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SEQUENCE STRATIGRAPHIC FRAMEWORK OF THE CANEY SHALE, ARKOMA BASIN SOUTHEASTERN OKLAHOMA

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SEQUENCE STRATIGRAPHIC FRAMEWORK OF THE CANEY SHALE, ARKOMA BASIN SOUTHEASTERN OKLAHOMA

A THESIS APPROVED FOR THE
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TABLE OF CONTENTS

LIST OF TABLES

Chapter 1: Introduction

LIST OF FIGURES

Chapter 1: Introduction

Chapter 2: Geologic Setting

Chapter 3: Core Analysis

Chapter 4: Well Logs

Chapter 5: Sequence Stratigraphy and Well Log Cross Sections

Chapter 6: Geological Maps

LIST OF PLATES

ABSTRACT

Many petroleum companies have turned their attention to the exploration and development of shale as unconventional resource plays. The focus of this study was the Caney Shale, which occurs in the Oklahoma part of the Arkoma Basin. The Caney is part of a larger group of formations from the top of the Hunton Limestone, upward through the Goddard shale. The Caney is an unconventional reservoir. The beds within the Caney vary in thickness from a few feet to over 20ft and are laterally persistent for miles. Although Caney production has occurred since 2005, producing approximately 1 BCF and 17 MBO, explanations of the geology of the field are not consistent among industry geologists.

Few studies have implemented the use of high frequency sequence stratigraphy in shales. Developing a detailed stratigraphic framework for the Caney, including depositional settings, reservoir characterization, petrophysical responses, and organic content, was the goal of this thesis. Four cores were utilized within the study area. The Cometti 2H-13 core was the primary core of interest due to its total coverage length. The Cometti was drilled by Newfield in April of 2007. Core was taken from the Sylvan Formation up through the Goddard Formation. In this core, the Caney shale is a dark grey to black shale, containing pyrite concretions, carbonate laminae, algal cysts, shell fragments and lag deposits. Six different facies were identified in the core: Massive bed, Non-Fossil Bearing, Massive Bed, Fossil Bearing, Faintly Laminated Bed: Non-Fossil Bearing, Faintly Laminated Bed: Fossil Bearing, Highly Laminated Bed: Non-Fossil Bearing and Highly Laminated Bed: Fossil Bearing. The core facies analysis performed

on the Cometti showed an overall trend from the Massive beds: Non- and Fossil- Bearing up to Highly Laminated Beds: Non- and Fossil- Bearing.

Sequence stratigraphic features identified on gamma ray logs within the study area are as follows. : Transgressive Systems Tract (TST) is characterized by a fining upward pattern or an increase in gamma ray API values. Regressive Systems Tract (RST) is characterized by a coarsening up pattern or a decrease in gamma ray. Sequence Boundary (SB) and Transgressive Surface of Erosion (TSE) comprise a compound surface formed during different stages of a sea level cycle. TSE occurs at the base of a TST. Flooding Surface (FS) occurs at the top of the TST. The Maximum Flooding Surface (MFS) occurs at the top of a Condensed Section (CS) and is characterized by the highest API reading and the finest grained shale.

The sequence stratigraphic framework developed from the core was applied to correlating digital well logs on 25 cross sections. To properly correlate the Caney from well to well, 10 FS and 10 TSE stratigraphic markers were picked; from those markers, 19 intervals were identified and mapped. Three main intervals of deposition were identified from the overall directions of each interval. Mapping each interval separately allowed for more accurate mapping and led to a better understanding of the depositional patterns of the strata. Comparison among the cycles from core analysis showed that Cycle 1 was transported and deposited from the west and Cycle 2 was transported and deposited from the northwest-southeast.

Shale's are becoming a prime target for exploration. A detailed stratigraphic framework leads to an improved understanding of reservoirs, advance exploration and develops plays.

CHAPTER 1

Introduction

Objective of the Study

The subject of this thesis is a sequence stratigraphic framework of the Caney Shale in the Arkoma Basin, southeastern Oklahoma. The Caney is part of a large shale package including a number of formations--- from the top of the Hunton Limestone, continuing up through the Goddard shale (Figure 1.1). The majority of the Caney shale is Upper Mississippian, (Meramecian, 340-333 my) in age (Elias 1959; Harris 1971; Monaghan 1985).

Shales have been traditionally thought to be hydrocarbon source rocks or seals, rather than reservoirs. Although many older vertical wells had potential shows, techniques to develop the shales as a resource have only evolved recently. Therefore shale lays are referred to as unconventional.

One of the first shale plays developed was the Barnett. Since then, a number of shales have been explored, including the Caney Shale of southeastern Oklahoma. The Caney is a significant hydrocarbon-bearing shale and the subject of this thesis research. Understanding the Caney parasequences, depositional setting, petrophysical responses, and organic content are all important to developing the Caney Shale. Developing a sequence stratigraphic framework allows us to predict pay zones more accurately and help determine optimal well locations.

