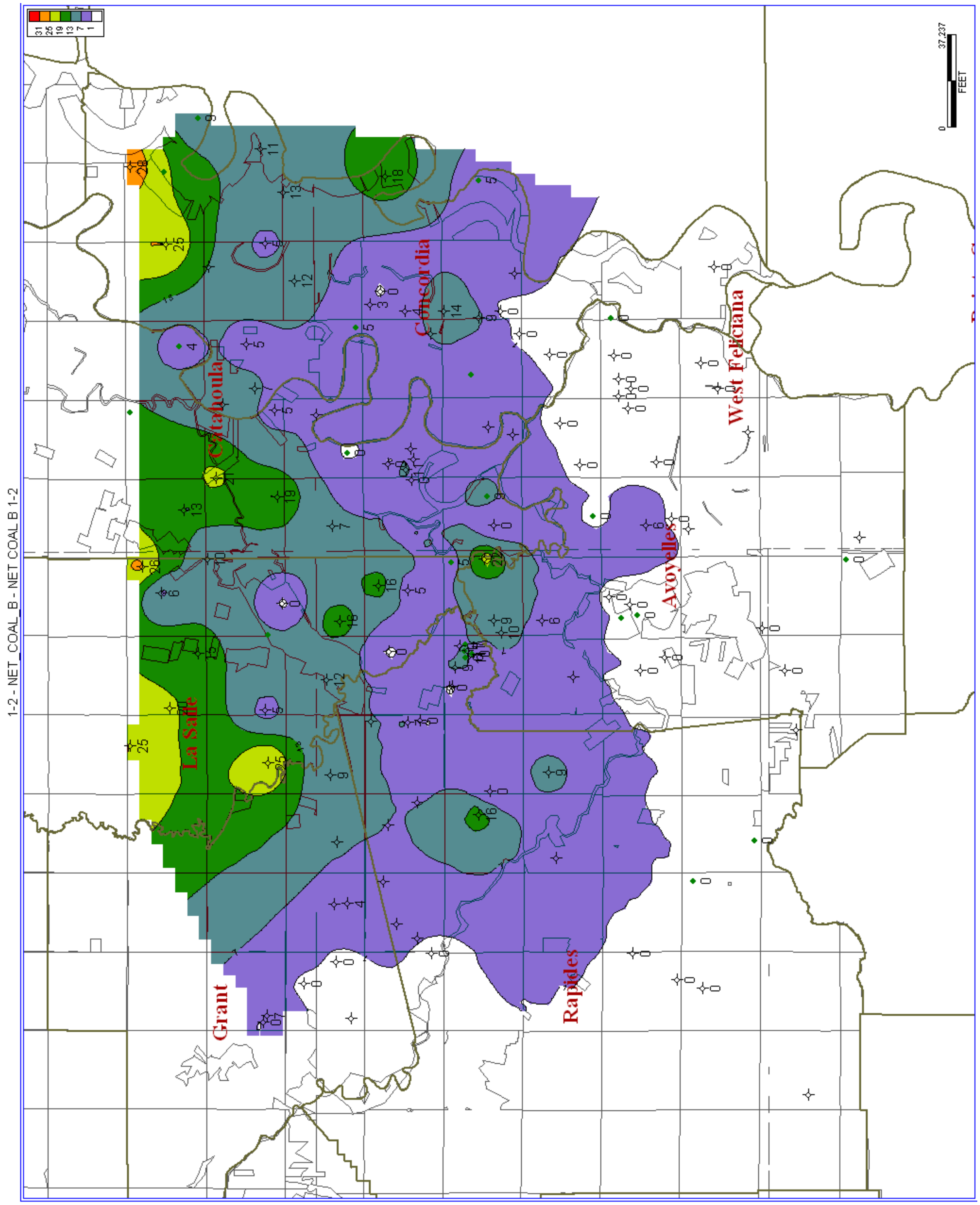

Figure 43. Interval Horizon 1 – Horizon 2 net coal isochore map.

Interval H2-H3

Interval H2-H3 is bound at its base by Horizon 2 and at its top by Horizon 3. This interval represents the second shallowest interval of the lower Wilcox Group. Interval H2-H3 can be recognized on well logs as a coarsening upwards set of parasequences and an upward-fining set of parasequences. This part of the lower Wilcox section contains lowstand, highstand, and transgressive systems tracts (Tye et al., 1991). This Interval is dated as between 58.5 Ma and 56.5 Ma. Out of 130 well logs selected for this study, 106 wells penetrate the Interval H2-H3.

The gross interval map shows a generalized thick area in the center of the study area with a maximum gross interval thickness of 746' from the Hassie Hunt Trust #2 in section 22-5N-4E of LaSalle Parish (Fig. 44). Wells to the north and south of the thick section are thin with values as low as 205' of gross interval thickness. On the eastern flanks of the study area many of the wells are thick with many wells having in excess of 400' of gross interval.

The net sand map is similar to the gross interval map (Fig. 45). A localized thick area is present in the north/central portion of the study area with wells having in excess of 450' of net sand localized in the southern portion of LaSalle Parish. To the east most wells have over 250' of net sand that increases to 599' of sand in the Fife Oil & Gas #1 well in Concordia Parish. To the south and west of these thick net sand accumulations sand values decrease substantially. Many wells spanning 60 miles have less than 200' of net sand in Rapides and Avoyelles Parishes

Like previously mapped intervals, the same features in the net sand map carry over to the net to gross ratio map (Fig. 46). There is a high value area in the north/central region of the study area and the entire eastern portion of the study area has high net to gross ratio values. Many wells have net to gross ratio values as high as 0.9 while lower values are around 0.2. The entire study area with the exception of the southwest has high net to gross ratio values. The high net to gross values are likely due to proximal, delta-front deposits, consisting of a wave dominated shoreface (Bhattacharya et al., 1991).

The net coal map of Interval H2-H3 shows thickest values in the north western portion of the study area (Fig. 47). The Robert Jenkins #1 in section 29-5N-2E of Rapides Parish contains 59'of net coal which is the highest coal footage documented in one interval within the lower Wilcox within this study area. Many wells surrounding the Robert Jenkins #1 have in excess of 20' of net coal. The Russell coal is a laterally extensive coal within this interval and has been mapped in detail throughout northern Louisiana in other studies. Coals within this interval tend to be thinner but more prevalent. This is due to dynamic changes in active and inactive depositional environments. There are also a few significant coal occurrences on the eastern limits of the study area. The R.B. Sharp #1 in Concordia Parish has 19' of coal with several wells around it averaging 10' of coal per well. Between these two consistent coal accumulations are some sporadic coal footages ranging from 0' to 17'. South of Township 2N there are no coal occurrences. This area south of Township 2N was likely basinward of the fluvial to paralic environments within which coals of northern Louisiana developed.

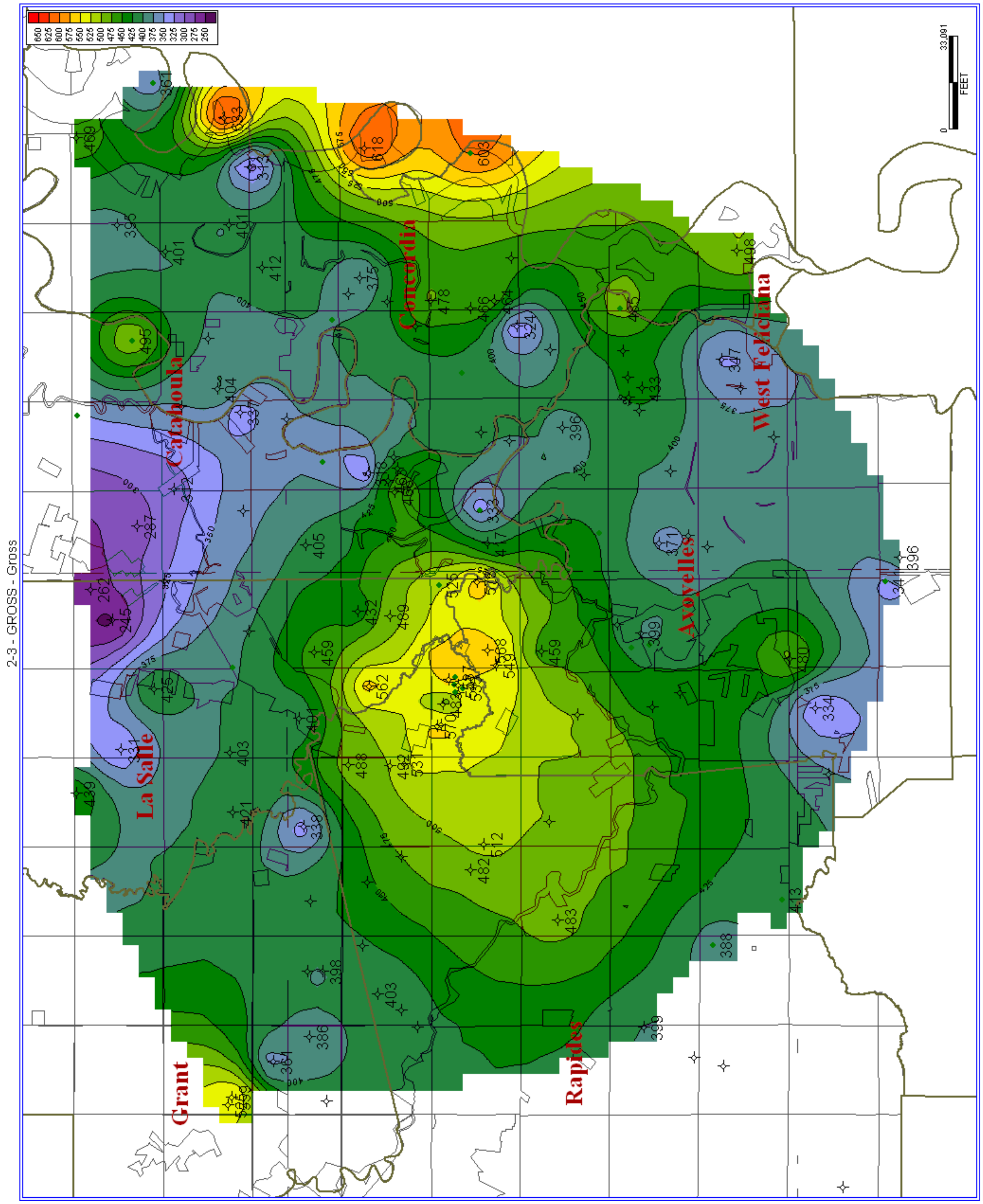

Figure 44. Interval Horizon 2 – Horizon 3 gross interval map.

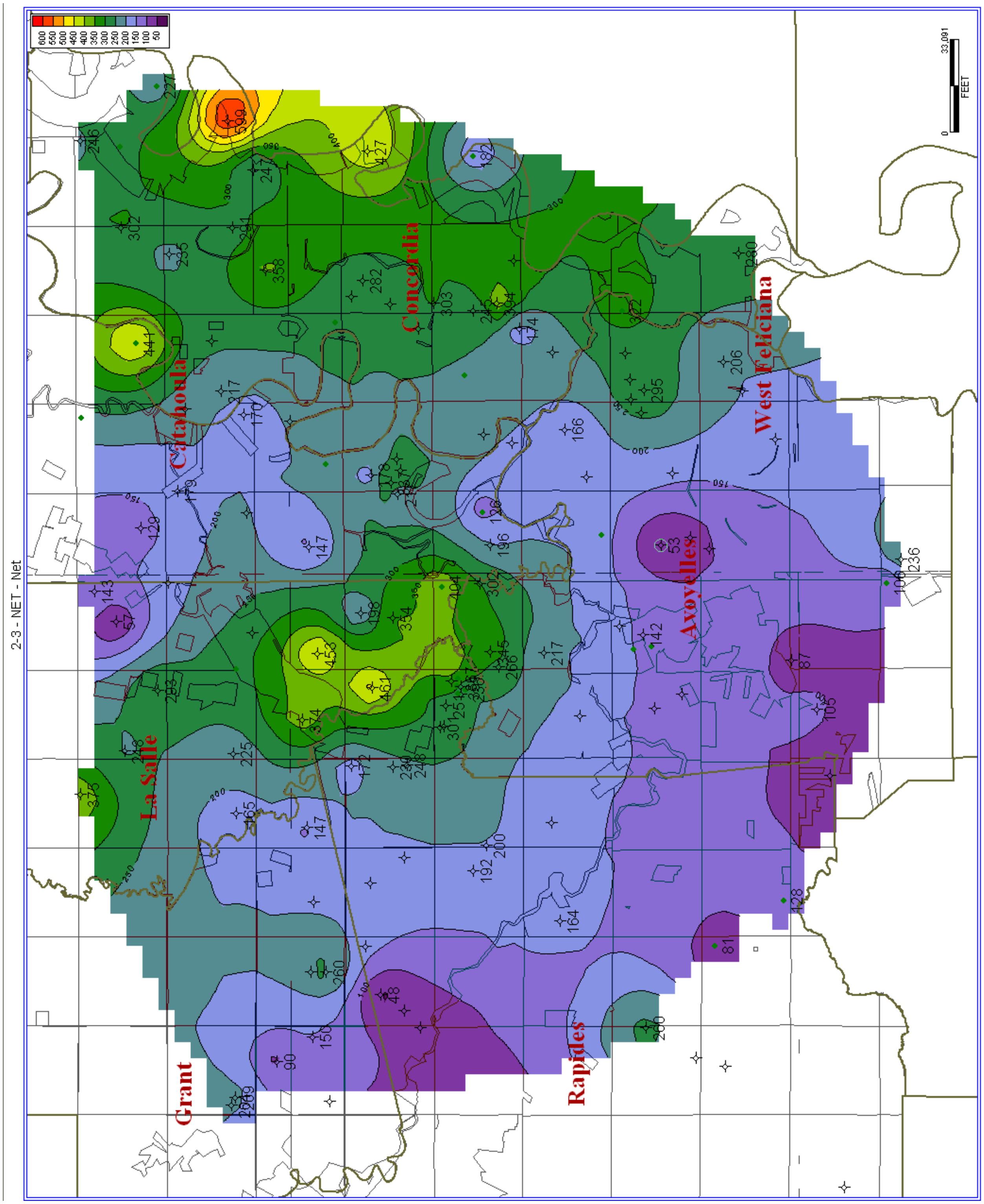

Figure 45. Interval Horizon 2 – Horizon 3 net sand map.

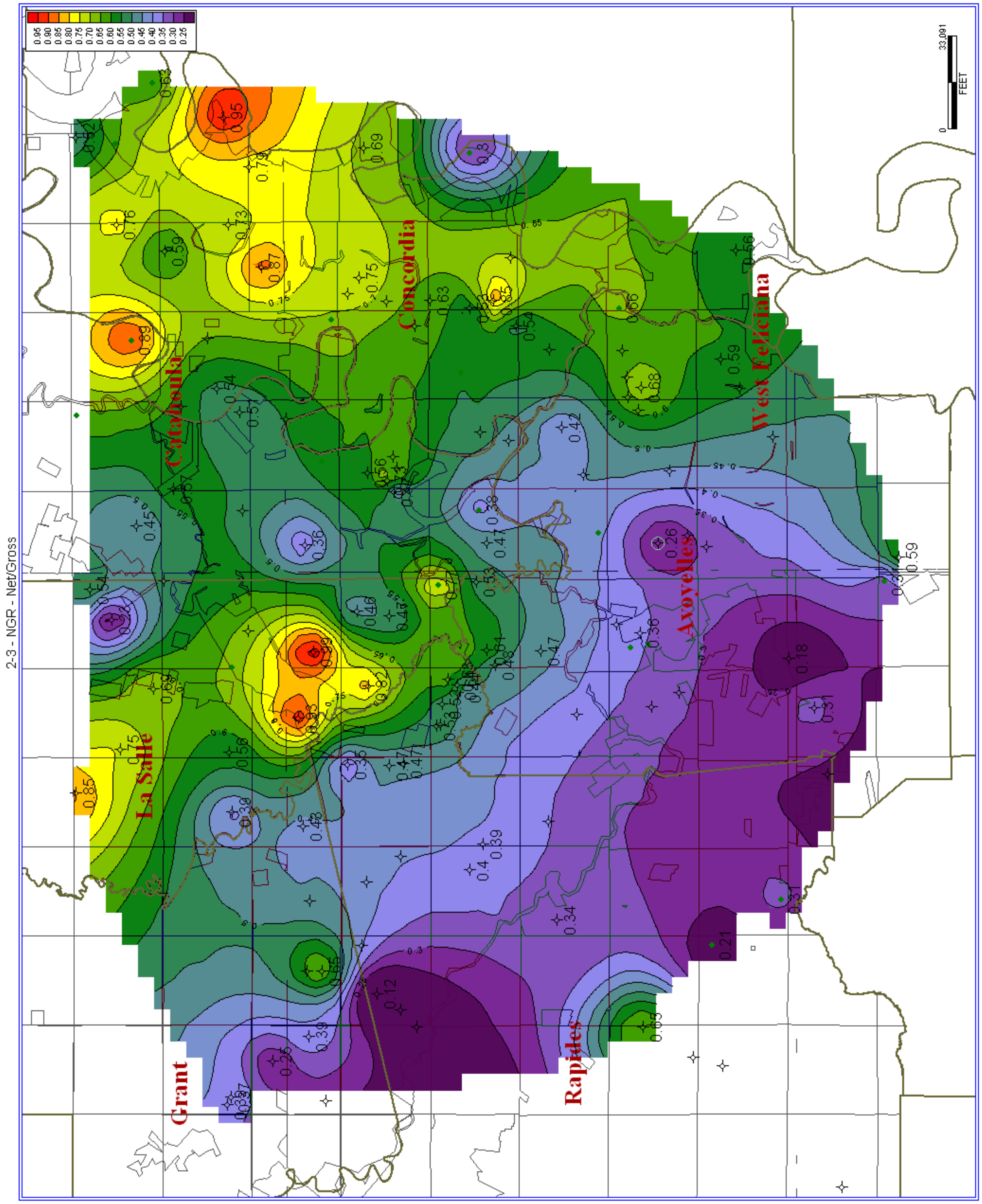

Figure 46. Interval Horizon 2 – Horizon 3 net sand to gross interval ratio map.

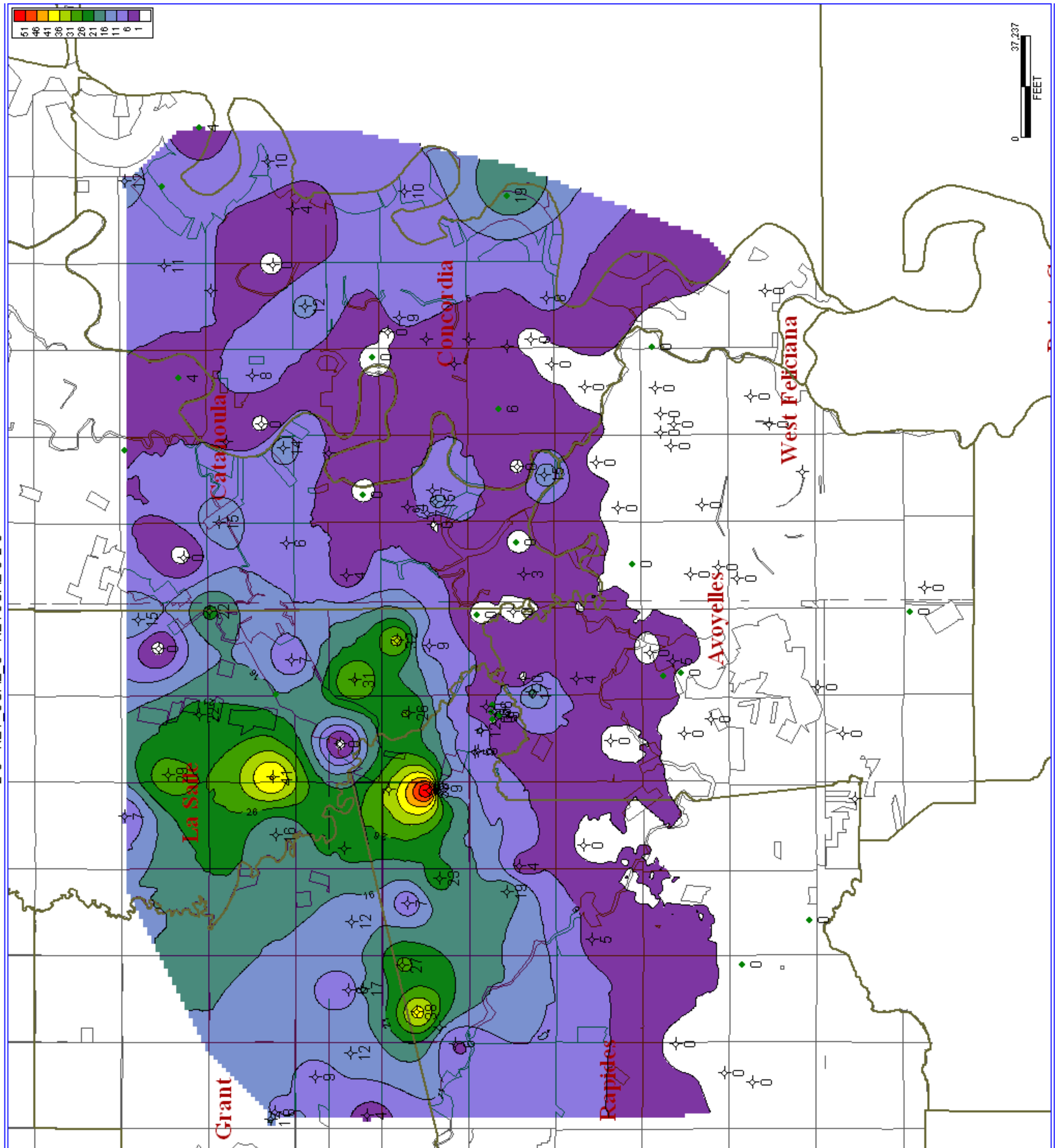

Figure 47. Interval Horizon 2 – Horizon 3 net coal isochore map.