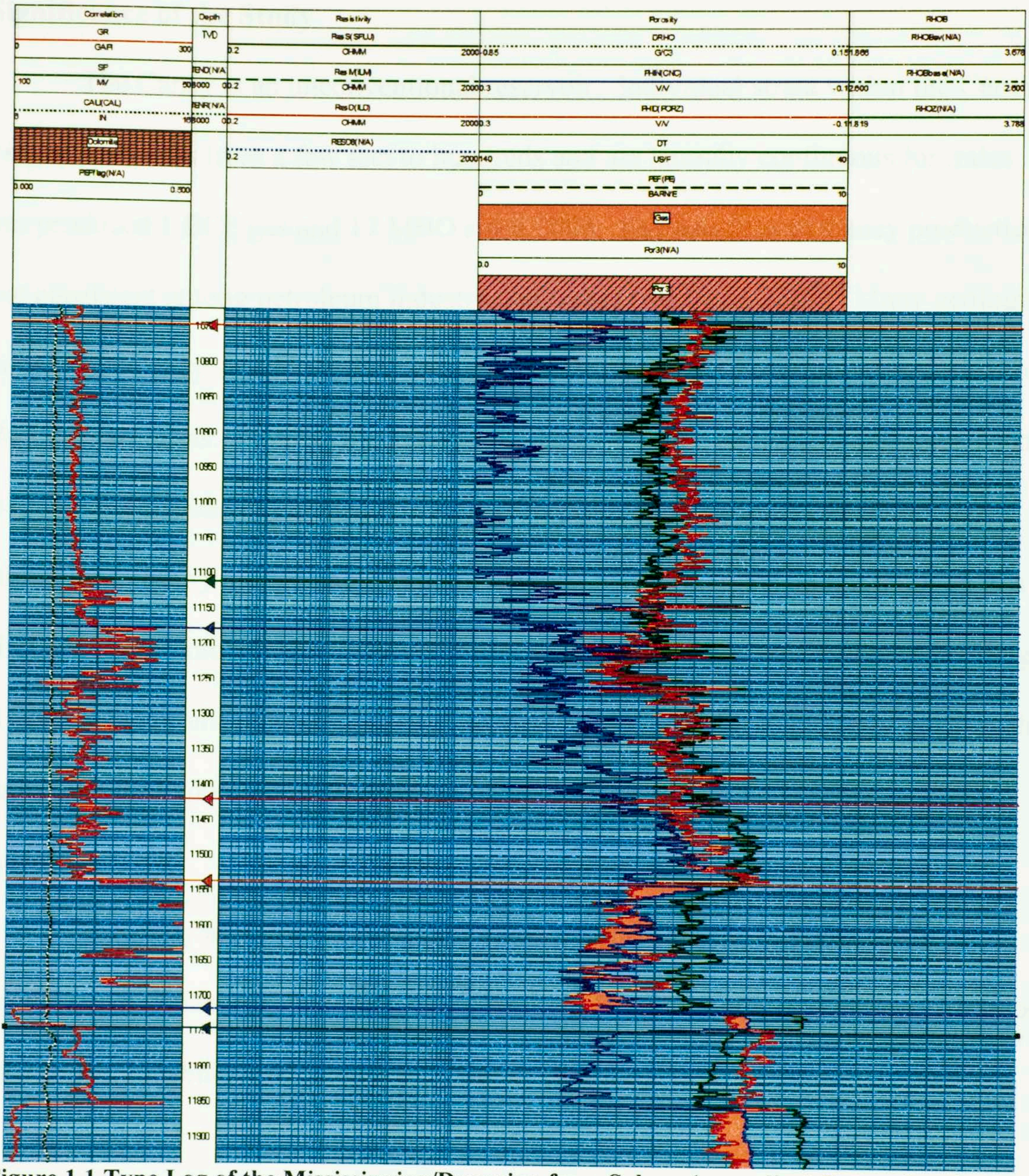


Figure 1.1 Type Log of the Mississippian/Devonian from Sylvan (green line) Formation through the Goddard (red line) Formation.

Significance of the Study

The Caney is an unconventional reservoir. Individual strata within the Caney vary in thickness from a few feet to hundreds and are laterally continuous for miles. It has produced 1 BCF gas and 17 MBO since 2005. Explanations of Caney production are not consistent among petroleum industry geologists (Andrews 2007). Many geologists believe the Caney should produce in a manner similar to the Fayetteville in the Arkoma Basin of Arkansas. Fayetteville and Caney shales are time equivalent and were deposited within the same basin (Figure 1.2). However, production varies between the two formations. Many factors could explain why the two formations do not produce in a similar manner, including a different source area, composition, and different bedding styles. A better understanding of the Caney is needed in order to properly develop the formation for hydrocarbon production.

Location

The study area covers the Caney shale trend within the Arkoma Basin of southeastern Oklahoma, including Coal, Haskell, Hughes, Latimer, Le Flore, McIntosh, Muskogee, Pittsburg, and Sequoyah counties (Figure 1.3).

Production

As of June 2005, 18 wells had been drilled in the Arkoma and Ardmore Basins that have produced oil or gas from the Caney Shale (Andrews 2007). Wells that have produced or are producing from the Caney are highlighted in Figure 1.4.

Previous Studies

The Caney stratigraphy, depositional history and reservoir characteristics within the Arkoma Basin have been previously studied by Elias et al. (1959), Harris (1971),

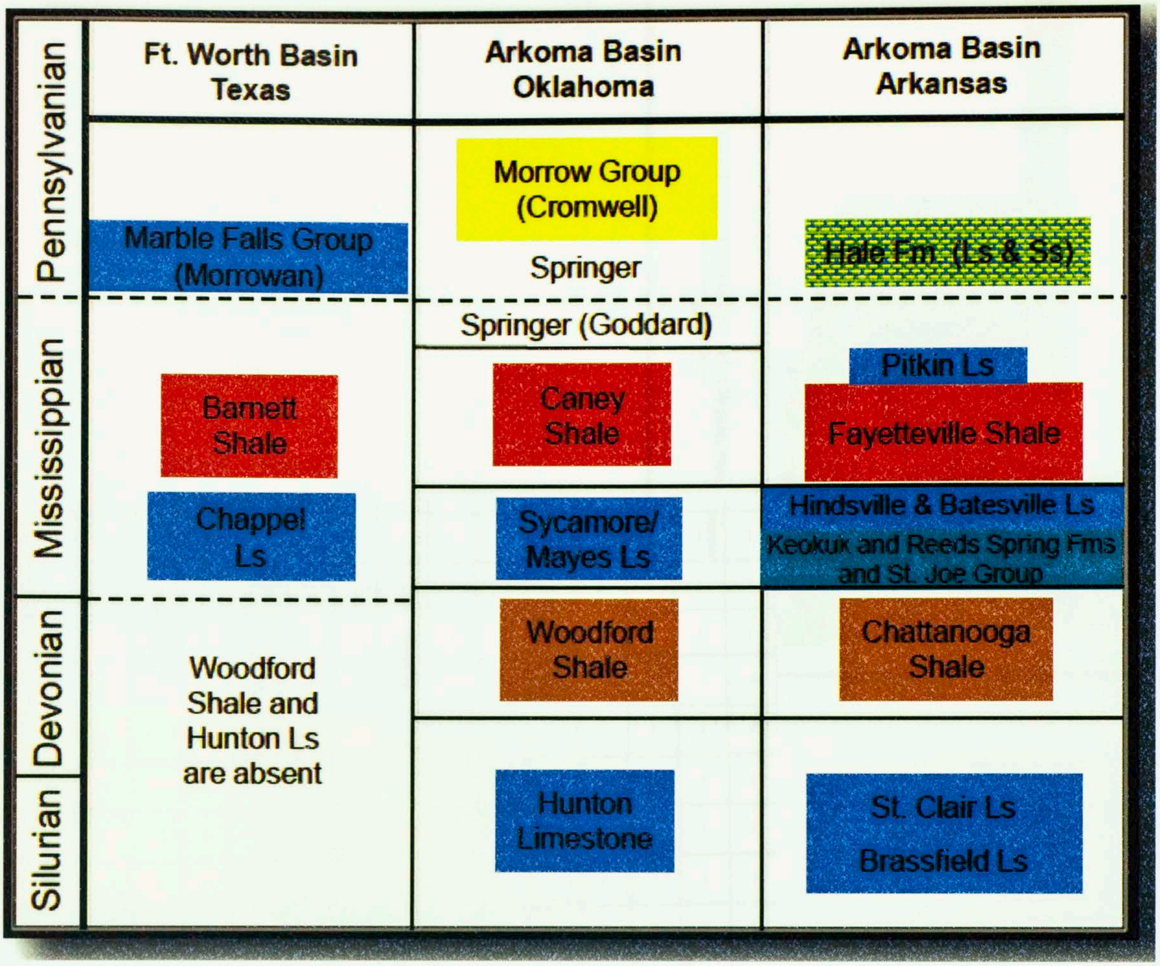


Figure 1.2: Stratigraphic column of the southern Mid-Continent Modified from Andrews (2009).