Interval H3-BBS

Interval H3-BBS is bound at its base by Horizon 3 and at its top by the Bottom of the Big Shale. This interval represents the highest interval of the lower Wilcox Group. Unlike the previous two intervals, Interval H3-BBS can be recognized on well logs as continuously coarse packages, indicative of an aggradational system. Out of 130 well logs that were assembled for this study area, 126 wells penetrate this interval.

The gross interval map shows a thin area to the northeast with wells gradually increasing in thickness to the west. Some wells have gross thickness values as low as 248' in the T. J. Guido & Serio #B-1 in section 46-4N-8E of Concordia Parish. There are two thick gross interval sections oriented northwest to southeast. The gross interval accumulation to the north is located in LaSalle Parish, the southern high gross thickness accumulation is located in Avoyelles Parish. These thick areas have over 800' of gross section in some wells and span multiple Townships. Separating these two thick accumulations is a much thinner interval of wells that are perpendicular to the northwest to southeast trending thick section. These thinner wells average 400' of section and are drastically different in log character. The well log response of these wells within the thin section is an elevated SP response and, because of the amount of shale, appears to be of marine origin. Interval H3-BBS is normally composed of interstratified sandstone and shale occurrences, but in this area the strata consists of an anomalously thick shale interval. Analogous shales in other areas have mostly been interpreted as submarine canyon fill (Hoyt, 1959). (McCulloh et al., 1986) found evidence of a large shale-filled channel within the lower Wilcox Group in portions of St. Landry and Avoyelles parishes. Figure 48 depicts the position of the St. Landry Canyon identified by (McCulloh et al., 1986) and its presence within the current study.

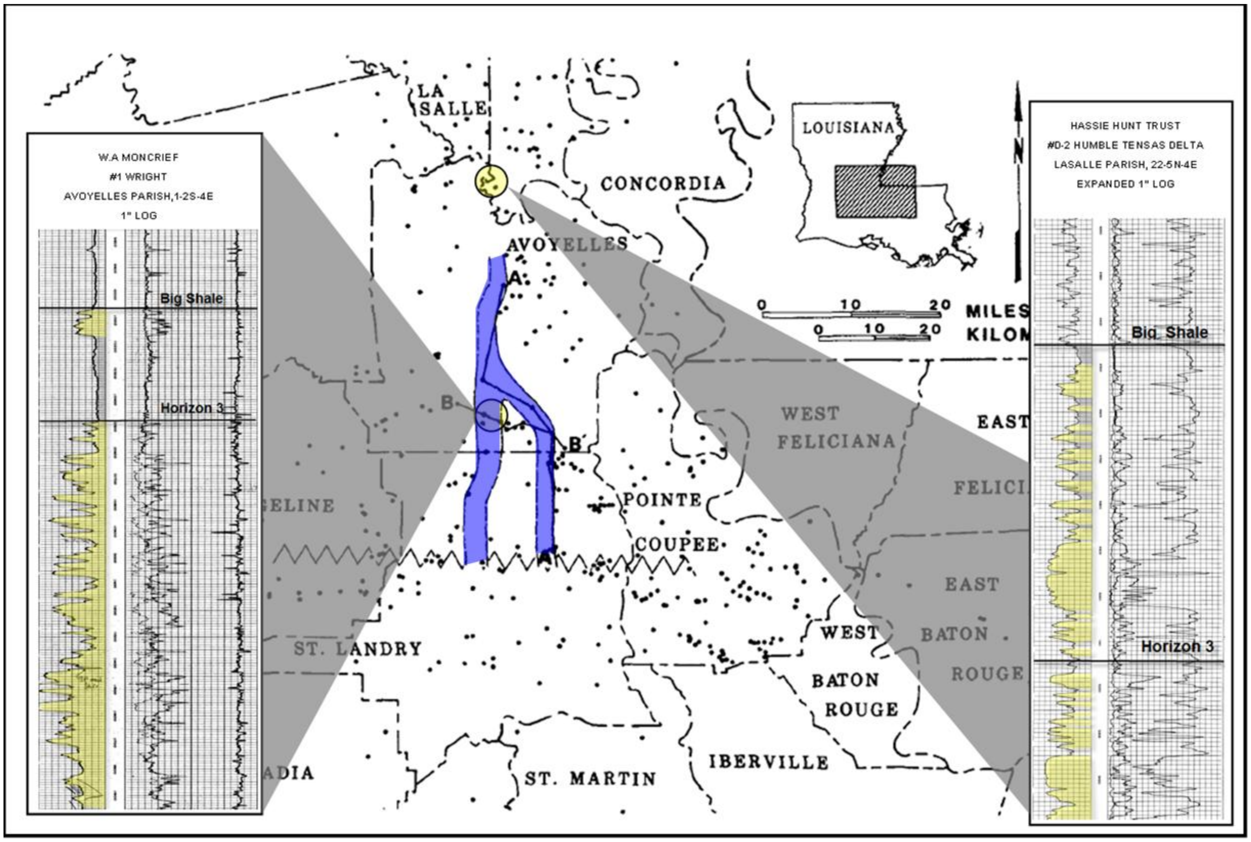

Figure 48. Shale filled-channel that is present within the lower Wilcox Group (Modified after McCulloh et al., 1986).

The gross interval and net sand maps of Interval H3-BBS show the existence of what is believed to be a branch of the St. Landry Canyon. Figure 50 shows the Humble-Tensas Delta D-2 (#129885) well in section 22-5N-4E of LaSalle Parish to have a reduction in sandy facies between the upper Wilcox and Horizon 3. This well has 50% less sand and gross interval thickness than surrounding wells. The Humble D-2 strata have likely been eroded by the St. Landry paleo-channel, replacing sand with interstratified shale (Fig. 49). The Humble D-2 has most likely encountered a branch of the paleo-channel that originates in Catahoula and Concordia Parish. The two branches of the paleo-channel meet in northern Avoyelles Parish where the channel continues for approximately 25 miles before bifurcating once more in southern Avoyelles Parish toward the south into St. Landry Parish.

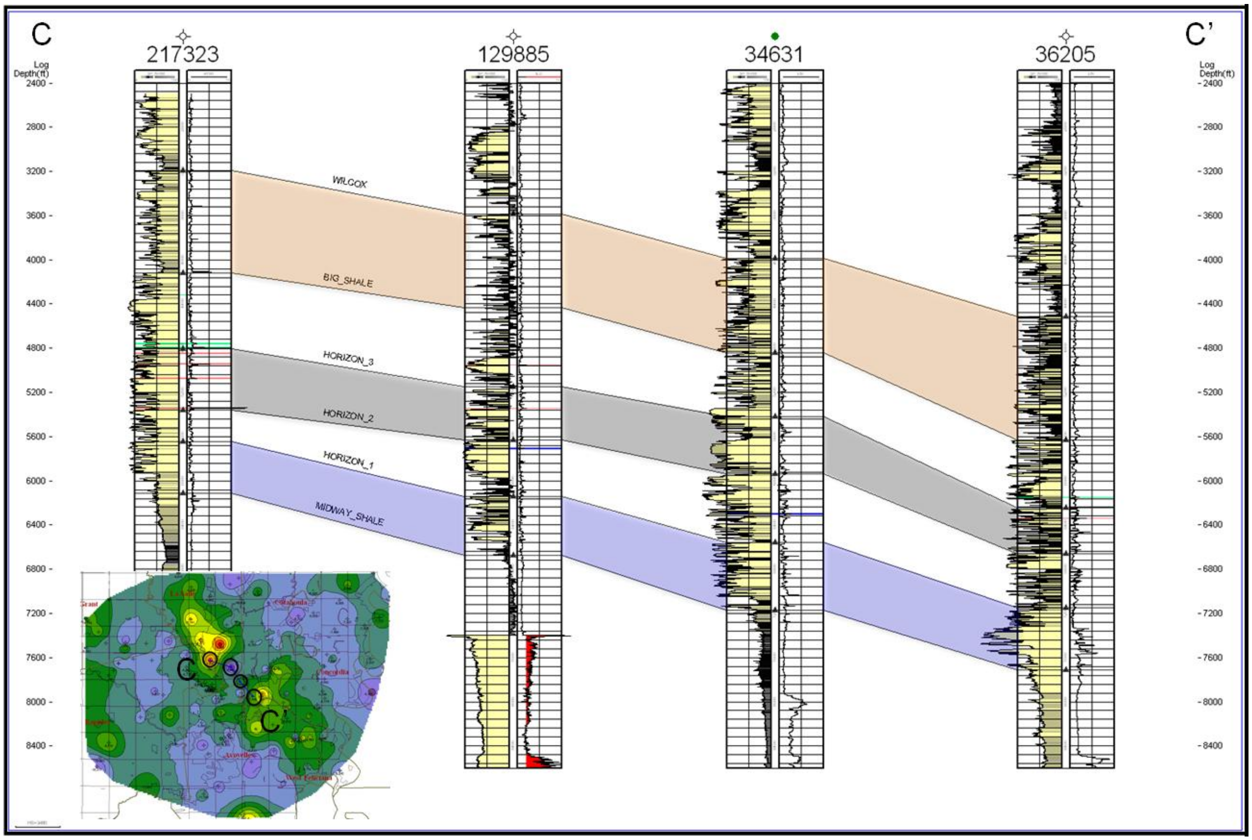

Figure 49. Cross section showing erosion in well #129885 at Horizon 3 to the Carrizo Sand.

Recent discoveries of productive Paleocene to Eocene aged Wilcox Group sands in the deepwater Gulf of Mexico has left scientists questioning how these sands were deposited so far offshore. At present there are multiple theories's regarding this topic. Rosenfield et al. (2003) found through paleogeographic reconstructions that the Florida Straits near Cuba were closed, effectively cutting off the Gulf of Mexico. This isolation of the Gulf of Mexico led to the drawdown in water level which caused deep incisions throughout the northern gulf coast. The most obvious features associated with drawdown of the Gulf of Mexico are the Yoakum, Smothers, Hardin and Lavaca canyons of southern Texas and the St. Landry canyon in central Louisiana (Sweet et al., 2011). These canyons resemble features seen in other basins like the Black Sea and the Mediterranean, which underwent desiccation

(Rosenfield et a., 2003). Berman et al., (2007) utilized results of recently drilled wells in the deepwater Gulf of Mexico to infer that drawdown occurred 55Ma, which brought sand-rich fan deltas into Alaminos Canyon and surrounding areas in the Gulf of Mexico, and accounted for deposition of the observed Wilcox deepwater sandstones.

Alternatively, a simpler theory is that thick Wilcox sands in the deep waters of the Gulf of Mexico were deposited by a large river system. Galloway (2008) argues that while the Florida Straits could have been closed during this time, the Suwanne Straits of northern Florida were open, preventing isolation of the Gulf of Mexico. Sweet et al. (2011) deduce that there is nothing unusual about the scale of canyons reported to have sourced the deepwater Wilcox Group sands, nor the distance over which these sands were transported. Sweet et al. (2011) postulate that the Wilcox aged basin-floor fans are the distal end of a continental-scale sediment dispersal system with slope to basin-floor mechanisms on the magnitude of a large continental-scale fluvial system.

The formation of the south Louisiana channel within a time period represented by an interval no thicker than Interval H3-BBS suggests that cutting was relatively rapid, as with canyons where mass movement systems are thought to have predominated (McCulloh et al., 1986). A more detailed explanation must await the deciphering of chronostratigraphic and lithofacies relations between the channel shale and the Big Shale marker, the tracing of the channel farther downdip to establish the nature of its terminus, and the development of sufficient syntheses of tectonic, paleohydrographic, eustatic, climatic, and other variations that took place during Wilcox deposition (McCulloh et al., 1986). The Yoakum has associated productive cut-and-fill, compaction, and stratigraphic hydrocarbon traps along its entire length (Chuber and Begeman, 1982), and this has great implications for the St. Landry

Canyon, as the shale-filled channel can act both as a source rock for oil or gas and also as a seal.

The net sand map best highlights the paleo-channels's orientation and thickness (Fig. 51). Based on the net sand map, the width of the channel is between 6 miles and 8 miles. The thick net sand wells are oriented in a northwest to southeast manner. Some of these wells have sand values greater than 500' are located in Township and Range 5N-3E, 6N-3E, 6N-4E, 7N-3E, 4N-5E, 3N-5E, and 3N-4E. Adjacent to these two accumulations of high net sand, many wells do not have a great deal of sand. The average net sand thickness for Interval H3-BBS is 239'; this showcases the high net sand areas of greater than 400'.

Like many of the net to gross ratio maps the Interval H3-BBS does not show any conclusive trends (Fig. 52). There are two low net sand to gross ratio areas in the northwest and southwest part of the study. These wells average 0.3 net to gross ratio with higher areas in the survey as much as 0.88 in the P.L Rountree #1 in Concordia Parish. This well and the two others near it are the only high value net to gross ratio wells. This is to be expected since these wells had high thicknesses in the gross interval and net sand maps. The lowest net to gross ratio value is in the Humble Tensas Delta #1 with 0.1 net to gross ratio. This abnormally low value adjacent to high net to gross ratio values is most easily explained by this well being cut by a paleo-channel filled with shale, giving the low net to gross ratio value. The average net to gross ratio value throughout this interval in the lower Wilcox Group within this study area is 0.46.

The net coal map for this interval is very similar to that of Interval H2-H3 except for less coal development. The greatest development of coal is concentrated in the north western portion of the study area. The Belle Exploration #1 in section 30-7N-4E of LaSalle Parish has a total of 45’ of net coal which is the greatest total thickness found in this interval within this study area. Other wells surrounding the Belle Exploration #1 contains values of net coal between 9’ and 24’. Coals within this interval are far less laterally extensive than those within Interval H2-H3 & Interval H1-H2. The coals within Interval H3-BBS are also generally thinner and are more numerous than coals of other intervals of the lower Wilcox. The coals of Interval H3-BBS seem to occur along a southwest to northeast trend. This was likely parallel to the orientation of the shoreline when the coal was being laid down in a paralic environment. The regions of 0’-10’ in purple on Figure 53 are likely intertidal swampy areas where peat accumulation was not consistent through time. Higher concentrations of coal likely depict areas of increased topographic relief that were unaffected by dynamic coastal processes, giving these locations longer time to accumulate peat.

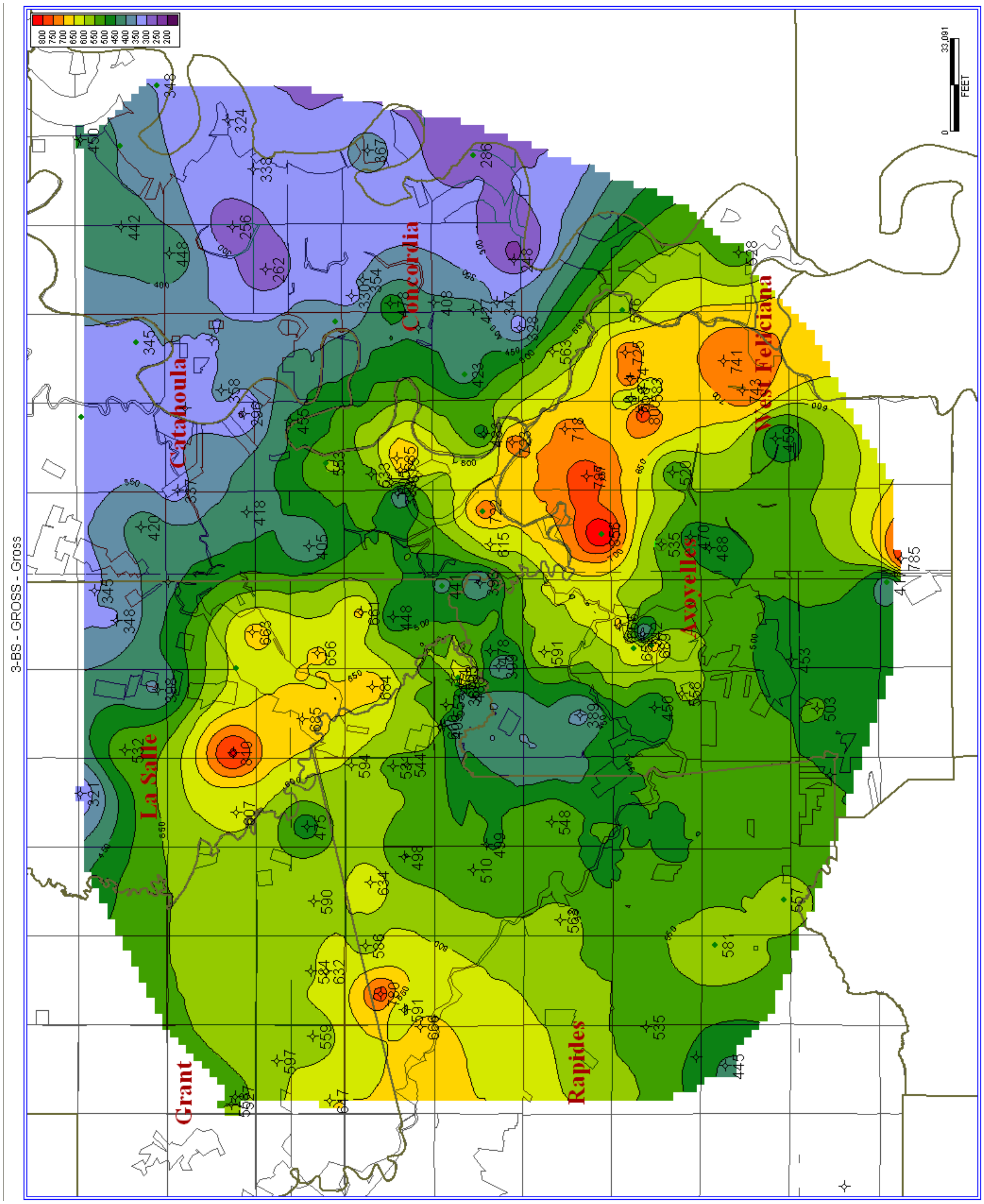

Figure 50. Interval Horizon 3 – Bottom of the Big Shale gross interval map.