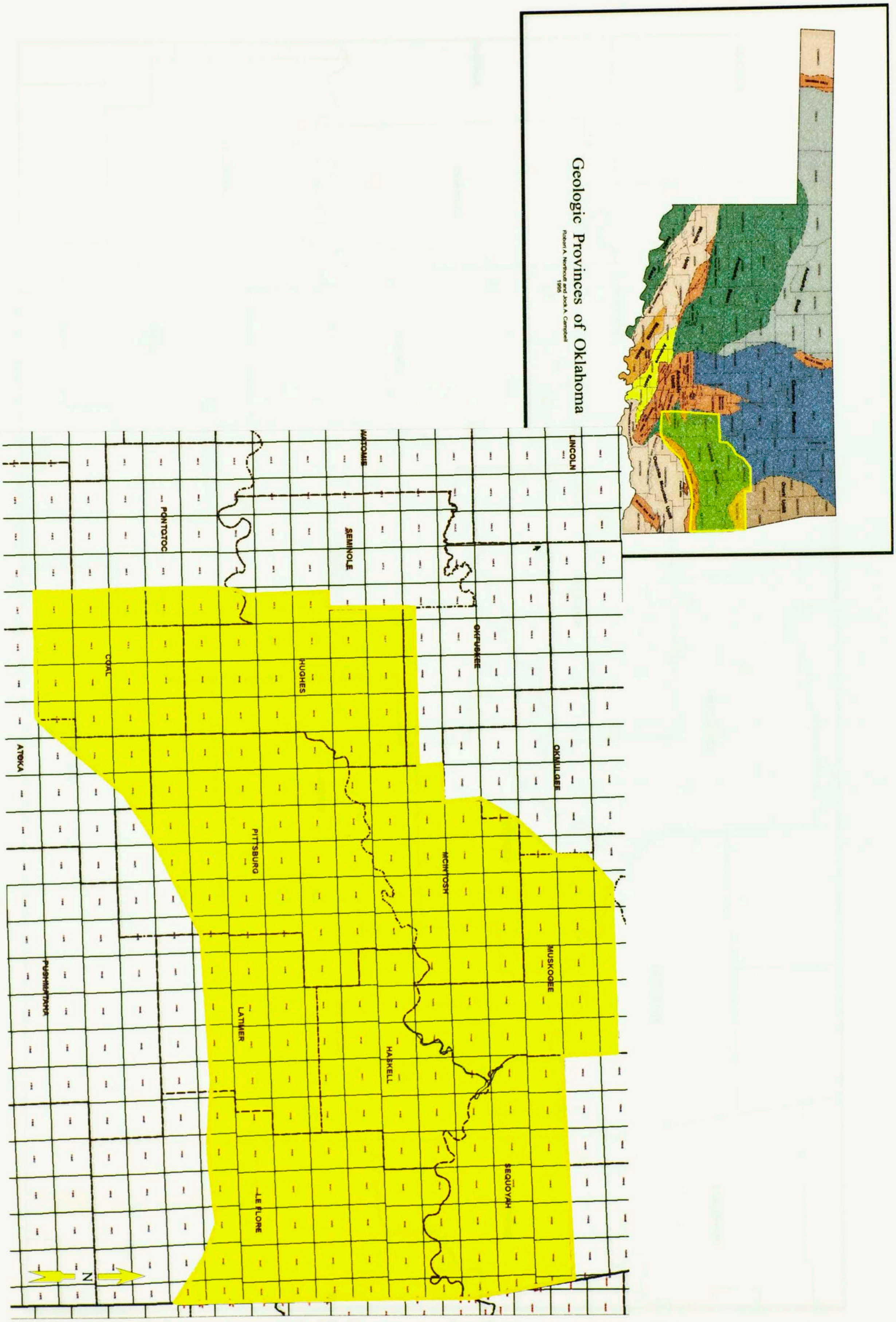


Figure 1.3: Location and Counties of the Caney Shale Study Area Modified from Northcutt et. al, 1995..

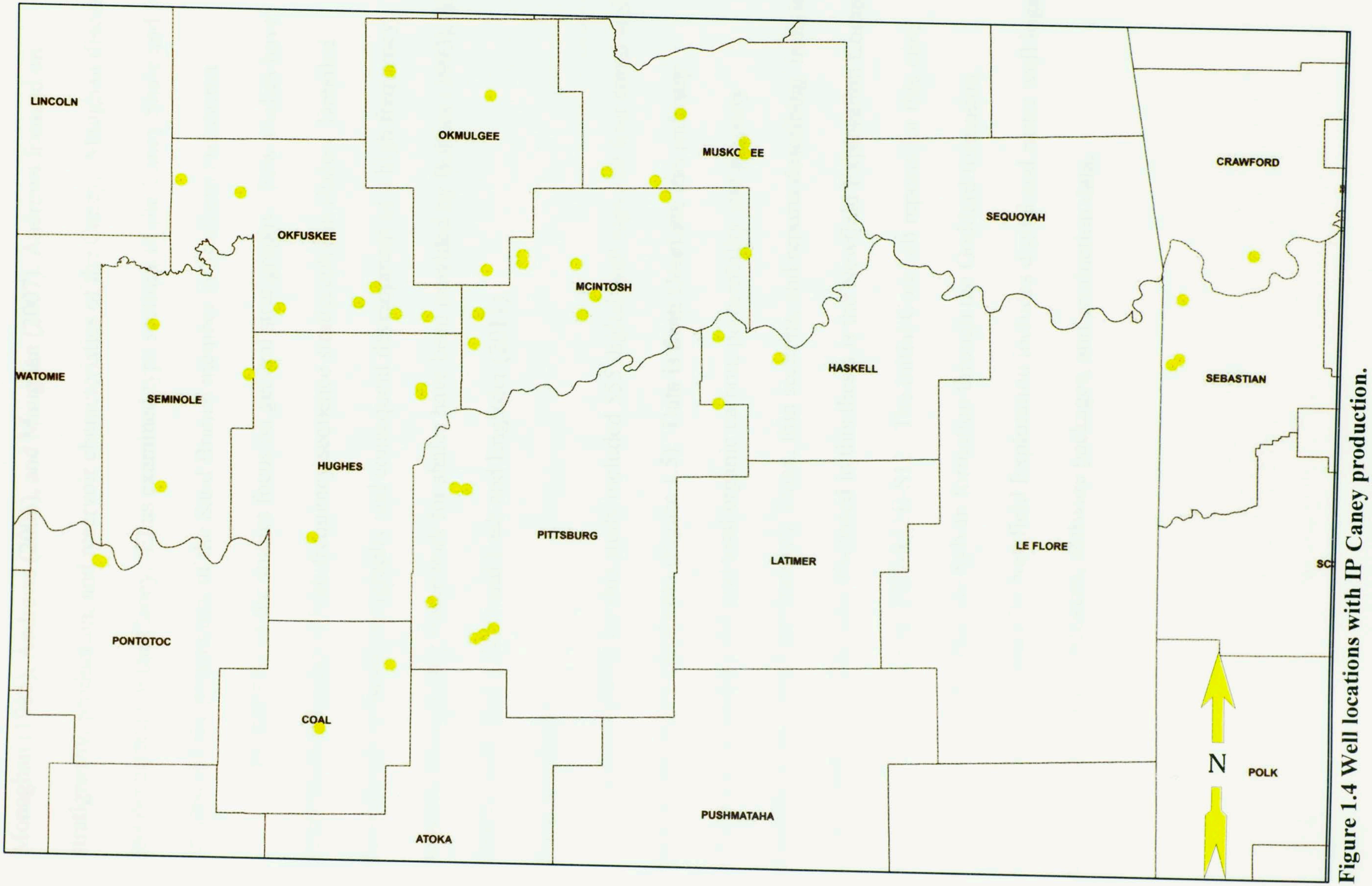


Figure 1.4 Well locations with IP Caney production.

Monaghan (1985), Andrews (2006), and Maughan (2007). Andrews focused on stratigraphy, production, and reservoir characteristics of the Caney. Maughan discussed gas occurrence in the Caney. Elias examined type sections of the Caney Shale and Harris interpreted the palynology of the Sand Branch member in Southern Oklahoma.