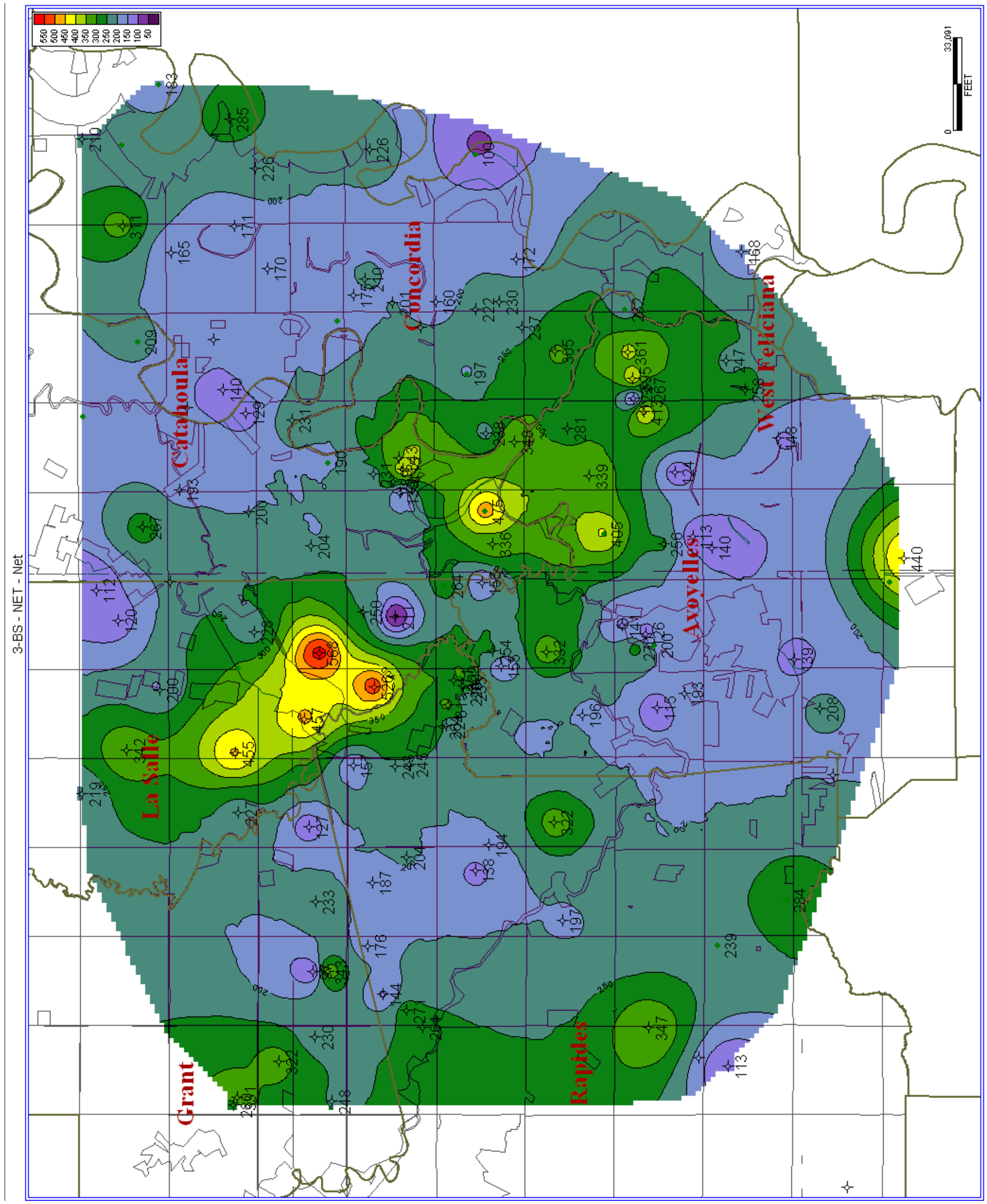

Figure 51. Interval Horizon 3 – Bottom of the Big Shale net sand map.

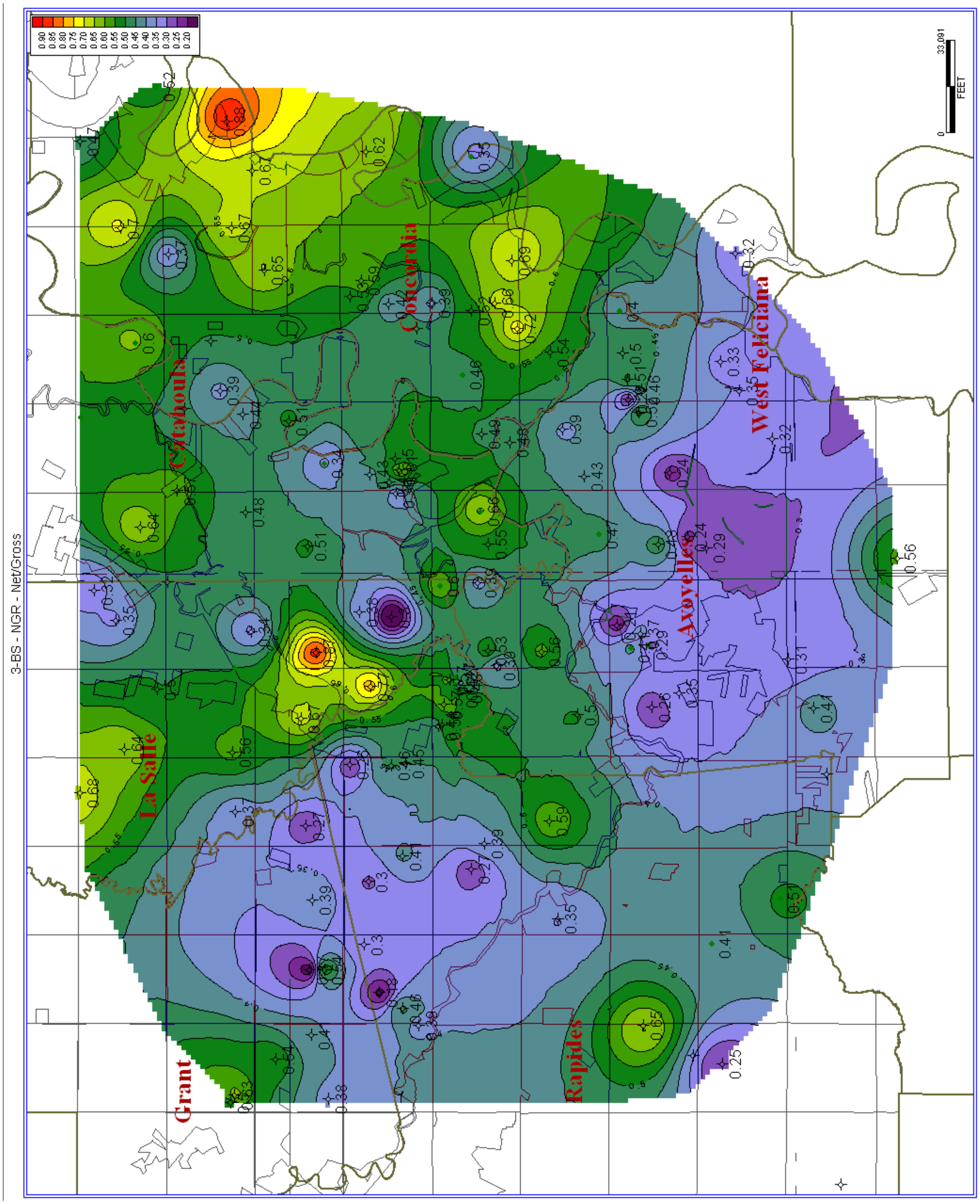

Figure 52. Interval Horizon 3 – Bottom of the Big Shale net sand to gross interval ratio map.

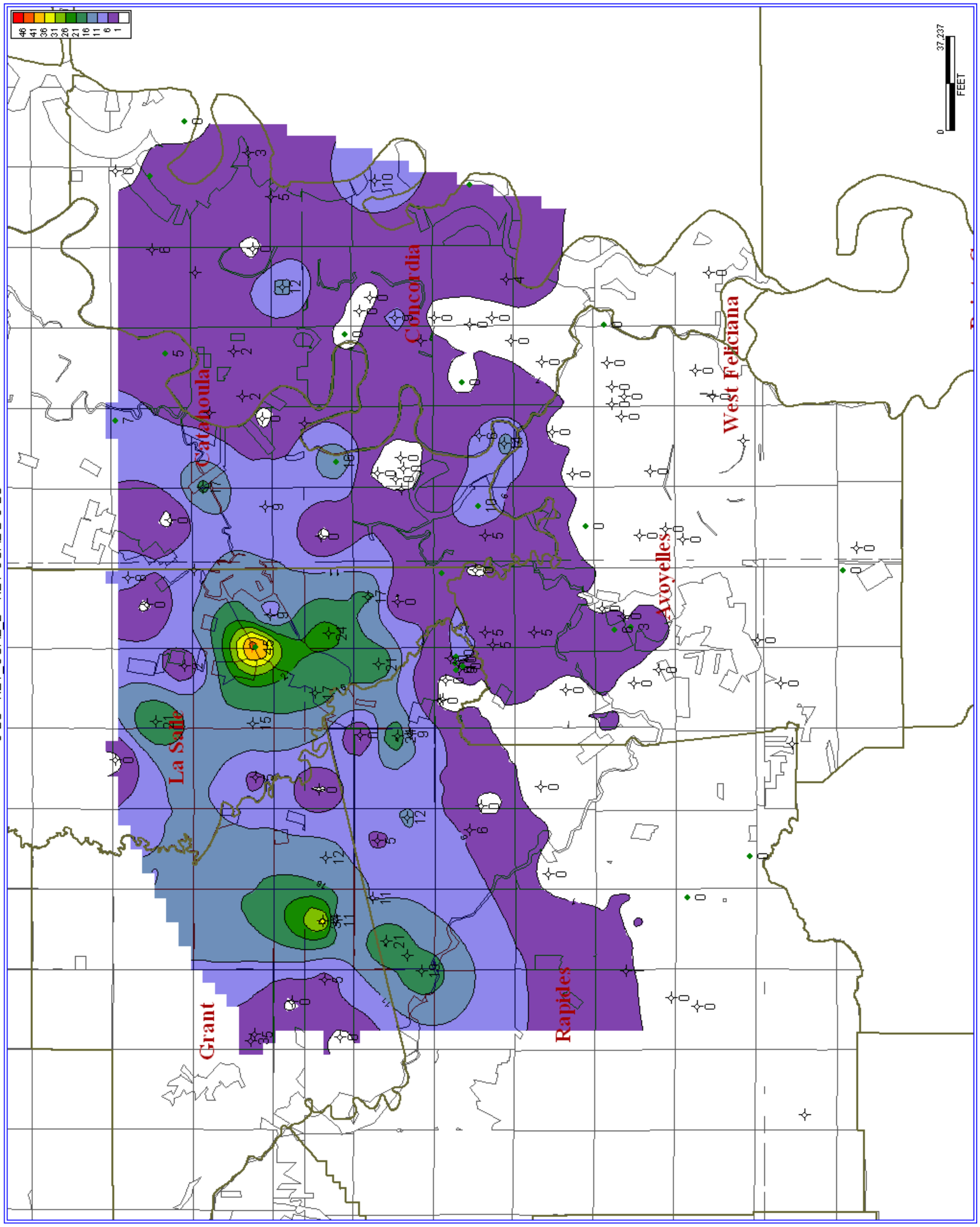

Figure 53. Interval Horizon 3 – Horizon Bottom of the Big Shale net coal isochore map.

Interval BBS-TOPW

The Interval BBS-TopW is bound at its base by the Bottom of the Big Shale and its top by the Carrizo Sand. This interval comprises the entire upper Wilcox Group. Out of the 130 well logs that were selected for this study area, all 130 wells penetrate this interval. This interval contains more penetrations than any other interval mapped. Additionally, it is the easiest to correlate; being bounded at the Bottom by the Bottom of the Big Shale, which is an easily recognized marker and at the top by the Top of the Carrizo Sand, which is similarly easy to recognize; throughout the study area, it is the most detailed and accurate interval analyzed in this project.

The gross interval map of Interval BBS-TopW is very similar in appearance to the structure map of the Carrizo Sand (Fig. 54). The well with the thinnest gross section is the Placid Oil #2 in LaSalle Parish with 513'. The Moncrief Ducote #1 in the southern portion of Avoyelles Parish has a total thickness of 1883'. That is 1370' of total increase in the upper Wilcox from the northernmost well to the southernmost well in the study area. The LaSalle Arch is clearly defined by the thin area with less than 1000' of section overlying it. On the flanks of the LaSalle Arch the gross interval map quickly thickens to the west by over 400' in less than 6 miles in some places. On the south and east side of the LaSalle Arch the thickening is much more gradual at a rate of about 100'-125' per 6 miles. On the west, south, and east boundaries of the study area, the gross interval thickness is 1500' or greater.

Unlike the gross interval map the net sand map doesn't have many prominent features (Fig. 55). The most noticeable feature is the high net sand area to the east. The Fife Oil & Gas #1 well in Concordia Parish has 1,093' of net sand. Based on the location and orientation of this high net sand belt, it is postulated that it is likely controlled by the Mississippi

Embayment. Many of these wells have over 700’ of sand while wells to the immediate west have significantly less. The well in the far southwest with over 1000’ of sand is clearly anomalous, this well has a different SP scale compared with other wells within the study area. The majority of the net sand values display no real pattern and vary between less than 100’ of net sand and 300’ of net sand.

The net to gross ratio map at Interval BBS-TopW is similar to the net sand map, toward the east, in defining the high sand area in Catahoula and Concordia Parishes (Fig. 56). Many of the wells in this area have net to gross ratio values of over 0.5. Directly in the center of the study area is another major sand accumulation. Many of the wells in this area have net to gross ratio values of over 0.4. Like previously stated in the net sand map section, the high net to gross ratio well in the southwest is anomalous. Petra computes sand footages based on normalization of all wells within the project; this wells SP scale falls outside of the range of normalization. On the perimeter of the sand accumulation in the center of the study area, there are lower net to gross ratio values varying around 0.2.

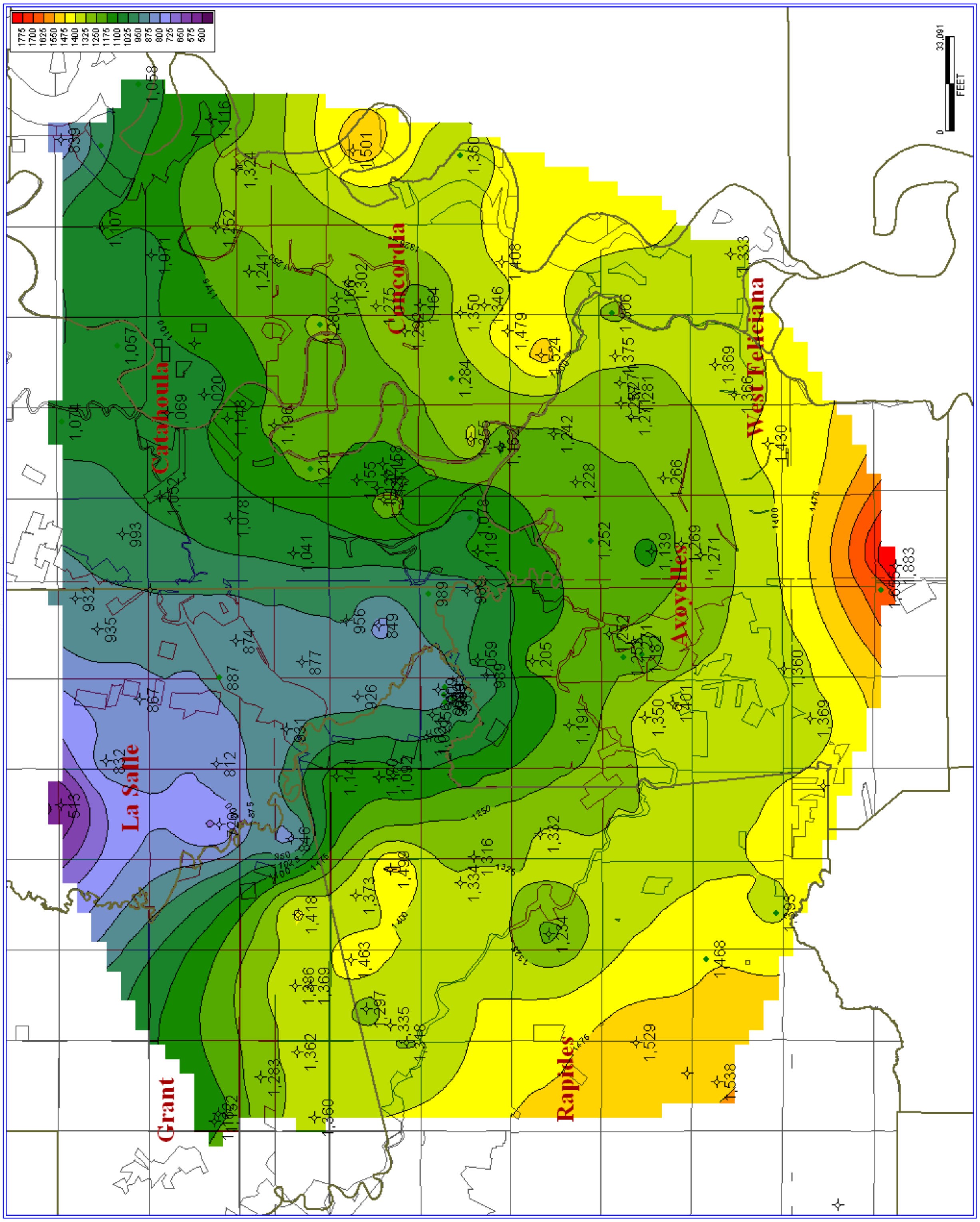

Figure 54. Interval Bottom of the Big Shale – Top of Carrizo Sand gross interval map.

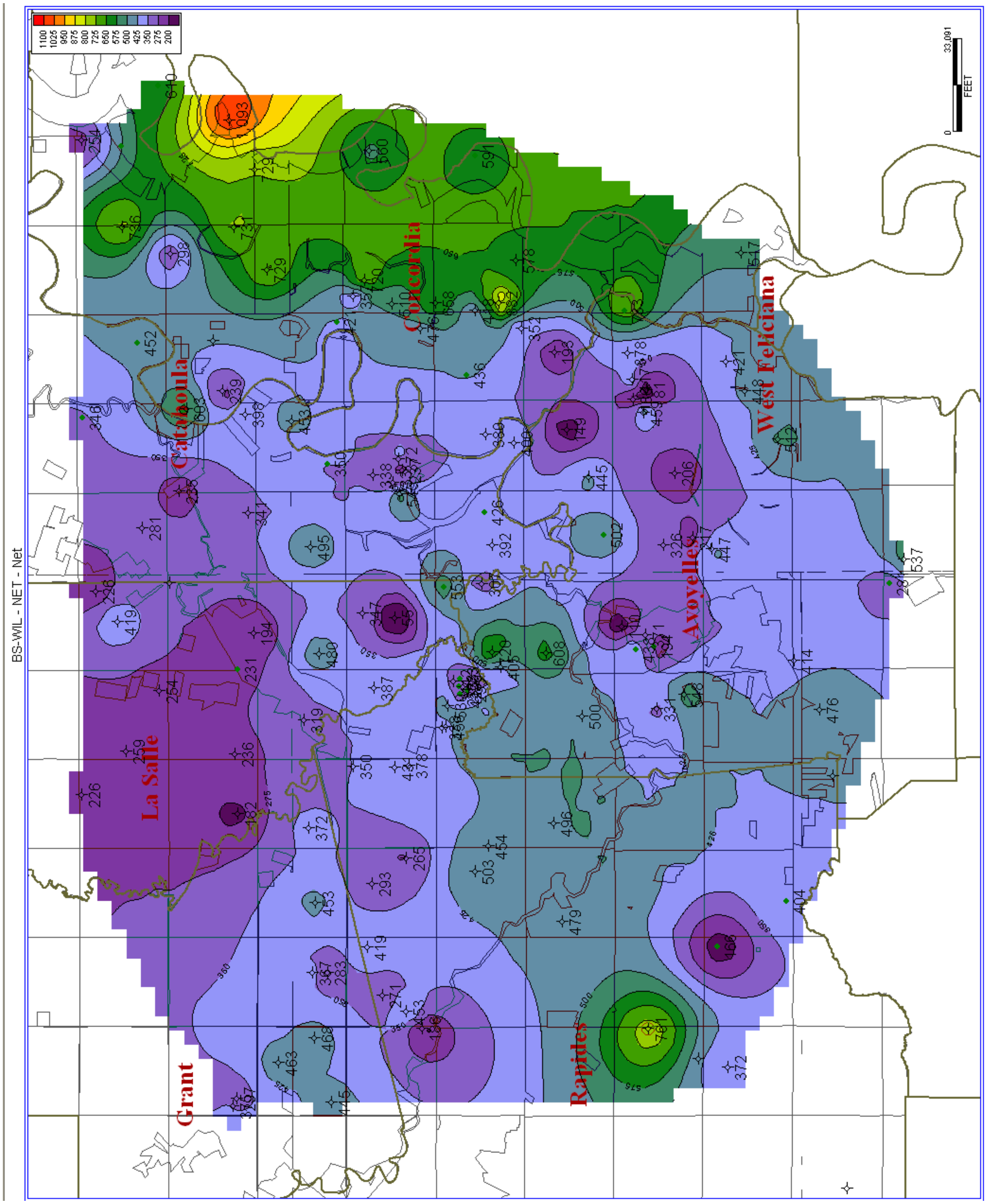

Figure 55. Interval Bottom of the Big Shale – Top of Carrizo Sand net sand map.