The majority of the studies focus on general stratigraphy. Few studies have implemented the use of high frequency sequence stratigraphy in shales. Detailed descriptions of shale stratigraphy and consequent development of a high frequency sequence stratigraphy framework for shales have been provided by Bohacs (1993), Singh (2008), Slatt et al. (2009) and Lash and Engleder (2011).

Data Available

Data available for this study included 555 digital well logs and four cored wells from southeastern Oklahoma (Figure 1.5). Data is from CoreLab, Inc. industry consortium included core and total organic carbon, permeability and porosity measurements, Hydrogen Indexes, Tmax, thin sections, and reports describing individual cores (Table 1.1). The core discussed in this thesis is the Newfield Exploration Company Cometti 2H-13 located at T2N-R11E-S12. The initial CoreLab reports for this core covered the interval from the Sylvan formation through the Goddard formation. Additional data provided by Newfield Exploration includes digital and raster well logs, scout tickets, verbal resources, software packages, and production data.

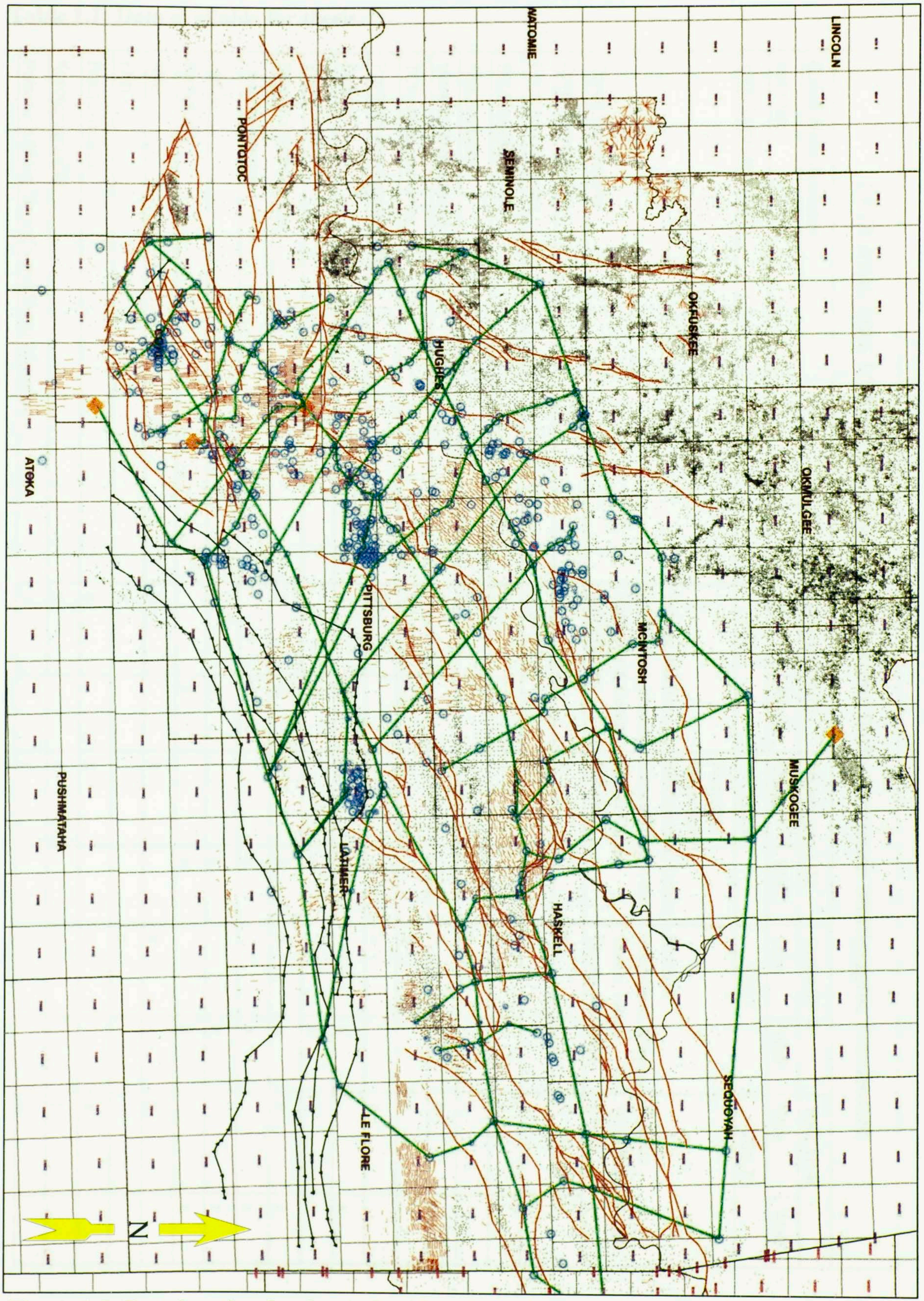


Figure 1.5: Data location for the study. blue circles indicate the wells with digital suite, orange diamonds are the cores wells. Faults indicated by red (normal) and Black (thrust) lines.