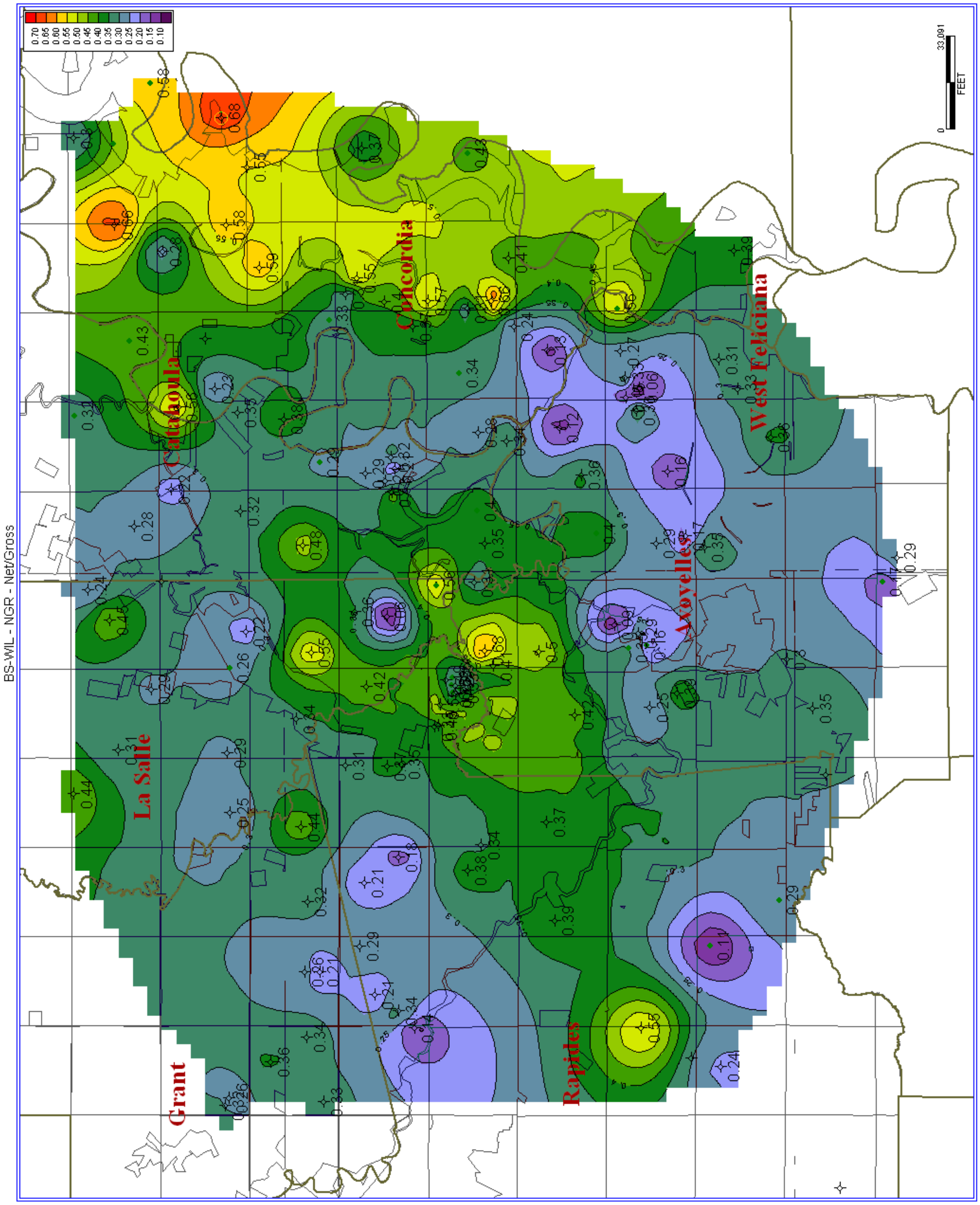

Figure 56. Interval Bottom of the Big Shale – Top of Carrizo Sand net sand to gross interval ratio map.

Lower Wilcox

The lower Wilcox Group is bound at its base by the top of the Midway Shale and at its top by the Bottom of the Big Shale. The major stratigraphic intervals identified within this study area are Interval TopMS-H1, Interval H1-H2, Interval H2-H3, Interval H3-BBS (Fig. 10). The three lowermost divisions of the lower Wilcox Group can be seen on well logs as coarsening upwards packages followed by a relatively coarse aggradational package. Approximately 70 wells in this study area penetrate the entire lower Wilcox Group.

The gross interval isochore map (Fig. 57) displays a thin section in the northern part of the study area. The Tensas Delta Land Co #1 has the lowest gross interval thickness out of all wells in the study area with 1,538’. The interval thickens by 1,006’ to the south and generally thickens to the east and west. The average gross interval thickness of all wells within the Lower Wilcox Group is 2,050’. Towards the south in section 33-3N-3E the Ellis Laborde #1 has the thickest gross interval within this study area with 2,543’ of section. Other nearby wells have gross interval thicknesses in excess of 2,200’. Generally around the perimeter of these thicker wells are wells with lower gross interval thicknesses, ranging from 1,700’ to 2,000’.

The net sand map of the lower Wilcox Group has similar patterns to the gross interval map (Fig. 58). There is a thin area in the northern portion of the study area in LaSalle and Catahoula Parishes. Additionally, a thin net sand accumulation is present in the southern portion of the study area in Avoyelles Parish. The Moncreif Wright #1 has the lowest net sand thickness in the study with 651’. The average net sand thickness within the lower Wilcox Group in this study area is approximately 1,155’. The greatest accumulation of net sand is in the P.L. Rountree Jr. #1 in section 20-7N-10E of Concordia Parish with 2,102’.

The higher net sand areas are concentrated in the center and northeastern portions of the study area.

As previously stated, many of the features of the gross interval thickness and net sand maps carry over to the net sand to gross interval ratio maps (Fig. 59). The lowest net to gross ratio value is 0.34 in the Moncreif Wright #1 and the Roy O Martin et al. #1. Generally, wells in the central and northeastern portions of the study area have much higher values. The average net to gross ratio value within the lower Wilcox Group is 0.56. The well with the greatest proportion of net to gross ratio content within this study area is the P.L. Rountree #1 with 0.93.

Net coal accumulation within the lower Wilcox Group is mostly concentrated in LaSalle Parish (Fig. 60). The Mary Pipes et al. #1 in section 19-8N-3E of LaSalle Parish contains 94' of net coal which is the highest amount of coal found within this study area (Fig. 61). 18 miles to the south the Robert C Jenkins #1 in section 29-5N-2E of Rapides Parish has 90' of net coal. Within this study area 86 wells had accumulations of coal within the lower Wilcox Group. The average net coal thickness in wells containing coal in the lower Wilcox Group within this study area is 17'. South of Township 2N there is no coal accumulation. All wells south of this boundary have no lower Wilcox coals and are interpreted as having accumulated in marine environments.

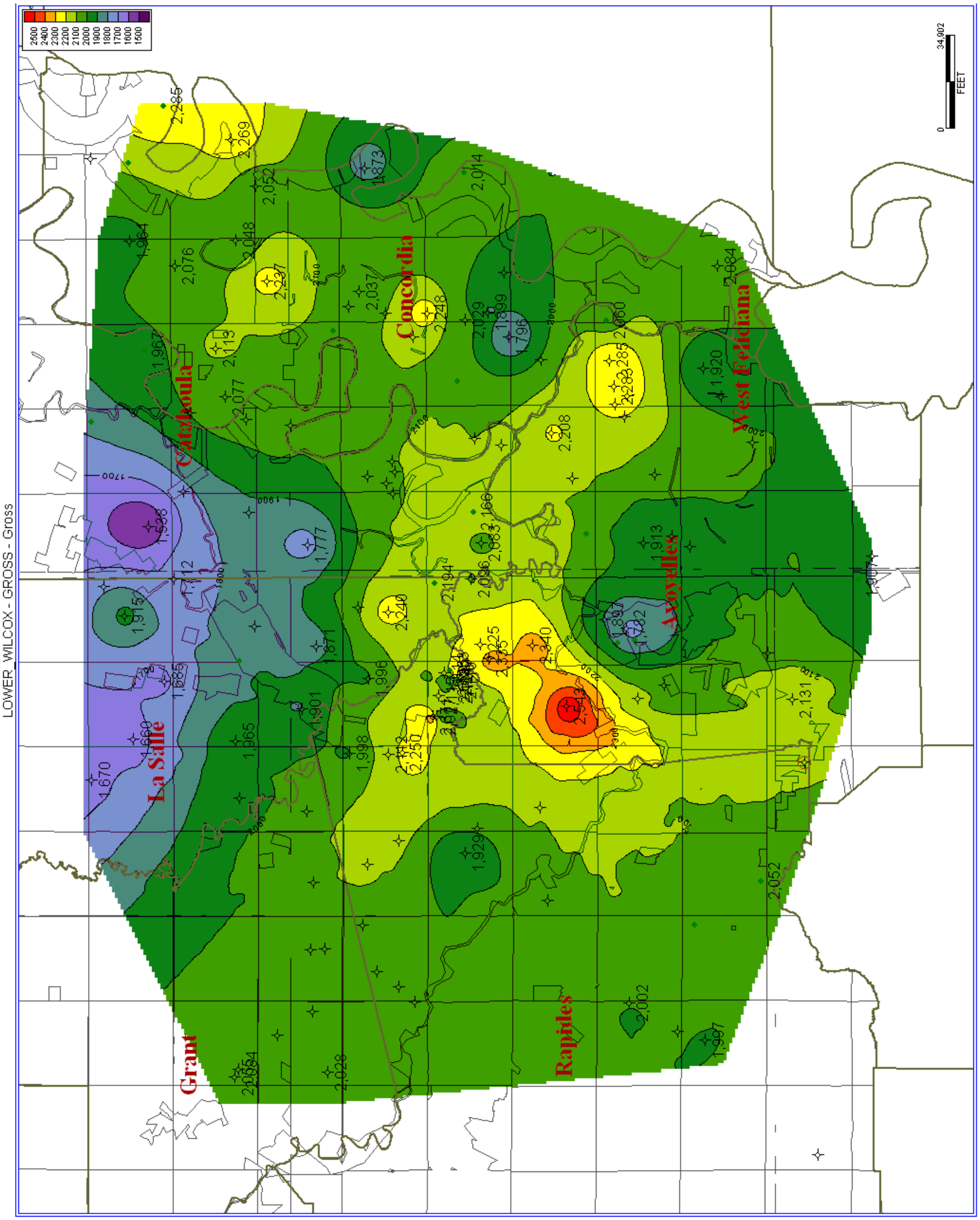

Figure 57. Lower Wilcox Gross Interval Map.

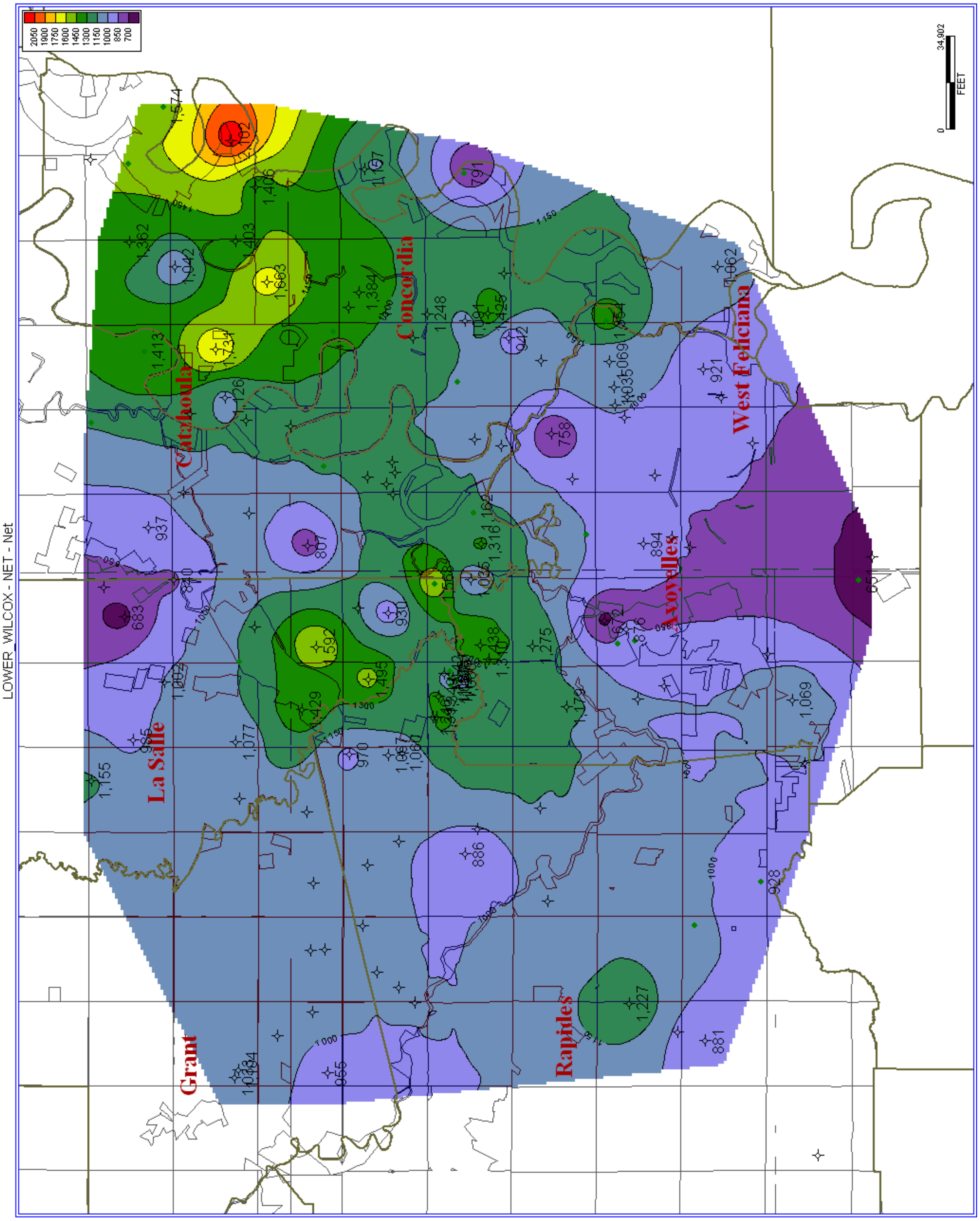

Figure 58. Lower Wilcox Net Sand Map.

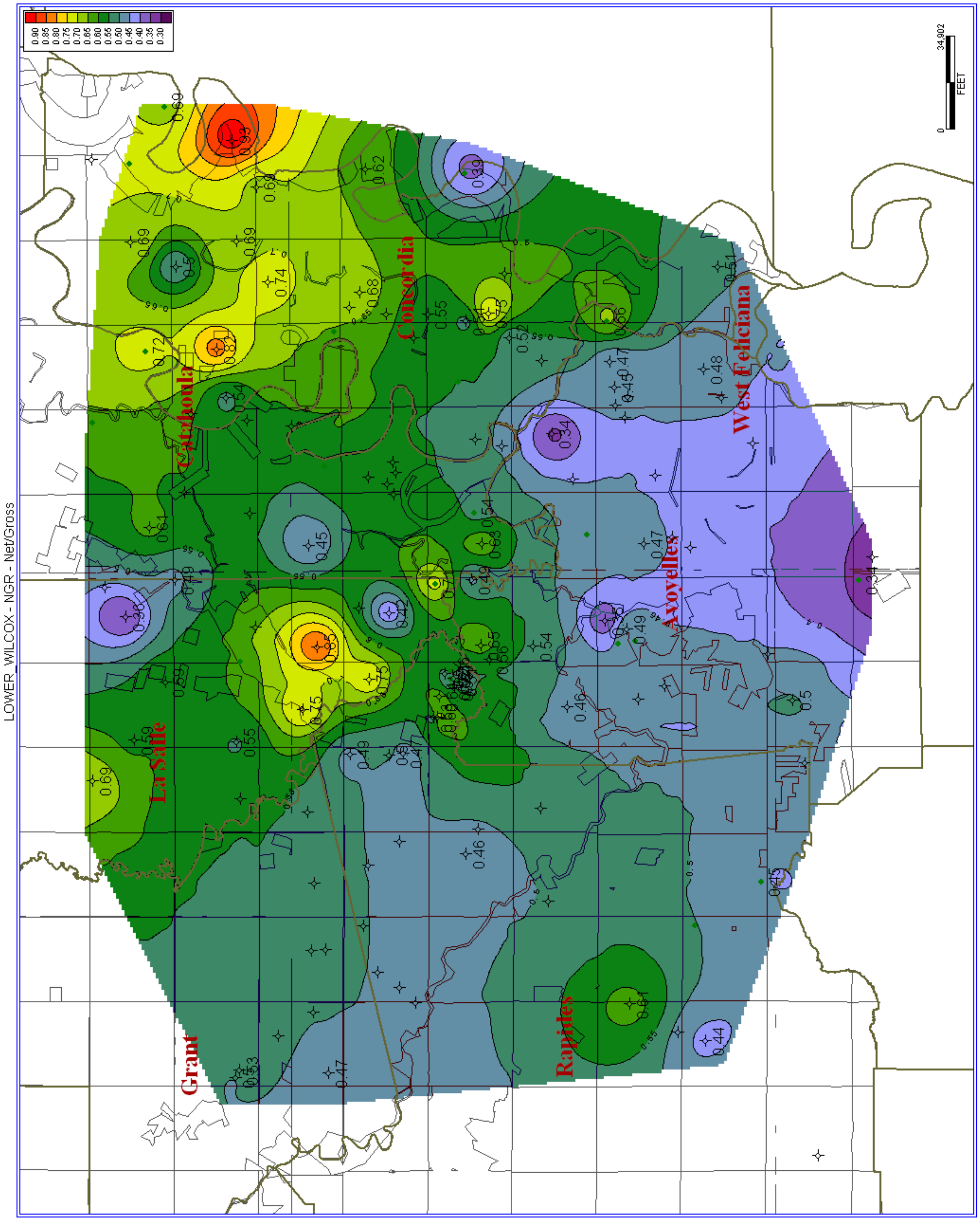

Figure 59. Lower Wilcox NGR Map.