DATA AVAILABLE FOR THESIS: Caney Shale, Arkoma Basin: Sequence Stratigraphic Framework								
Cored Wells Available	Cometti 2H-13		Muskogee 1-15		Cattle 5H-8		York 1H-8	
Data Set	Core	Well	Core	Well	Core	Well	Core	Well
Total Core Length (ft)	669.5		121.6		520.7		206.75	
Cored Formations	Sylvan, Hunton, Woodford, Mayes Woodford, Caney, False Caney		Hunton, Woodford, Kinderhook, Upper Caney (Mayes and Lower Caney Missing)		Hunton, Woodford, Mayes, Caney, False Caney, Goddard		Hunton, Woodford, Mayes, Caney	
Core Photographs	x		x		x		x	
Plugs and Samples	x		x		x		x	
SEM Images	x		x		x		x	
Thin Sections	x		x		x		x	
Vitrinite Reflectance	x		x		x		x	
TOC measurements	x		x		x		x	
Porosity and Permeability	x		x		x		x	
Caliper		x		x		x		x
Gamma Ray		x		x		x		x
Spectral Gamma Ray	x	x	x	x	x	x	x	x
Density-Neutron		x		x		x		x
Sonic		x		x		x		x
Resistivity		x		x		x		x
XRD	x		x		x		x	
FMI	x				x			
Fracture data	x		x		x		x	
Kerogen quality	x		x		x		x	
Poisson's Ratio, Young's and Shear Modulus	x		x		x		x	

Table 1.1: Data available for thesis.

Geology of Gas Shale

Shales have been traditionally thought to be hydrocarbon source rocks or seals, but not reservoirs. Until recently, they have typically been defined as uniformly stratified and homogeneous; most recently, a number of studies have stated that there is substantial variability throughout shales (Slatt et. al 2009). Source rocks are often regionally extensive and filled with hydrocarbons. Although many older vertical wells had potential shows, low permeability resulted in poor production. Recent technology advances with horizontal drilling and completion have turned potential shows into economically viable hydrocarbon plays. The drilling and stimulation techniques allow for increased effective permeability. In part, due to the recent advancements in engineering technology and the unusual methods of geologic analysis, shale production is referred to as unconventional.

Lithology

According to the Dictionary of Geological Terms (1984), a shale is a “detrital sedimentary rock formed by compaction of clay, silt or mud”. It may be red, brown, black or grey in color. There are a number of different minerals that compose shales; clays, quartz, feldspars, carbonate particles, organic material, pyrite, and other minerals in small portions (Singh 2008).

Organic Geochemistry

Gas Shales are characterized by having high organic matter. Organic matter is measured as follows:

- Total Organic Carbon (TOC): TOC is a measure of the total organic matter within the total mass of the rock. Organic matter comprising greater than 3% of the total mass of the rock is considered to have hydrocarbon potential.
- Virtrinite reflectance (Ro): %Ro is a measure of the thermal maturity of shale. Ro measurements from 0.6% to 2.4% fall in the mature window.
- Rock-Eval pyrolysis: Rock-Eval pyrolysis includes measurements of S1, S2, S3, Tmax, Hydrogen Index (HI) and Oxygen Index (OI). S1 represents bitumen already existing in the shale. The amount of hydrocarbons remaining from thermal breakdown of kerogen is S2. The S3 measures the produced oxygen-bearing compounds released at high temperature. Tmax indicates the maximum temperature for hydrocarbons to be released. It is also indicates the stage of maturation. S2 and S3 determine Hydrogen Index and Oxygen Index, which indicate kerogen type. Quality gas shales have HI values greater than 350 mg HC/g.

Organics are preserved under anoxic condition. There are a number of anoxic and oxic depositional environmental indicators, including minerals and Relative Hydrocarbon Potential (RHP) (Fang et. al, 1993). Phosphatic nodules are usually present within organic rich intervals in shales including the Barnett, Woodford, and Montney (Slatt and Rodriguez, in press). Slatt and Rodriguez (in press) describe Pyrite, as well as phosphatic nodules as indicators of reducing environment of deposition. Pyrite is common throughout the Barnett, Haynesville, Marcellus, Woodford, Horn River and Caney shales. Relative Hydrocarbon Potential (RHP) is a measure of oxygen levels in the environment of deposition. RHP (S1+S2/TOC), can be correlated with sea level changes and bottom water (environmental)oxygen conditions. High numerical values of RHP indicate anoxic bottom water condition related to maximum flooding events. Minimum RHP values correspond to oxic conditions occurring during shallowing of the marine water depth.

Paleoenvironment and Paleoecology

There are a number of shale gas plays in the United States (Figure 1.6). Most are marine, and Devonian-Mississippian in age (Figure 1.7). Depositional environments, composition, TOC levels, and maturity make each play unique.

Since many shales vary depositionally, they tend to vary in color and appearance. For example the Sylvan Shale is green while the Caney Shale is dark grey. The depositional environments of the Sylvan may have been shallower and more oxic. Dark color of shale usually indicates a large amount of organic matter deposited under anoxic conditions (Potter 1980).

Sequence Stratigraphy

Sequence Stratigraphy is based upon an understanding of the relations among eustatic sea level, depositional settings and accommodation space. The traditional sequence stratigraphic principles used in many common sandstone reservoirs are now being applied to shale reservoirs with minor variance. The following list is of the sequence stratigraphic terminology used in this thesis: LST (lowstand systems tract), TST (transgressive systems tract), RST (regressive systems tract), CS (condensed section, MFS (maximum flooding surface), MRS (maximum regressive surface), TSE (transgressive surface of erosion), SB (sequence boundary), and the order of cyclicity (geologic time for completion of fall-rise cycles of sea level change). RST is considered an analog to HST (highstand systems tract). The order of cyclicity includes, 2nd order (10

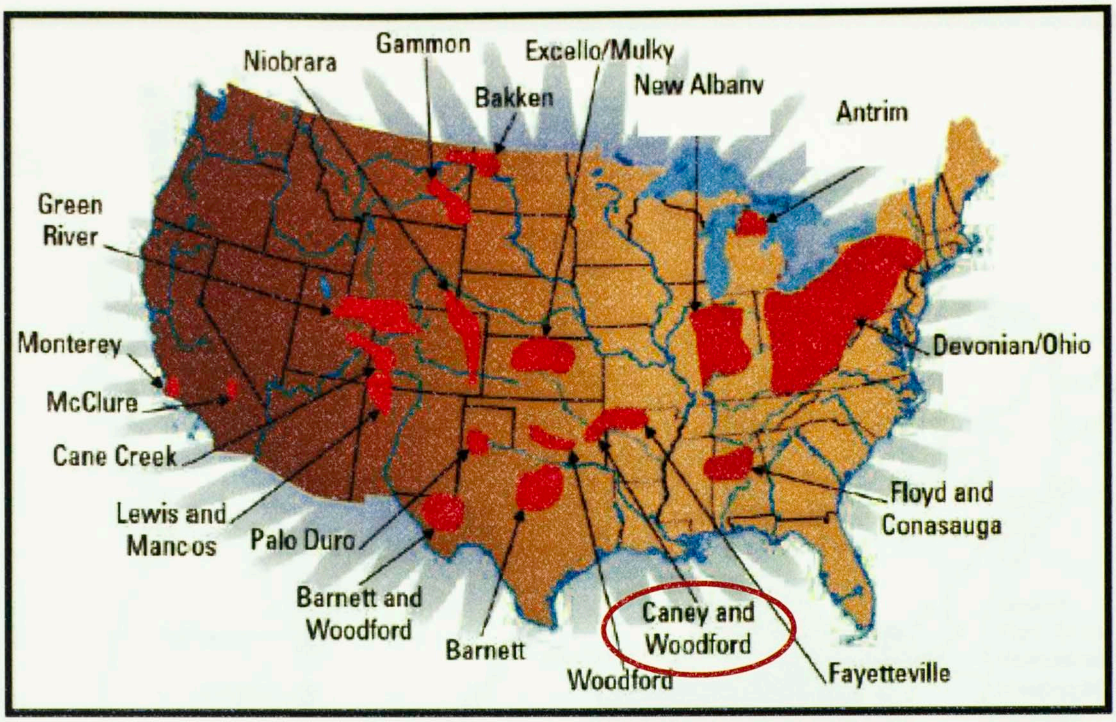


Figure 1.6: Gas shale plays throughout the United States (After Frank and Jochen 2005).