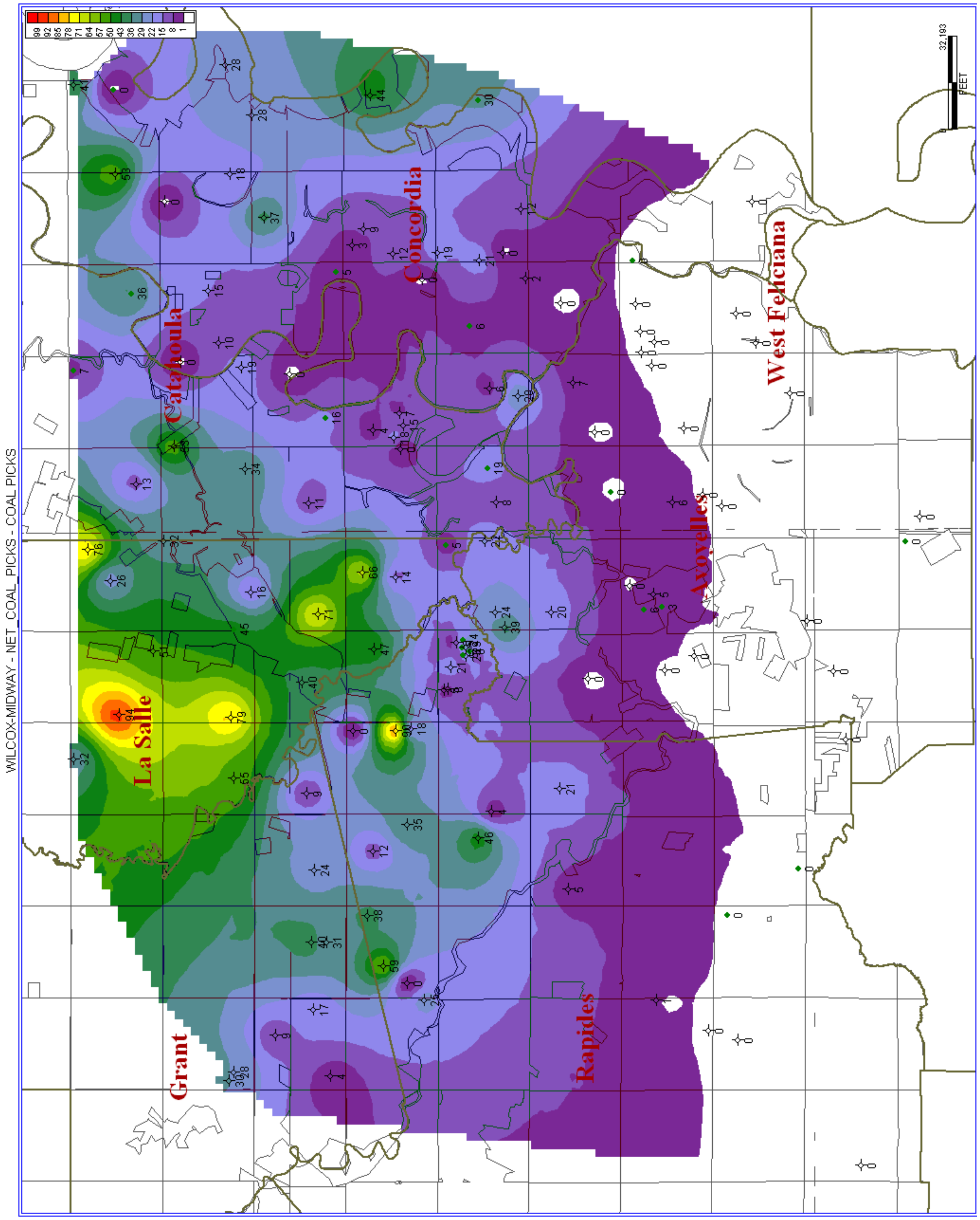

Figure 60. Lower Wilcox Net Coal Map.

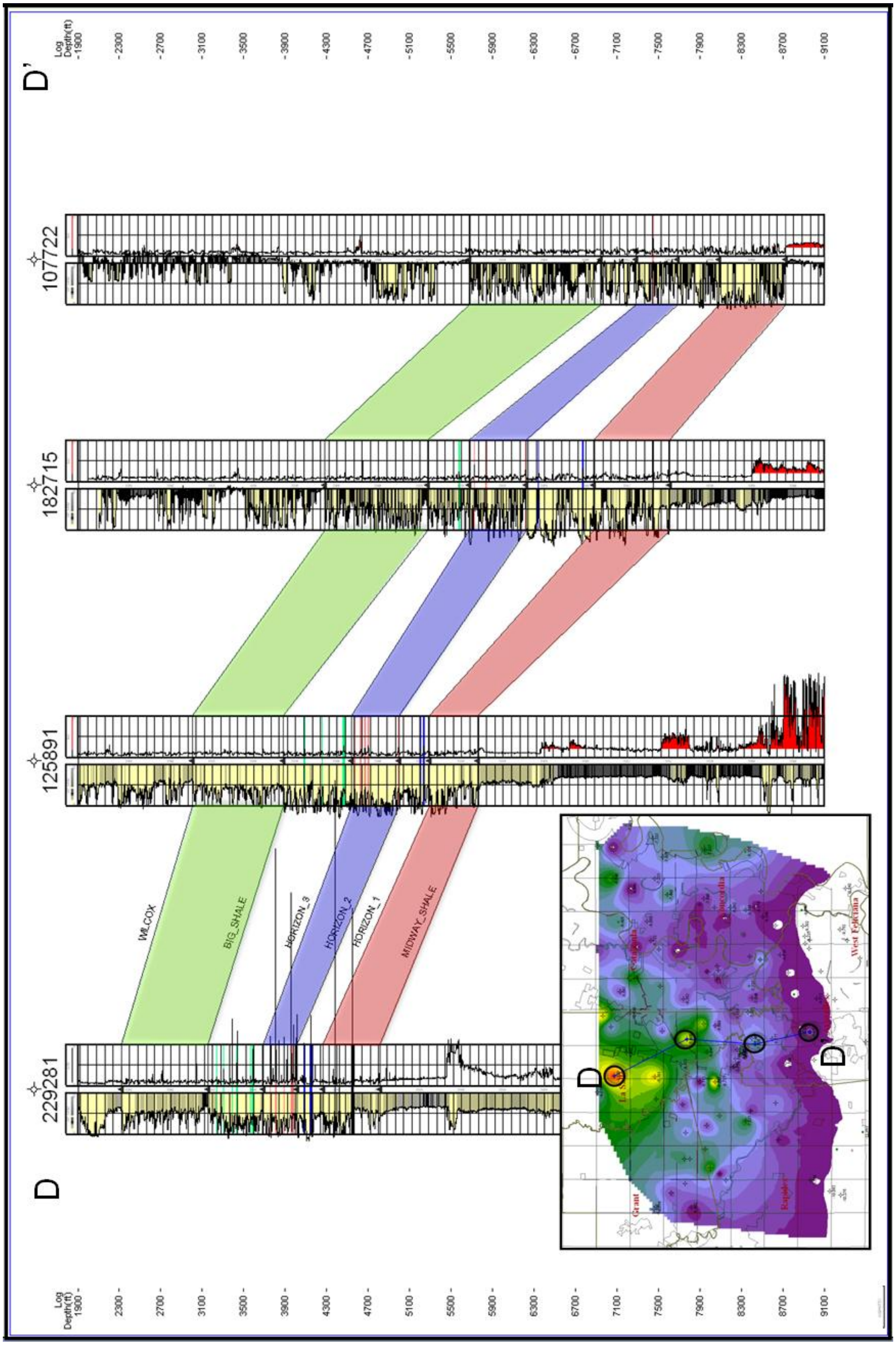

Figure 61. Cross section D-D'.

Reynolds Coal

The Reynolds coal is found in the Interval H1-H2. The Reynolds coal, also known as the "Big Coal," is the most laterally extensive and thickest coal throughout northern Louisiana. The environment of deposition for the Reynolds coal was in paralic swamps. Paralic swamps pertain to the intertongued marine and continental environments found on the landward side of a coast (Encyclopedia of Geomorphology, 2013). The Angelina-Caldwell Flexure defines the shelf edge and the shoreline was near the developing flexure throughout the period of deposition of the Reynolds coal (Kinsland, 2013). Kinsland (2013) postulated that the Reynolds coal was deposited in lagoonal environments possibly behind barrier islands or behind other elevated shoreline deposits. The areas in the southeastern portion of the study have a sparser well density and most wells do not reach the Reynolds coal horizon. For this reason the Reynolds coal horizon was picked on the coal where it was present and on its correlative stratigraphic position in wells where coal is not present. This produces a map that shows the anticipated depth of the Reynolds coal throughout the study (Fig. 62). Its shallowest penetration in this study is at a depth of -3,354' and as deep as -11,015'. Unlike other sub-regional studies to the north, this study contains far steeper dip to the south in the lower Wilcox. From the most northern point in the study area to the southernmost point there is over 6,000' of relief within all horizons of the lower Wilcox. The Reynolds coal demonstrates 7,661' of structural dip from the Placid Oil #2 well to the Moncreif Ducote #1 to the south. The structure map at the Reynolds coal is basically identical to the Horizon 1 structure map. The Reynolds coal is stratigraphically less than 200' above the Horizon 1 surface in most wells in the study. Strong south-southwest dip is seen at the Reynolds coal horizon structure map. Dip is gentler near 3500' to about 6,000', after 6,000' dip steepens in the central portion of the study quite rapidly as the result of the nose of the LaSalle Arch. The effect of the LaSalle Arch is visible with the increased west and east dip on the flanks of the arch. Well penetrations are low toward the west so the arch isn't defined as well as in the western portion of the study area.

Unlike the Reynolds coal horizon structure map where the horizon of anticipated coal occurrence was mapped, the Reynolds coal isochore is from actual measured coal thickness (Fig. 63). The Reynolds coal was deposited in an aggradational shelf margin systems tract where the shoreline stayed relatively stable for a period of time sufficient to produce in excess of 30 feet of coal just to the north of this study (Kinsland, 2013). Approximately 41 wells within the study area encountered the Reynolds coal in varying thicknesses. The thickest wells are located in the northern limits of the study area in LaSalle and Catahoula Parishes. The IPB LLS #1 in LaSalle Parish contains 19' of coal which is the thickest occurrence of Reynolds coal found within the study area. Other nearby wells average between 13' and 17' of Reynolds coal. The average thickness of Reynolds coal in the lower Wilcox is 10' for wells that encountered Reynolds coal. The southernmost occurrence of Reynolds coal is in section 8-3N-2E of Rapides Parish with 8' of coal. The Lee Lumber Company #2 in section 8 having coal accumulations this far south suggests that this location was locally high, aiding in a relatively consistent environment where peat could accumulate, decay, and form coal. Areas in white with 0' of Reynolds coal are where conditions were not suitable for coal development or preservation during this time interval. Since there is no Reynolds coal toward the south half of the study area, it should be interpreted that this boundary south of Township 3N was the margin of a marine environment (i.e. the shoreline).

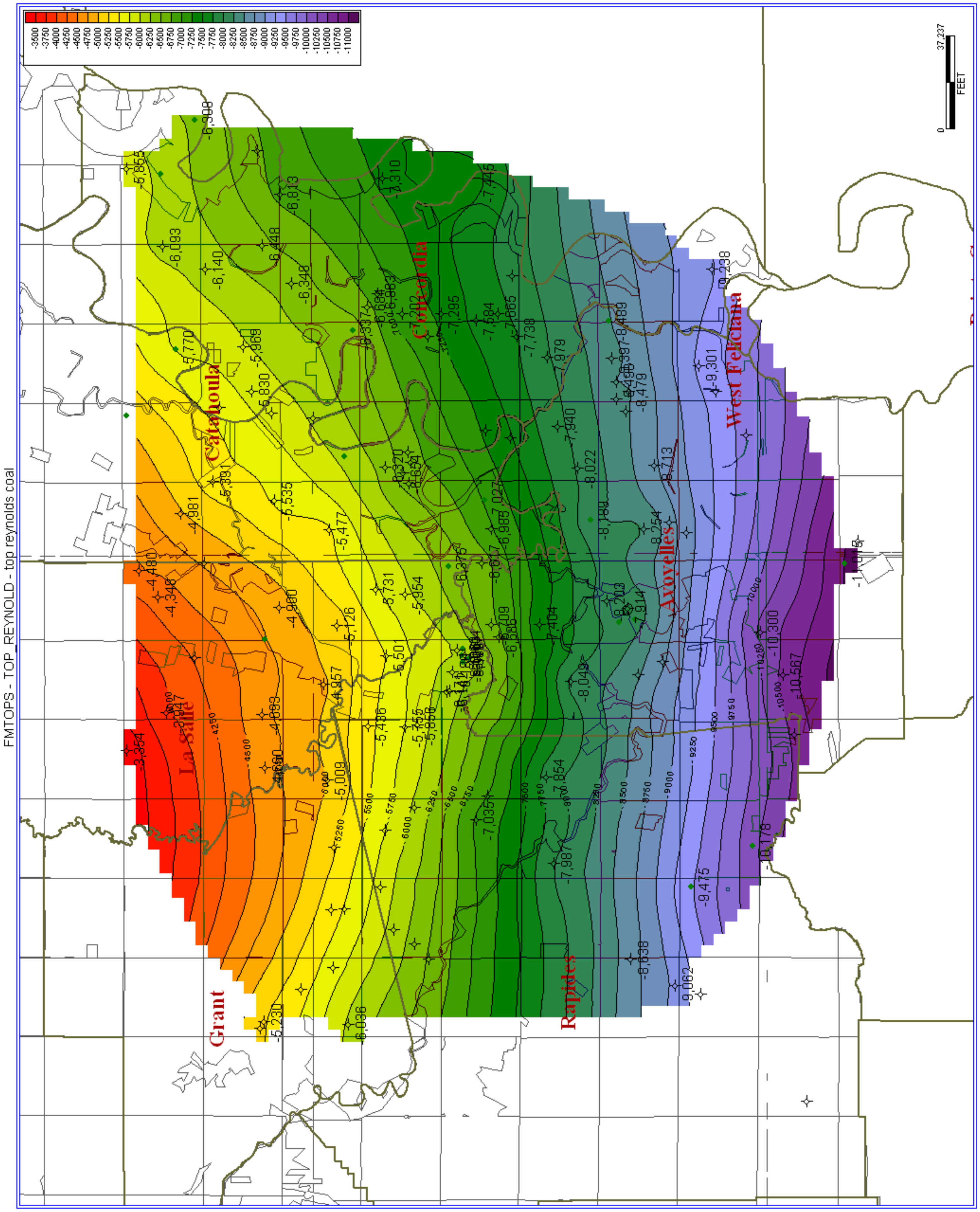

Figure 62. Reynolds Coal Structure Map.

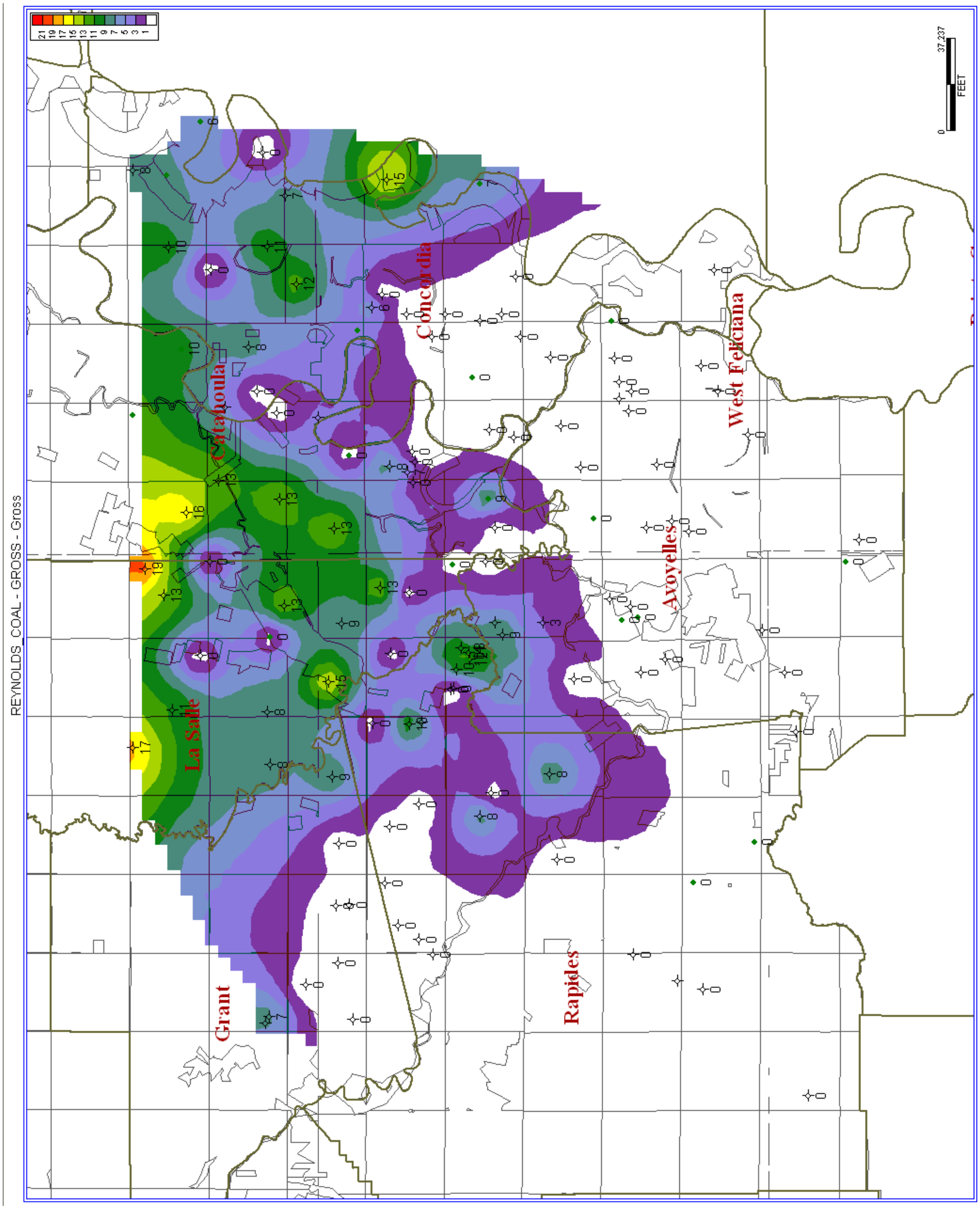

Figure 63. Reynolds Coal Isochore Map.

Russell Coal

The Russell coal occurs in Interval H2-H3. The Russell coal is found in accumulations parallel to the Angelina-Caldwell Flexure. The Russell coal was deposited in a paralic depositional environment (Kinsland, 2013). The Russell coal is generally thinner and less prevalent than the Reynolds coal. As previously stated in the Reynolds coal section, many of the wells toward the southern portion of the study area do not contain the Russell coal. To compensate for this in construction of the structure map, the correlative depositional surface has been picked to show the anticipated depth at which the Russell coal would have been encountered. Many more wells reached the Russell coal depositional surface than the Reynolds coal surface. This produces a structure map with much more well control and an overall better structural picture (Fig. 64). The shallowest penetration of the Russell coal in this study is at -3,006'. The deepest penetration is at -10,725'. There is a total of 7,719' of structural relief from the northernmost well to the southernmost well. The Russell coal mapping surface is less than 100' above the mapping surface of Horizon 2, and the structures of Horizon 2 and the Russell coal are nearly identical. The structure map at the Russell coal has contours that are more evenly spaced, better defined structural features, and more confident contour positioning than the Reynolds coal structure map. Similar to all lower Wilcox horizons, strong south dip is present with the LaSalle Arch creating west and east dip on the flanks of the arch.

The Russell coal isochore map is very similar in orientation and extent to the Reynolds coal isochore (Fig. 65). The Russell coal is not as thick as the Reynolds coal or as prevalent with only 32 wells that have an occurrence of Russell coal. The thickest occurrence of Russell coal is 13' seen in three wells the Mamie O Mcgraw #1, Tensas Delta Land Co #1, and the Cotton Estate #1. The average thickness of Russell coal is 8’ in wells that encounter it within this study area. The Russell coal is generally thinner than the Reynolds coal, possibly because sea level was not stable for as long a period during the transgressive systems tract of Interval H2-H3 (Kinsland, 2013).

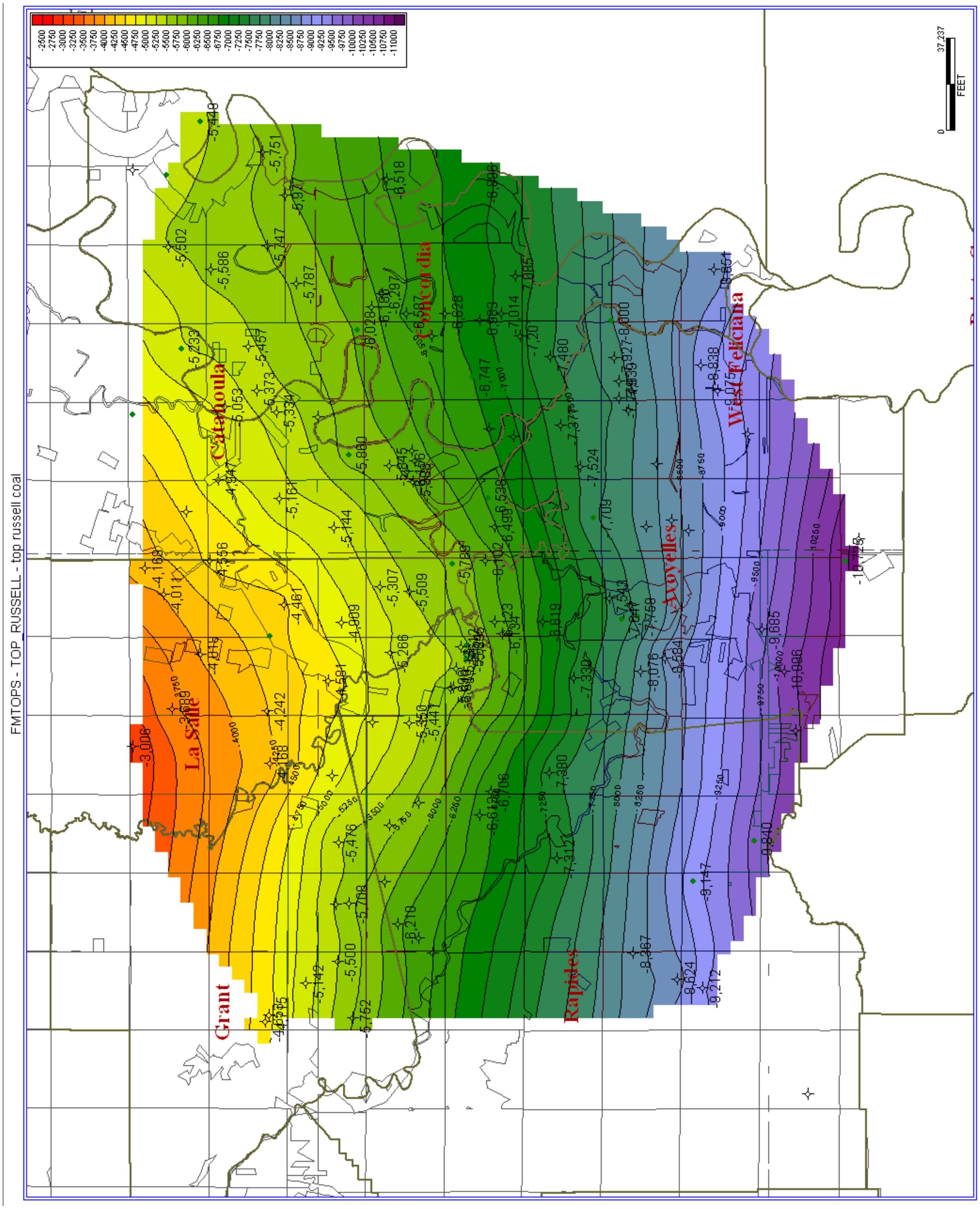

Figure 64. Russell Coal Structure Map.

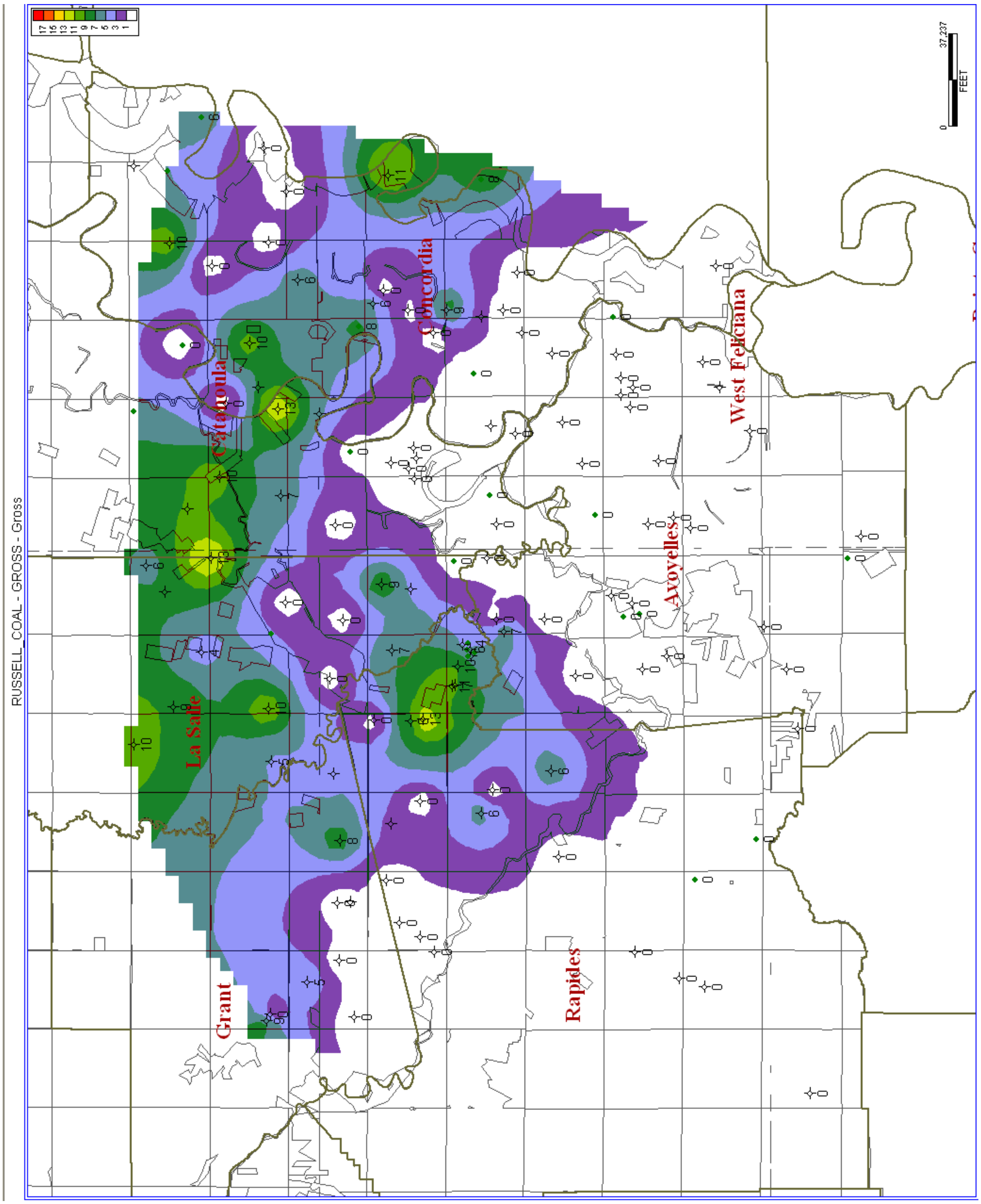

Figure 65. Russell Coal Isochore Map.

SUMMARY

Conclusions

The purpose of this study was to investigate coal occurrences within the lower Wilcox Group in portions of Rapides, Avoyelles, Grant, LaSalle, Concordia, and Catahoula Parishes, Louisiana. The depositional systems of the lower Wilcox Group were also evaluated with the use of structural maps, gross interval thickness maps, net sand maps and net sand to gross interval ratio maps.

Coal development in this portion of central Louisiana is rather poor compared with areas just north of the study area. However, the best developed coals within the study area are situated just south of the Angelina-Caldwell Flexure and on top of the LaSalle Arch. The LaSalle Arch was topographically high and, apparently, was a stable environment for paralic coal accumulation. This evaluation of this area at the present sub-regional scale with the use of more detailed logging suites has uncovered that there are no coals in some areas where coals had previously been mapped during the reconnaissance studies. Areas south of Township 2N were found to contain no lower Wilcox Group coal accumulation. The area south of Township 2N was in a marine environment not suitable for coal accumulation. Areas found to contain no coals, where coals were previously mapped, are generally in the southern portions of the study area where the high resistivity values previously interpreted to be due to coals are likely due to calcareous pelagic sediments.

It should be noted that well control within this study area is rather sparse throughout when compared with the well density necessary to adequately sample and define the fluvial, paralic, and shallow marine sedimentary facies of much of the lower Wilcox Group. This should be kept in mind when analyzing the gross interval isochore, net sand, and net sand to gross ratio maps which contain “bullseyes.” These anomalies occur when there are not enough data points to define the actual facies distribution. Petra then generates local “bullseyes” that are not representative of geological reality.

The best developed coals to the north are paralic coals that accumulated in coastal marsh environments. The Reynolds coal was deposited in an aggredational shelf margin systems tract where the shoreline stayed relatively stable for a period of time sufficient to produce in excess of 30 feet of coal just to the north of this study area (Kinsland, 2013). The Russell coal is not present as far south as the Reynolds coal development. The Russell coal likely did not prograde as far south because the period of time between regressive and transgressive systems tracts was too short for adequate coal accumulation. Due to this abrupt sea level rise, swamp and marsh environments were limited, reducing the thickness and extent of Russell coal compared with the Reynolds coal.

Findings support that the St. Landry Canyon is present north of the McCulloh et al. (1986) study. The change in structural relief of the Bottom of the Big Shale compared with Horizon 3 and the Carrizo Sand suggests an erosional event. The paleo-channel can be seen in the Interval H3-BBS net sand map where a 6-8 mile wide section is cutout. These paleo-channels trend south along the flanks of the LaSalle Arch, likely as a bifurcation into the main channel of the St. Landry Canyon. These shale-filled channels are easily compacted causing differential compaction and resulting in the increased relief of the Bottom of the Big Shale Horizon.

RECOMMENDATIONS

This study area would greatly benefit from more detailed work in the shallower intervals of the lower Wilcox Group. Horizon 2 and younger intervals should be looked at more extensively. In this study area wells that reach the Midway Shale and see the entire lower Wilcox Group were utilized and are much rarer than the quantity of wells which reach the depth of Horizon 2. A more detailed study utilizing these additional shallower wells would greatly increase the detail and knowledge of the depositional regimes above Horizon 2.

This study not only identified coal occurrences of the lower Wilcox Group but also found some interesting features within the Interval H3-BBS. Within the Interval H3-BBS large shale intervals within normally more sandy facies are found. These are interpreted to be shale filled-channels which are likely submarine canyons. Further research into the location, orientation, and causes of these canyons would be a great benefit to understanding the lower Wilcox Group in the area.

Ideally the use of 3-D seismic data in this area would be of great significance. The seismic data would allow the user to see large scale structural and stratigraphic features that cannot be seen through correlation of widely spaced well logs alone. The 3-D seismic data could possibly show paleo-channels, salt diapirs, unconformities, and faults.

Core analysis was not used in this study. Subsequent more detailed studies should integrate core data into the project to be able to characterize these lower Wilcox Group coals better. Understanding coal properties of the lower Wilcox and being able to describe their producibility and petrophysical data would be a great addition to the coalbed methane research group.

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APPENDIX A: WELL DATA

UWI/API #	SERIAL #	WELLNAME	WSN	SURF LONG.	SURF LAT.	K.B
17079203700000	196348	J M HAAS	425	-92.232115	30.969792	78
17029204000000	125265	C C MILLER	426	-91.642623	31.277674	70
17009001800000	100128	B QUINN	427	-91.960123	31.105985	54
17009000600000	61966	P BASCM KELONE ET AL	428	-92.155029	31.142086	66
17009000780000	37753	JAMES OLIVER UNIT	429	-92.060526	31.175884	87
17009001290000	72636	ROY O MARTIN ET AL	430	-91.836123	31.22898	53
17009002100000	103338	SW IMP CO /G/	431	-91.886723	31.123283	56
17009002350000	91568	SOUTHWESTERN IMPROVE	432	-91.802222	31.163878	50
17009201900000	153268	UNA M MOORE	433	-92.084027	31.144486	88
17009202000000	154890	WRIGHT	434	-92.012921	30.912991	80
17009202140000	157523	E L LYLES ET AL	435	-92.156427	30.982089	70
17009202150000	157624	M J DUCOTE	436	-91.985719	30.89879	70
17009202620000	175012	BROADHEAD	437	-92.089759	31.303671	60
17009202940000	184398	EMMA MARSHALL	438	-91.793316	31.053999	50
17009203600000	201188	BROADHEAD	439	-92.011155	31.313464	59
17009203820000	205757	ED RB SUA;BORDELON E	440	-92.087393	31.162345	87
17009205480000	217013	BLACK STONE MINERALS	441	-91.779776	31.164246	62
17009205570000	221373	BLACK STONE	442	-91.791681	31.1509	58
17009205590000	222532	BLACK STONE	443	-91.749312	31.16898	51
17025014070000	50885	ROANE B ROBINSON	444	-91.887028	31.419676	60
17025015330000	36434	LA DELTA HDW LBR COI	445	-91.929527	31.31028	60
17025205660000	151929	MISSIANA	446	-91.881727	31.390877	49
17025215330000	208284	MISSIANA	447	-91.895375	31.399939	54
17029002730000	44160	F D BROWN	448	-91.789527	31.56617	65
17029013690000	49644	MADISON OIL & DEVELO	449	-91.681822	31.437972	50
17029013950000	43992	ANGELINA HARDWOOD CO	450	-91.690924	31.399874	60
17029017690000	80307	ANGELINA HARDWOOD LU	451	-91.699524	31.317776	46
17029018750000	92970	ANGELINA LUMBER COMP	452	-91.720322	31.273176	53
17029207330000	137677	ELLIS	453	-91.747223	31.240077	50
17043004150000	46533	JOE SHORTER	454	-92.604046	31.461776	153
17043200500000	128508	POLLOCK	455	-92.456241	31.480078	209
17059026810000	53390	LA DELTA HDW LMBR CO	456	-92.04453	31.430378	54
17079000310000	64909	ESTELLE H SMITH ET A	457	-92.519541	31.372578	90
17079000470000	104165	JANIE MOORE ETAL	458	-92.426639	31.426277	167
17079000480000	72928	SOUTHEASTERN TIMBERL	459	-92.482442	31.411377	129

17079000540000	52842	U S A	460	-92.354235	31.421279	85
17079000550000	70200	L D HATAWAY	461	-92.324736	31.388378	99
17079004520000	111055	MCGINTY	462	-92.15103	31.346879	64
17079004680000	86554	ELBERT RYDER	463	-92.175331	31.34938	93
17079005860000	85045	C O FREEMAN ET AL	464	-92.425935	31.083186	150
17079202090000	141200	LANGSTON	465	-92.520241	31.150686	186
17079202630000	161902	HOWARD RYDER	466	-92.176302	31.352893	94
17079203530000	188402	KEMMONS WILSON ET AL	467	-92.564462	31.072937	213
17079203860000	207312	VUA;HOLT	468	-92.500793	31.388591	110
17079204380000	220169	AUS C RA SUB;VANDERL	469	-92.373942	31.01525	95
17025213990000	202206	WOMACK	470	-91.824207	31.499077	57
17025215920000	211663	C7 RA SUC; PLACID OI	471	-91.872808	31.464314	63
17025012980000	26787	TENSAS DELTA	472	-91.968101	31.4815	60
17025013760000	39343	LA DELTA HDW LBR CO	473	-91.907903	31.3938	54
17025208000000	168650	MISSIANA	474	-91.868361	31.393916	50
17025217230000	226866	MISSIANA WL	475	-91.850281	31.281299	52
17025015570000	36205	LA DELTA HWD LBR CO	476	-91.9674	31.3028	66
17059027640000	34631	EXXON-TENSAS-DELTA S	477	-92.0151	31.3505	56
17059205900000	129885	HUMBLE-TENSAS DELTA	478	-92.0503	31.3987	66
17059248480000	217323	EXXON-TENSAS DELTA 1	479	-92.130097	31.419644	66
17059204080000	125891	HUMBLE-TENSAS DELTA	480	-92.0907	31.4732	68
17059203990000	125726	SL 1462	481	-92.1667	31.4881	62
1705925146000	228489	WX D RC SU117;SL 168	482	-92.108056	31.553056	48
17059247040000	215489	SL 14382	483	-92.066704	31.537141	78
17059022410000	112956	BODCAW FEE	484	-92.2054	31.5565	203
17059233740000	192800	IPB LLS	485	-92.273512	31.553318	68
17029206640000	135388	WINSTON	486	-91.536	31.5331	76
17029004380000	33306	FISHER LUMBER CO	487	-91.601413	31.554026	65
17029222260000	190932	THOMAS NEWMAN ET AL	488	-91.65067	31.521803	65
17029012580000	112810	RABB SWD	489	-91.710902	31.453598	61
17029220250000	185909	MADISON OIL & DEVELO	490	-91.664041	31.426931	64
17029229740000	219669	VUA;MORGAN ET AL	491	-91.51578	31.42035	73
17029015900000	60477	R B SHARP	492	-91.5215	31.3173	73
17029017350000	91349	ANGELINA HDW LBR CO	493	-91.6907	31.3572	64
17029013610000	111801	ANGELINA LUMBER COMP	494	-91.719602	31.371899	49
17029228660000	214538	ANGELINA BBF	495	-91.772354	31.326482	52
17029230250000	226102	COX SWD	496	-91.8414	31.308428	62
17029018000000	82000	YAKEY	497	-91.6909	31.2945	50
17009002990000	100972	L M HOLMES	498	-91.848603	31.021599	53

17009003030000	91401	ROY O MARTIN LUMBER	499	-91.7599	31.0728	60
17009205560000	221132	BLACK STONE	500	-91.81718	31.15384	68
17009201370000	138350	R O MARTIN LUMBER CO	501	-91.700288	31.171471	53
17009001450000	72637	G G SNOWDEN-EL	502	-91.890501	31.207998	57
17009001190000	46437	FISHER	503	-91.956403	31.1936	57
17009001760000	103507	B QUINN	504	-91.9688	31.1348	52
17009002880000	102947	B QUINN	505	-91.973002	31.087599	55
17009204840000	212195	VUA;W DESCANT	506	-92.10085	31.007234	67
17009000630000	77817	FLORENCE BERNARD UN	507	-92.139002	31.1145	70
17009000730000	107722	EDWIN BARBIN	508	-92.0707	31.1529	88
17009000460000	38419	ELLIS LABORDE	509	-92.163503	31.215398	96
17009202240000	160712	DUPUY	510	-92.090415	31.250551	80
17079005770000	44997	C KELLER	511	-92.397502	31.235399	140
17079005780000	71523	LEE LUMBER CO.	512	-92.285901	31.242998	110
17079000700000	43198	MARIE BROUSEK	513	-92.3109	31.3076	104
1707920362000	192863	ALEXANDRIA LBR & LAN	514	-92.340494	31.320478	165
17009202870000	182715	BROADHEAD	515	-92.106545	31.295332	70
17043004180000	72891	U S A 72891	516	-92.3758	31.47729	176
17043004120000	73033	HUGHES USA	517	-92.5305	31.4782	190
17043003570000	73195	USA 73195 122C	518	-92.6006	31.55419	195
17079005340000	91082	EOTA REALTY COMPANY	519	-92.1202	31.33509	60
17079200980000	125104	eota-morace 125104	520	-92.1233	31.34139	59
17043200390000	127435	POLLOCK	521	-92.4555	31.4656	200
17079201330000	129006	EDGAR R SLAY ETAL 12	522	-92.2204	31.43969	79
17043200620000	136996	DUKE ETAL 136996	523	-92.6092	31.55849	194
17079203000000	172810	MICHEAL WILSON SWD 1	524	-92.1286	31.33542	67
17043004260000	109101	H N TANNEHILL HEIRS	525	-92.2899	31.48409	83
17079203340000	181003	JOHN TYLER ET AL	526	-92.12896	31.33221	73
17079203430000	182874	ELBERT LUCAS	527	-92.13784	31.33201	94
17079203520000	188263	ROBERT C JENKINS	528	-92.2209	31.39903	84
17079203740000	198801	MAMIE O MCGRAW	529	-92.21932	31.38506	86
17079005230000	32883	A N FLOYD	530	-92.1371	31.33489	85
17079005660000	33181	LESSIE	531	-92.1328	31.32799	94
17043003580000	43760	TAYLOR	532	-92.5591	31.51409	180
17079204390000	219410	USA-LROC 34	533	-92.55395	31.10109	255
17025217160000	225982	TL SU28; ROUTON D	534	-91.818665	31.704214	61
17025005190000	41857	TENSAS DELTA LAND CO	535	-91.9456	31.6459	51
17025010110000	106099	BURROUGHS	536	-91.904243	31.609403	64
17025202160000	128235	T D HOR	537	-91.9293	31.5421	56

17025206090000	152618	COTTON ESTATE	538	-91.8168	31.5443	55
17059242600000	209642	IPB WALKER ET AL ND	539	-92.132107	31.630289	147
17059251710000	229281	MARY PIPES ET AL	540	-92.202222	31.6625	192
17059217220000	168739	IPB 1	541	-92.251433	31.706188	121
17059217710000	170237	IPB 17	542	-92.052835	31.670592	224
17059018170000	47264	TENSAS DELTA LAND CO	543	-92.0095	31.6195	120
17059236110000	197548	IPB LLS	544	-92.018309	31.692072	200
17025015900000	119537	MITCHELL SWD	545	-91.733057	31.649267	63
17029229010000	215157	VUA;MARY T SMITH ET	546	-91.80944	31.602165	67
17029221560000	188719	L W MAGOUN	547	-91.731518	31.575436	97
17029003870000	103450	FISHER LBR CO	548	-91.631233	31.616492	66
17029000650000	90963	J GLANTON	549	-91.6008	31.663298	65
17029207870000	140633	J BALFOUR MILLER ET	550	-91.50073	31.702692	64
17029213540000	163995	L TUSC RA SUG;JOHN D	551	-91.506779	31.664325	65
17029204590000	126393	LEARNED-PEABODY	552	-91.4383	31.627	64
17029226920000	209349	P L ROUNTREE	553	-91.47968	31.557949	57
17029223870000	198470	THOMPSON ET AL	554	-91.636154	31.057237	55
17079006110000	46964	CROWELL LAND	555	-92.7019	30.956	156

APPENDIX B: HORIZON DEPTHS

WSN	SERIAL#	WILCOX	BBS	HOR. 3	HOR. 2	HOR. 1	TOPMS
425	196348	-8171.8					
426	125265	-4909	-6316.97	-6564.58			
427	100128	-6149.15	-7418.24	-7888.66	-8244.2	-8725.27	
428	61966	-5893.34	-7243.68	-7693.8	-8260.38		
429	37753	-5370.65	-6622.53	-7288.33	-7737.83	-8257.38	-8519.08
430	72636	-5160.84	-6402.83	-7120.71	-7516.98	-8094.07	-8610.41
431	103338	-6104.95	-7370.9	-7891.35	-8226.81		
432	91568	-5679.59	-6936.16	-7494.12	-7901.83		
433	153268	-5608.77	-6790.32	-7479.56			
434	154890	-8340.91	-9996.02	-10412.9	-10754.3	-11240.2	-11903.3
435	157523	-7882.04	-9251.14	-9753.66	-10117.7	-10749.9	-11381.7
436	157624	-8500.95	-10384.2	-11168.8	-11565		
437	175012	-4183.27	-5242.45	-5720.16	-6288.24	-6843.41	-7467.44
438	184398	-6702.43	-8068.2	-8811.64			
439	201188	-4235.85	-5225.17	-5617.87	-6191.04	-6720.86	-7321.02
440	205757	-5478.49	-6730.37	-7382.1	-7803.67		
441	217013	-5671.37	-6942.35	-7716.55	-7982.2	-8578.72	-9225.27
442	221373	-5797.58	-7079.03	-7662.15	-8095.12	-8688.71	
443	222532	-5641.08	-7016.2	-7741.62	-7966.26	-8585.87	-9301.7
444	50885	-3897.26	-5051.85	-5585.2	-5903.66	-6359.84	
445	36434	-4492.73	-5571.13	-6293.19	-6626.09	-7202.8	-7737.31
446	151929	-4102.63	-5216.48	-5891.58			
447	208284	-3996.03	-5117.64	-5722.48	-6185.09	-6697.23	
448	44160	-3625.01	-4645.3	-5003.49	-5407.55	-6182.09	-6722.03
449	49644	-4408.95	-5575.13	-5904.65	-6260.09		
450	43992	-4469.29	-5744.61	-6222.86	-6681.03	-7366.26	
451	80307	-4816.18	-6166.53	-6593.2	-7059.68	-7683.71	-8195.84
452	92970	-5069.32	-6548.69	-6876.9	-7220.56	-7869.31	-8344.54
453	137677	-5131.01	-6654.84	-7217.49	-7587.49	-8103.2	
454	46533	-3274.44	-4634.12	-5281.2	-5821.48	-6182.71	-6662.46
455	128508	-3268.73	-4654.94	-5239.27			
456	53390	-3326.55	-4282.69	-4944.16	-5376.01	-5754.73	
457	64909	-4007.92	-5325.45	-5991.25			
458	104165	-3635.46	-5098.48	-5684.5			
459	72928	-3790.75	-5087.6	-5867.85	-6271.08		
460	52842	-3740.98	-5114.16	-5747.74			
461	70200	-3848.89	-5348.05	-5846.27			
462	111055	-3672.89	-4629.39	-5182.66	-5665.59	-6251.68	-6743.99
463	86554	-3672.03	-4694.16	-5097.39	-5727.98	-6239.84	-6720.9

464	85045	-6812.72	-8281.2	-8862.19	-9249.76		
465	141200	-5979.64	-7508.16	-8042.67	-8441.97	-8934.91	-9510.23
466	161902	-3649.1	-4669.72	-5269.87	-5839.53	-6282.81	-7040.25
467	188402	-6740.34	-8278.24	-8723.66	-9296.45	-9887.93	-10274.8
468	207312	-3867.05	-5202.3	-5793.07			
469	220169	-7608.54	-9001.08	-9558.57	-9971.64	-10439.4	-11052.9
470	202206	-3740.85	-4936.47	-5391.27			
471	211663	-3744.23	-4954.57	-5507.18	-5907.46		
472	26787	-3334.38	-4375.86	-4780.41	-5184.95	-5675.56	-6153.27
473	39343	-3987.66	-5239.54	-5628.71	-6094.71	-6593.94	
474	168650	-4076.06	-5234.17	-5918.72			
475	226866	-4833.63	-5995.62	-6718.48			
476	36205	-4444.58	-5563.53	-6178.95	-6596.4	-7082.71	-7646.49
477	34631	-3929.4	-4783.4	-5359.45	-5884.58	-6498.8	-7113.02
478	129885	-3520.27	-4368.85	-5086.03	-5562.42	-6074.34	-6608.53
479	217323	-3125.2	-4051.67	-4736.1	-5298.1	-5581.89	-6047.45
480	125891	-2937.46	-3814.24	-4470.66	-4930.16	-5216.17	-5685.04
481	125726	-2639.53	-3570.64	-4255.99	-4656.63	-5032.41	-5471.82
482	228489	-2571.73	-3458.28				
483	215489	-2769.82	-3643.46	-4306.22	-4736.27	-5037.17	
484	112956	-2384.46	-3196.31	-4006.49	-4409.91	-4696.48	-5161.1
485	192800	-2473.28	-3193.25	-3800.18	-4221.54	-4686.33	
486	135388	-4052.8	-5376.96	-5714.55	-6027.54	-7043.58	-7429.25
487	33306	-3933.04	-5185.03	-5441	-5841.64	-6673.52	-7232.74
488	190932	-3971.99	-5212.86	-5474.38	-5886.15	-6718.03	-7449.75
489	112810	-4177.59	-5457.6	-5794.79	-6128.41		
490	185909	-4351.37	-5653.45	-6007.87	-6382.39	-7061.25	-7690.03
491	219669	-4462.72	-5964.15	-6330.78	-6948.81	-7402.73	-7836.84
492	60477	-4761.05	-6120.77	-6406.78	-7009.88	-7547.04	-8134.51
493	91349	-4679.67	-5843.76	-6251.68	-6729.93	-7428.54	-8091.77
494	111801	-4588.13	-5879.91				
495	214538	-4697.65	-5981.66	-6404.34			
496	226102	-4692.34	-6047.38	-6530.31			
497	82000	-4929.4	-6275.06	-6622.02	-7086.2	-7733.24	-8173.98
498	100972	-6975.36	-8405.42	-8864.91			
499	91401	-6462.5	-7831.24	-8571.9	-8919.29	-9314.14	-9751.51
500	221132	-5766.63	-7037.61	-7837.15			
501	138350	-5680.37	-6986.27	-7562.4	-8047.74	-8602.92	-9046.37
502	72637	-5251.46	-6479.46	-7266.75	-7665.16	-8130.83	
503	46437	-5292.81	-6545.15	-7401.58	-7815.32	-8319.84	
504	103507	-5860.45	-6999.81	-7534.93	-7740.62	-8204.8	-8912.8

505	102947	-6331.01	-7601.65	-8089.27			
506	212195	-7439.61	-8799.33	-9252.47	-9732.36		
507	77817	-6190.43	-7591.34	-8149.29	-8774.15		
508	107722	-5580.64	-6851.28	-7193.55	-7592.09	-7995.32	-8632.98
509	38419	-4977.17	-6168.1	-6733.3	-7399.1	-8087.99	-8560
510	160712	-4632.14	-5837.14	-6427.92	-6887.41	-7501.63	-8176.8
511	44997	-5087.07	-6321.03	-6884.09	-7366.61	-8065.23	
512	71523	-4972.55	-6304.25	-6852.72	-7435.13	-7904.65	
513	43198	-4467.48	-5783.01	-6282.01	-6793.55	-7194.86	
514	192863	-4374.21	-5708.04	-6217.83	-6699.68	-7097.8	-7636.92
515	182715	-4210.78	-5200.1	-5598.64	-6147.22	-6803.64	-7535.07
516	72891	-3217.93	-4635.56	-5225.38			
517	73033	-3242.34	-4604.1	-5162.78	-5548.97		
518	73195	-2539	-3691.26	-4218.51	-4777.18	-5304.43	-5775.31
519	91082	-3812.87	-4717.79	-5421.09	-6008.5	-6374.31	-6951
520	125104	-3762.86	-4671.9	-5145.46	-5681.16	-6296.93	-6785.69
521	127435	-3375.5	-4744.25	-5376.24	-5774.3		
522	129006	-2973.34	-4114.53	-4708.16	-5196.07	-5518.85	-6112.75
523	136996	-2484.13	-3646.05	-4204	-4729.14	-5158.2	-5701.09
524	172810	-3773.05	-4696.72	-5184.4	-5677.01	-6315.87	-6812.33
525	109101	-2972.24	-3818	-4292.61	-4630.8	-5018.37	
526	181003	-3799.87	-4732.92	-5405.9	-5952.46	-6438.78	-6972.43
527	182874	-3788.24	-4684.03	-5176.1	-5700.04	-6369.69	-6808.42
528	188263	-3313.42	-4483.14	-5013.88	-5506.21	-5974.1	-6595.62
529	198801	-3430.53	-4522.99	-5066.88	-5597.92	-6097.14	-6772.82
530	32883	-3750.36	-4674.03	-5185.64	-5685.95	-6324.81	-6755.84
531	33181	-3853.89	-4758.81	-5246.43	-5780.94	-6365.84	-6868.72
532	43760	-2933.3	-4216.05	-4813.47	-5174.5		
533	219410	-6390.68	-7895.82	-8343.72	-8670.79	-9252.74	-10083.2
534	225982	-3066.36	-4140.08				
535	41857	-3031.69	-4024.94	-4445.05	-4731.62	-5268.59	-5562.54
536	106099	-3280.22	-4331.9	-4668.54	-4980.32		
537	128235	-3380.82	-4458.77	-4876.51	-5283.04		
538	152618	-3639.7	-4787.99	-5083.82	-5421.28		
539	209642	-2354.97	-3222.11	-3619.83	-4045.3	-4378.28	-4907.42
540	229281	-2127.29	-2959.74	-3491.59	-3822.53	-4068.3	-4620.02
541	168739	-1835.25	-2348.6	-2670.02	-3109.36	-3396.1	-4018.12
542	170237	-2530.39	-3465.21	-3812.99	-4057.82	-4475.16	
543	47264	-2755.84	-3727.16	-4168.37	-4598.1	-4900.92	-5439.32
544	197548	-2648.99	-3581.03	-3926.02	-4187.55	-4616.01	
545	119537	-3400.85	-4458.09	-4803.09	-5298.32	-5902.06	-6425.12

546	215157	-3458.9	-4527.93				
547	188719	-3657.93	-4739.37	-5108.83	-5482.14	-6313.43	-6852.22
548	103450	-3709.46	-4780.61	-5228.55	-5629.19	-6288.57	-6856.14
549	90963	-3576.92	-4684.24	-5126.61	-5521.68	-6206.11	-6648.48
550	140633	-3452.53	-4291.8	-4741.92	-5210.79	-5928.16	
551	163995						
552	126393	-3696.56	-4754.55	-5102.95	-5463.98	-6415.78	-7039.38
553	209349	-3937.77	-5053.68	-5377.2	-5806.89	-6615.21	-7323.02
554	198470	-6424.78	-7757.97	-8286.46	-8784.57	-9288.77	-9841.55
555	46964	-7796.68	-9193.84	-9619.06	-10111.1	-10712.5	-11672.3

APPENDIX C: COAL DEPTHS AND THICKNESSES

WSN	SERIAL#	TOP REYNOLDS COAL	TOP RUSSELL COAL	REYNOLDS COAL GROSS	RUSSELL COAL GROSS
425	196348			0	0
426	125265		-7084.84	0	0
427	100128			0	0
428	61966		-8075.61	0	0
429	37753	-8203.07	-7542.56	0	0
430	72636	-7940.23	-7377.24	0	0
431	103338	-8712.55		0	0
432	91568		-7778.89		0
433	153268		-7758.22	0	0
434	154890	-11015.33	-10725.16	0	0
435	157523	-10567.42	-10095.6	0	0
436	157624			0	0
437	175012	-6709.03	-6122.9		0
438	184398		-9074.68	0	
439	201188	-6617.29	-6101.65	0	0
440	205757		-7646.55	0	0
441	217013	-8497.52	-7938.65	0	0
442	221373	-8478.88		0	0
443	222532	-8397.11	-7926.95	0	0
444	50885	-6320.33	-5844.66	7.99	0
445	36434	-7026.88	-6538.39	8.94	0
446	151929			0	
447	208284	-6654.1	-6156.45	7	0
448	44160	-5830.27	-5372.69	0	
449	49644	-6683.8	-6186.2	5.96	5.96
450	43992	-7202.42	-6586.61	0	0
451	80307	-7583.68	-6982.71	0	
452	92970	-7738.34	-7200.72	0	0
453	137677	-7979.17	-7479.52	0	0
454	46533	-6035.96	-5751.68	0	0
455	128508			0	0
456	53390	-5730.94	-5306.83	12.92	8.7
457	64909			0	0
458	104165			0	0
459	72928		-6209.71	0	0
460	52842			0	
461	70200			0	0

462	111055	-6180.42	-5512.89	9.99	9.99
463	86554	-6141.84	-5617.78	0	7.23
464	85045	-9475.48	-9147.08	0	0
465	141200	-8638.19	-8367.39	0	0
466	161902	-6170.52	-5698.05	0	10.61
467	188402		-9212.16	0	0
468	207312			0	0
469	220169	-10178.39	-9840.41	0	0
470	202206				
471	211663		-5860.23	0	0
472	26787	-5476.67	-5143.55	13	0
473	39343		-5987.94	0	0
474	168650			0	0
475	226866			0	0
476	36205	-6984.97	-6499	0	0
477	34631	-6375.45	-5789.32	0	0
478	129885	-5953.68	-5508.52	0	
479	217323	-5501.1	-5266.07	0	7
480	125891	-5126.27	-4909.26	8.67	0
481	125726	-4956.73	-4581.39	15.17	0
482	228489			0	
483	215489	-4899.56	-4460.66	13	0
484	112956	-4693.46	-4241.98	8.08	10.48
485	192800	-4660.45	-4167.75	8.08	4.85
486	135388	-6812.73	-5977.06	7.45	0
487	33306	-6448.16	-5746.94	10.53	0
488	190932	-6348.49	-5786.83	11.92	5.96
489	112810	-6337.06	-6028.47		7.89
490	185909	-6883.43	-6296.97	0	0
491	219669	-7310.01	-6518.16	15.17	11
492	60477	-7444.96	-6896.1	6.97	8
493	91349	-7294.87	-6627.72	0	8.67
494	111801			0	0
495	214538		-6746.71	0	0
496	226102			0	
497	82000	-7665.39	-7013.85	0	0
498	100972			0	0
499	91401	-9300.72	-8838.31	0	0
500	221132			0	0
501	138350	-8489.26	-7999.58	0	0
502	72637	-8021.55	-7524.45	0	0

503	46437	-8189.18	-7709.49	0	0
504	103507	-8253.86		0	0
505	102947			0	0
506	212195	-10300.42	-9684.61	0	0
507	77817		-8583.92	0	0
508	107722	-7914.46		0	0
509	38419	-8049.32	-7329.65	0	0
510	160712	-7403.99	-6818.87	2.98	0
511	44997	-7986.77	-7311.61	0	0
512	71523	-7853.76	-7379.95	8	5.96
513	43198		-6705.82	0	0
514	192863	-7035.13	-6612.74	7.81	5.96
515	182715	-6685.91	-6133.51	9	7
516	72891		-5475.52	0	7.95
517	73033		-5499.52	0	0
518	73195	-5229.83	-4715.48	7.45	0
519	91082	-6144.45	-5894.63	7.99	4
520	125104		-5611.97		
521	127435		-5708.39	0	
522	129006	-5436.16		0	0
523	136996		-4652.72		8.94
524	172810	-5999.55	-5523.88	13.99	6
525	109101	-5008.71		8.71	
526	181003	-6117.32		10.52	
527	182874	-5999.91		12.27	
528	188263	-5754.74	-5350.23	10.48	8.38
529	198801	-5855.77	-5440.89		13.26
530	32883	-6105.46		9.99	
531	33181				
532	43760		-5142.26	0	5
533	219410	-9062.18	-8624.47		0
534	225982				
535	41857	-4981.15		16.15	
536	106099	-5391.39	-4947.15	12.92	9.75
537	128235	-5534.84	-5161.23	13	6.53
538	152618		-5334.3	0	13
539	209642		-4017.91	0	4.33
540	229281	-3946.9	-3689.2	10.84	8.71
541	168739	-3354.38	-3006.03	17.42	10.45
542	170237	-4348.32	-4011.32	13	
543	47264		-4556.34	0	13

544	197548	-4479.99	-4168.21	19.39	6.46
545	119537	-5770.4	-5233.29	9.69	0
546	215157		-5053.23		0
547	188719	-5968.79	-5457	7.89	10
548	103450	-6139.89	-5586.42	0	0
549	90963	-6093.49	-5501.9	9.99	9.99
550	140633	-5854.65		7.99	
551	163995				
552	126393	-6308.34	-5448.94	6	6
553	209349		-5751.23	0	0
554	198470	-9237.79	-8650.92	0	0
555	46964			0	0

APPENDIX D: LOWER WILCOX INTERVAL NET COAL FOOTAGES

WSN	SERIAL #	TOP MS-HOR.1	HOR. 1-HOR. 2	HOR. 2-HOR. 3	HOR 3-BBS
425	196348				
426	125265			8	4
427	100128	0	0	0	0
428	61966	0	0	0	0
429	37753	0	0	0	0
430	72636	7	0	0	0
431	103338	0	0	0	0
432	91568	0	0	0	0
433	153268	0	0	0	3
434	154890	0	0	0	0
435	157523	0	0	0	0
436	157624			0	0
437	175012	10	9	0	5
438	184398	0	0	0	0
439	201188	0	22	0	0
440	205757				6
441	217013	0	0	0	0
442	221373	0	0	0	0
443	222532	0	0	0	0
444	50885	0	0	4	0
445	36434	0	9	0	10
446	151929			15	0
447	208284	0	11	7	0
448	44160		7	0	2
449	49644	0	3	0	0
450	43992	0	4		9
451	80307	12	9		0
452	92970	2	0	0	0
453	137677	0	0	0	0
454	46533			4	0
455	128508			6	34
456	53390	0	16	32	17
457	64909	0	0	6	19
458	104165			27	11
459	72928			38	21
460	52842			7	5
461	70200			23	12
462	111055	0	9	12	0
463	86554			8	
464	85045	0	0	0	0
465	141200	0	0	0	1
466	161902	0	0	5	0
467	188402	0	0	0	0
468	207312				

469	220169	0	0	0	0
470	202206				
471	211663	0	0	0	16
472	26787	0	7	4	0
473	39343	0	0	0	
474	168650			7	0
475	226866			15	14
476	36205	0	0	3	5
477	34631	0	5	0	
478	129885	0	5	9	0
479	217323	0	0	26	21
480	125891	0	16	31	24
481	125726	10	12	0	17
482	228489				45
483	215489	0	0	7	9
484	112956	17	5	41	15
485	192800	9	25	16	5
486	135388	6	13	4	5
487	33306	13	5	0	0
488	190932	0	12	12	12
489	112810	0	5	0	0
490	185909	0	0	9	0
491	219669	6	18	10	10
492	60477	5	5	19	
493	91349	5	14		0
494	111801				
495	214538			6	0
496	226102			0	6
497	82000	0	0	0	0
498	100972				
499	91401	0	0	0	0
500	221132	0	0	0	0
501	138350	0	0	0	0
502	72637	0	0	0	0
503	46437	0	0	0	0
504	103507	0	6	0	0
505	102947			0	0
506	212195	0	0	0	0
507	77817	0	0	0	0
508	107722	0	0	5	0
509	38419	0		0	0
510	160712	5	6	4	5
511	44997	0		5	0
512	71523	12	9	0	0
513	43198	0	0	4	0
514	192863	6	16	19	6
515	182715	6	10	17	5
516	72891			12	12

517	73033	0	0	12	5
518	73195	7	7	8	5
519	91082	0	7	6	10
520	125104	0	0	0	0
521	127435	0	4	17	11
522	129006				0
523	136996	10	0	17	3
524	172810	5	11	6	
525	109101		9		0
526	181003	0	11	7	10
527	182874	8	11	0	5
528	188263	0	7	59	24
529	198801	0	0	9	9
530	32883	0	6	0	0
531	33181	0	0	8	0
532	43760	0	0	9	0
533	219410	0	0	0	0
534	225982				7
535	41857	0	13	0	0
536	106099	0	21	15	17
537	128235		19	6	9
538	152618	0	5	14	0
539	209642	11	15	22	2
540	229281	24	20	29	21
541	168739	0	25	7	0
542	170237	20	6	0	0
543	47264		10	22	
544	197548	27	26	15	8
545	119537	22	4	4	5
546	215157				
547	188719		5	8	2
548	103450				
549	90963	11	25	11	6
550	140633	0	28	12	0
551	163995				
552	126393	3	9	4	0
553	209349	4	11	10	3
554	198470	0	0	0	0
555	46964				

APPENDIX E

A Guideline for Beginning Coalbed Natural Gas Research Projects Using Various Software and Research Tools

Completed for Dr. Gary Kinsland
By: Scott G. Comegys
September 2006

(Modified by Adam Kruse)

TABLE OF CONTENTS

The following guideline was completed as part of an independent research project for Dr. Kinsland as a means of assisting students in creating projects in PETRA or Kingdom for the Coalbed Methane Research Group at the University of Louisiana at Lafayette. The information contained herein is a compilation of knowledge gained from the research experiences of Gary L. Kinsland, Joshua Kull, Scott G. Comegys, Chris A. Guidry, Eric J. Dew, Richard W. Ball, Michael B. Sheahan, William R. Copeland and Dan Han. The purpose was to try to expedite the process of surmounting the obstacles commonly encountered when trying to learn how to build a project of this kind, especially by those who have little or no experience in some of the software suites used at this institution.

The following workflow has been modified to make it more applicable on a sub-regional scale.

Chapter 1: Obtaining Well Data from LDWR

The first step should be determining the project area. Using latitudes and longitudes, parish boundaries, township-ranges, and sections can be used to limit the mapping area. Many wells have been digitized from previous projects; when compiling multiple projects be sure that each individual project area falls within the bounds of the newly formed project area.

Next locate the LDWR 2001 (Louisiana Desktop Well Reference) files on one of the CBNG group's computers, or the Energy Institutes backup hard drive. Within this file are .dbf files that can be opened in Excel. They are database files and they contain all of the information used to run the LDWR program. Each .dbf file has a unique parish number, the parish number can be found by, *SONRIS > Sonris Lite > Codes/Lookups > Parish Information.* Extract the .dbf files that contain the information needed, e.g. Well data for parishes and land grid data (located in Map Data folder). Open the .dbf in Excel for the parish’s wells. Copy and paste all of the well information into one large spreadsheet and save as a new file. This should produce a very large spreadsheet with all parishes covered in the project. Click on the upper-left corner of the spreadsheet to highlight the entire sheet (or press ctrl+a).

Go to the toolbar and select the following:

Data > Sort > Latitude > Ascending

Discard all well information above and below the selected latitude boundaries by highlighting the rows (on the left hand side with the row numbers), right clicking, and selecting delete. Now repeat the process for longitude. This produces all well information needed for the study area. Wells can also be limited by parish, township, and range. An important note: This represents well information that is current up to 2001 only. Further researches are needed to get more recent well information. Save the file and then repeat the sorting process by Total Depth to see what depth ranges are in the data. Scroll to the bottom of the list and choose the deepest one hundred and fifty wells. This allows getting started without getting bogged down with excess searching for logs on SONRIS. However, take note of the total depths of these wells, as there is usually a rough correlation between the total depth of a well and the depth at which logging starts. While using the deepest wells is the best-case scenario, it is important that the wells used have high-quality logs that penetrate the interval you are interested in. This will also most likely affect the distribution of wells over the project area.

When completing a sub-regional project, upload all the wells that are in your mapping area. You can sort and limit the wells once they are in the Petra project. Having all the wells in the project, allows for project goals and objectives to change without having to download the data again.

Chapter 2: Using SONRIS (www.sonris.com)

What is SONRIS? SONRIS is the Louisiana Department of Natural Resources' Strategic Online Natural Resources Information System. It has many uses, but our needs deal primarily with the raster log and well information mages. SONRIS Lite Select the SONRIS Lite option from the Database Access Menu. The Well Information menu lists various methods to query wells. Parish searches may take a while, as all wells within the parish will be listed. Knowing the Township/Range or API/Serial Number expedites the process. After the search, a list of wells and their info will appear on the screen. Information highlighted in blue is hyper-linked to additional information. Document Images Select this tab under the Document Access menu on the left hand side, under the Database Access menu. Choose the Office of Conservation from the topmost drop down menu. At the bottom of the information menu is an entry space for Serial Number (SN). I recommend using this search method. Enter SN and left click the Execute Search icon. Pressing enter will not automatically initiate the search. In the lower left screen some tabs will show up: They will list office and document type. Well logs will be labeled by log type and scale. There will be other information files as well. Well files have also been scanned. These images can be opened directly from the link and may contain information on tops, elevations, etc. Tops information is located on the back (second scanned image) of completion reports at the bottom. In uncertain areas, completion reports will be a valuable asset. For logs: scroll to the right side of the screen, right click on the Download tab and then save file as. The file must be saved as a .tif image to be recognized. Opening the file directly and then saving it through the Panagon viewer will not be recognized. Save the file by the API (all previous projects have logs saved as API). Sometimes there are different log types available. They differ by log type, scale, etc. Differentiate these in the file names, for example: 123456_BHC, 123456_DIL_2 in; file names can be long or short, so try to keep them easy to read and uniform. Digitize as many logs as possible (porosity, SP, GR, ILD, SN) because the more logs available in the project will make it easier in identifying coals in the project. Open the logs in Neuralog, PETRA, or the viewer, and figure out what curves are on the log, how deep the curves are, log quality, etc. Consider getting one log in at a time and then digitizing the curves, or doing them all together. *SONRIS can be temperamental, it is recommended that you:evaluate which logs are of good quality and useful, and download them immediately. Tip: It is better to have an extra log downloaded to fall back on, rather than no log at all.*

With all of the well information and log images a project can be constructed GIS SONRIS also has a GIS application that can be used if desired; there is an online tutorial that explains the program in detail. There is an option to view USGS topographic maps as a layer, and this should be used when no elevation information is available in well files or on the logs. Since LDWR contains only wells available in 2001, you can search for updated logs in your mapping area. Many wells are on the GIS maps however; many wells do not have their associated raster logs. To access numerous well files from GIS interactive maps:

Interactive Maps > Use zoom tool to zoom to area of interest

(must be zoomed in enough to show well locations) > Turn on Oil/Gas

Wells > Highlight Oil/Gas Wells > Click the Identify tool > Identify by rectangle tool > Select area of interest

A window will pop up with all the wells in selected area with well information (there can be hundreds of wells in a selected area, therefore a smaller area is easier to deal with and a less likelihood of crashing). This information can then be input in the Document Image search. This will allow for a large search of logs in a relatively short amount of time.

Chapter 3: Digitizing Raster Images Using Neuralog

Open the Neuralog and create a new project. Begin by opening a log image that was downloaded from SONRIS. *File >Open > Log Image > Link to new project*

It is important to have all the well header information in the new digitized format.

Edit > Well log Properties Input all pertinent information from well log header (i.e. API, Kelly Bushing, etc.). The first step in digitizing it setting up the depth and scale axis. Click the Create Scales and Depth Axis button > On the left side of the depth track, click once and assign proper depth value > Go to bottom of well and assign the lowest depth of interest > Press the Create scales and Depth axis button again, this will make the crosshair red, assign left side value first, then right side > Horizontal button allows for horizontal scale to be assigned, right clicking allows for the computer to make picks (the better the logs, the better the computer does at picking the scales) (Tip: It is not necessary to assign a depth scale by 10 foot interval. Every 50 foot will suffice. > Vertical scale must be assigned, similar to horizontal, right clicking will allow computer to pick scale locations > Most logs were not scanned perfectly straight, so one must adjust the scales sothey follow the log most accurately. After both the horizontal and vertical scales are assigned, click the Edit depth or Scale Axis button > Adjustments to the depth scale can be made while going up the log > When finished straightening the log scales, click the digitize curve button , a pop-up will ask what kind of curve is being digitized > The computer has different functions that allow picking of the curve easier, choose tracer type , right click and the computer will follow the curve (again, the better the quality of the log, the better the computer will do) > This process will be repeated for each curve , there may be multiple curves on a single depth/scale axis, in which a single depth axis would be acceptable (resistivity logs for example) > When all curves are completed, File >Export Digital Logs > Select all curves, Preserve Peaks, Smooth outputs, View After generation, add formatting information> OK > View and check log for errors (i.e. missing sections, scales off, etc...) Save digital logs as the API number (ex. 17059237760000.las). This allows importing the files as single wells, or in groups. All previous projects have .las files in the same format. Since some of the SP curve only has the interval value, the maximum and minimum value should be set up carefully with count the interval values. It doesn't matter, if all the SP curves have the same range of max and min, all the curves will be normalized after imported in PETRA.

Chapter 4: Creating a Project in Petra

Open the program, choose a name, and save the project. Do not share it or connect it to another project. In the following discussion, terminology will be used that is unfamiliar to first time users of PETRA. The program offers a built in tutorial and covers the basics in detail (see PETRA manual in Sandstone or the Basic Training Class Workbook). The PETRA training manual is online at: ftp://ftp.rac.louisiana.edu/upload/EI/coalbed methane /articles/Choose a map projection Project > Settings > Set Map Projection > Custom Projection tab: Lambert Conformal Conic Ellipsoid: Clarke 1866 State Plane: Louisiana North (NAD 1927) Set Datum as NAD 1927 (North American Datum) Bring in Base Map The coalbed methane group has provided a basemap as a PETRA overlay (.ovl) file. Obtain this from the group folder at the ftp site and select (in the map module) Overlay > Load > Overlay file Follow the instructions below to build a landgrid from LDWR 2001 from scratch or scroll down to the instructions for bringing in township/range lines. The section lines and labels are already included in the coalbed methane land grid.

Go into the Map Module

Overlay > Load > Import

Under File tab:

Browse for the shape file from LDWR

Merge with the current layer

File Type: ESRI Shape File (LAT LON)

Load Into Layer: LANDGRID

Import > OK

Start with the entire state. If it does not appear after selecting OK, go to Display > Data Limits > Use Overlay Extents.

Repeat the process for Section, TWP & RGE.

Each parameter, i.e. section lines, imported into the program can be located in its own layer. This enables the user to turn different layers off and on and is helpful when making various maps.Return to the Main Module Before importing well data that was created in Chapter 1, a couple of more things need to be done:

Save the spreadsheet as a CSV (Comma Delimited) in Excel.

Project > Import > General Well Data From > Generic ASCII file

Import File > Browse for file

Data Format Select UWI or API Number from upper-right pull down menu. Highlight the API number in the topmost row and click the + symbol. Repeat the process for all of the columns, but DO NOT highlight the commas. Bring in LAT/LONG and let PETRA calculate X/Y values automatically. Also, PETRA will automatically determine parish and state from the API number (Wells > Set State/Cty from API Number). Skip rows that have column titles in them. Import .las files into project. This is accomplished in the main module Logs > Import Las file, or Logs > Batch las import. It will be beneficial to upload the raster images as well. Some detail is lost in the digitizing process it is sometimes necessary to view the original raster image. To batch upload the raster images, Project> Import> Raster Logs From> Uncalibrated TIFF Files.

Chapter 5: Identify Sand and Coalbeds

Previous coalbed natural gas work at the University of Louisiana Energy Institute involved using a resistivity cutoff value to define coals, known as the Quick-Look Technique (Kull, 2006). When mapping smaller areas with more well control, one must use a more precise way of defining coal beds. This will be done by examining individual logs in cross section and using as many curves as possible to identify coal beds. Digitized logs may have different curve names for similar measurements, e.g., ILD, LN, AITH are all electrical resistivity records measured by different tools. PETRA has a feature that allows the user to alias logs of similar nature under a single curve title. For example, all of the long resistivity curves mentioned above may be grouped as Res_Long and the short resistivity can be grouped as Res_Short.

STEP 1: Normalize SP (Main Module)

Compute > From Logs > Normalization

Normalization makes all the logs have the same scale. Petra only allows one scale for each kind of log. SP logs come in many different scales; therefore it will make correlation much easier when all the SP logs have the same scale. One should try different types of normalization and see which one yields the best results. Do not normalize resistivity logs, as most, if not all are already the same scale, 0 -10 ohms.

In the Crosssection and Log correlation Module, SP logs can be displayed in color intervals to depict interpretation as sand or shale. The ILD curve can be done as the same way. Logs > Scales and Display Options > GeoColumn > Colors The colors can be manually chosen or automatically interpolated. After the log curves display in the cross section, some curves will have a problem with the color interpretations. In order to prevent this problem, try to use logs that, before normalization, had the same scale and were taken by the same well logging company. If this is not possible, for the individual curve, the normalization should be applied again by changing the mean value of the curve.

STEP 2: Create Formation Tops (Main Module)

Before correlating the formation tops in the cross section module, the formation tops must be created. Fm Tops tab > + New Top > Type in the Formation Top name, for example: "Carrizo" > OK

Repeat this for all remaining Formation Top in the project.

STEP 3: Create a Zone (Main Module)

Zones > Add/Modify (Zone Maintenance) > New Zone Interval Definition

Upper Depth = Wilcox

Lower Depth = Midway

Create zones for each interval to be interpreted. I recommend creating zones for each zone of the Lower Wilcox. To do this, the upper and lower boundaries (tops) of the interval must be determined, i.e. BS, 3, 2, 1, MY.

STEP 4: Correlate Formation Tops (Cross Section Module)

To select the wells needing correlation:

Wells > Select Wells > Wells From A List > Select Wells from Available Wells > Accept...

To correlate Formation Tops for the wells: Choose a given "Top" from the "Tops" drop down menu > Start > Left click on the log to pick the Top > to finish picking Tops, right click.

Only after all Formation Tops are correlated correctly, can you move on to"Computing Log Statistics" and "Computing Net Footages," for each new correlation will call for new computations of Log Statistics and Footages.

STEP 5: Creating Maps (Map Module)

Click on the "Create a Grid" button > Data > Zone Data To Grid > Choose Zone to Grid > Choose Zone Data > OK

Click on the "Contour o Grid" button > Grid > Choose Grid to Contour from drop down menu > OK

STEP 5: Compute Log Statistics (Main Module)

Compute > from logs > Statistics

Select log data from > SPSelect: Mean, Percentile N = (ex. 5 & 95)

Compute for Zones > Zone of Interest

Experiment with different percentile ranges. The ultimate goal is to view the histograms and see how the mean plots, i.e. does it capture the thin, or less prominent sands? Go into Histogram Module and view histograms for wells.

Depths > Depths tab > Select Zone

Return to Main Module: Compute > from Zones > Equation Expression

Transform: SPCUTOFF = (PC5SP + PC95SP)/2

Assign Z Data:

Output Zone: Zone of Interest

Equation Variables: PC5SP _ Zone > Wilcox > PC95SP

> Assign

Repeat for PC95SP

In Histogram Module:

Define Picks > Choose Zone > 5th/95th percentiles, mean, cutoff

Repeat for each zone.

STEP 6: Compute Net Footages

Compute > from logs > footages

Footages:

Check: Gross, Net, Net/Gross

Log Curves & Conditions

Gamma Ray

SP

Min Cutoff = -1000 (this makes sure all SP values

are included, Max = mean).

Depth Zones > Zone of Interest

Options: Gross is Interval Thickness only. Compute for all selected wells. *This will process all of the wells selected in the Main Module.*

Filter: Check tops, use interval. In order to save time you can batch process your calculations. Simply enter your settings (carefully) for every calculation you want to complete, and choose a single interval. Verify the upper and lower tops in the “Filter” tab bind the interval you picked. Save each template (this includes zone and interval calculations automatically) as specific file names (Ex. 3-2 Interval Net Sand Calculation). Once you have saved a template for the entire interval and calculations you want to run go to the “Batch” tab. Click the < button and enter all of the file names by clicking on them, when finished click open. This will add all of the selected files to the batch process menu. To finish click “Process Batch Template”.

STEP 7: Identify Coal

The Quick-Look Technique utilized only the ILD logs using a cutoff value where any amount greater than the cutoff value is defined as coal. This method is not very specific and should not be applied to a smaller detailed mapping area. Ideally a suite of logs (porosity, gamma ray, electrical) will be available for every well, however that is not the case since most of the wells come from SONRIS. There are still a number of wells that have many logs available, and these wells should be examined first. Coal beds have a unique signature, low GR, low density, high resistivity and high transit time. Therefore, if you have all of these different kinds of logs it will be more accurate than using just the resistivity. Coals should be identified as a spike in resistivity. It turns out to be a spike due to the high resistivity and rather thin beds, typically less than 12 feet. Certain parameters can be set up in Petra so that where curves cross there is coal (i.e. resistivity crosses porosity curve). To make this worthwhile one must have a large number of wells with all the same kind of porosity logs.

STEP 8: Picking Coals

Petra has a tool to pick pay in the cross section module in which can be used to pick coalbeds as well. Use the Pay Intervals toolbar: Begin by selecting the New Pay Name and assigning a name to the coalbeds in the interval of interest. A different "Pay" is to be assigned to each individual interval, similar to what has been done in the previous CBNG theses. There should be four different pay zones, each associated with an interval. A different color for each pay zone makes it easier to identify and correlate. Below are the established intervals, pay zone names, and associated colors:

Interval Horizons Pay Name Color

1 MY-1 Coal_A Black

2 1-2 Coal_B Blue

3 2-3 Coal_C Magenta

4 3-BS Coal_D Light Green

Once the four pay intervals have been created, pick the top and base of each coal bed can begin. Picking pay intervals is performed by using the Pay Interval tool, , which ensures the correct coal is selected for the proper interval. When all the coal has been picked for a selected interval, right click and save to database. When all the coal beds have been selected for their proper interval, use the summation tool to add the footage to the database. Make sure that the pay is being summed into the correct zone and in the correct item. A new item will have to be created for the interval, such as NET_COAL_A for the deepest interval. This can be done in the main module, Zones (tab) > Maintenance > Select Zone of interest > Data Items (tab) > + New Item

Now that the wells have the coalbeds selected and summed for each interval, the whole lower Wilcox can be summed in the main module. Create a new zone item in the Wilcox-Midway zone and name it Net_Coal_Picks. Once the Net_Coal_Picks has been created, all the different zones can be summed into that item by the following,

Compute > From Zones > Summation > Z Items to Sum...

Select all the summed coal values and store results in the Wilcox-Midway Zone.

Step 9: Exporting Figures: The following steps must be followed to export maps and cross sections from Petra to other programs like Microsoft Word. Map Module/Cross Section Module > File > Print Preview > XPS

Document Writer > OK > Set Legend Parameters > OK > Save as a .xps file > File > Save As > .jpeg file

BIOGRAPHICAL SKETCH

Charles Chaisson was born on October 26, 1988 in New Orleans, LA. He spent the majority of his childhood in Destrehan, LA, where he attended Destrehan High School. Charles played basketball in his early high school years before transitioning into football where he was recognized as an All-District player, Wendy's High School Heisman runner-up, and an All-State Academic Athlete. Charles graduated high school in May of 2007 and started attending the University of New Orleans in the fall of 2007. Charles began college with the intent of becoming a Mechanical Engineer but was introduced to the Geosciences. As a recent geology undergraduate student Charles began working with a civil engineering company in May of 2009 as a geology and lab technician. Charles later joined Covington Exploration in May of 2010 where he really began to understand subsurface geology and became familiar with the oil industry. In the summer of 2011 Charles graduated from the University of New Orleans with a Bachelors of Science in Geology. He then started his graduate work at the University of Louisiana at Lafayette in the spring of 2012. On October 12, 2012 Charles was blessed with the birth of his first child Logan Ray Chaisson. Charles intends on receiving his Master of Science in Geology in the summer of 2014. Charles is currently working as a Geologist at Covington Exploration in Covington, LA.