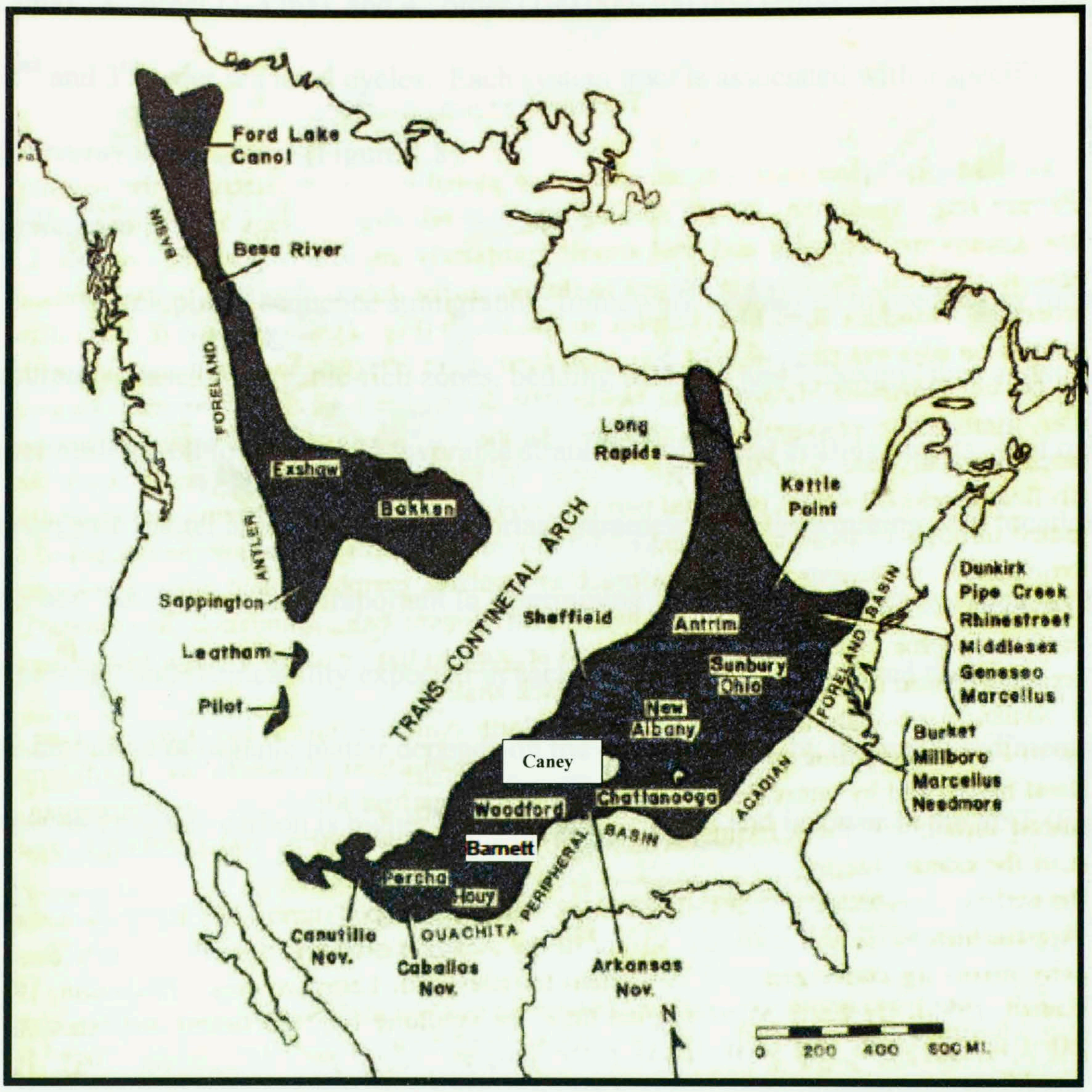


Figure 1.7: Distribution of Devonian/Mississippian Shales of North America (Modified after Ettensohn 1998 and Singh 2008).

-25ma) , 3rd order (1-3 ma), and 4th order (100,000-300,000 years). This thesis identifies a 2nd and 3rd order sea level cycles. Each system tract is associated with a specific gamma ray log response (Figure 1.8).

Application

Developing a sequence stratigraphic framework enables us to predict pay more accurately, based on organic-rich zones, bedding patterns, and lithology, thus assisting in determining well locations and favorable strata for horizontal drilling targets. Not only are organic matter and mineralogy important parameters for determining well location and pay, but they are also important in determining the capacity to store gas, and the type of porosity and permeability expected in each play. Singh (2008) stated that the accumulation of organic matter depends on the dilution affect by inorganic sediments; therefore, organic carbon is higher in condensed sections and is lower in the RST (Figure 1.9).

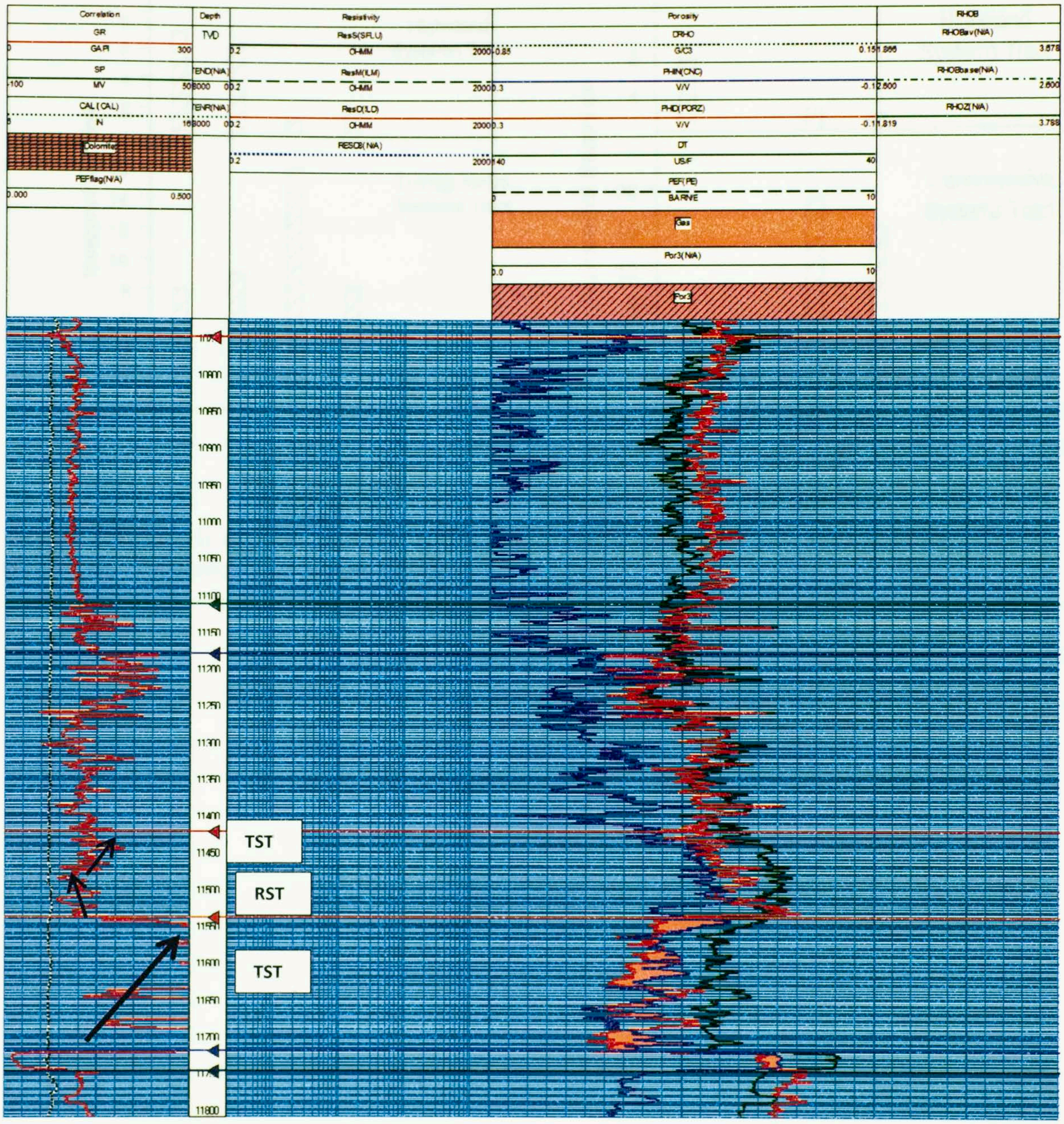


Figure 1.8: System Tract association with specific gamma ray log response.

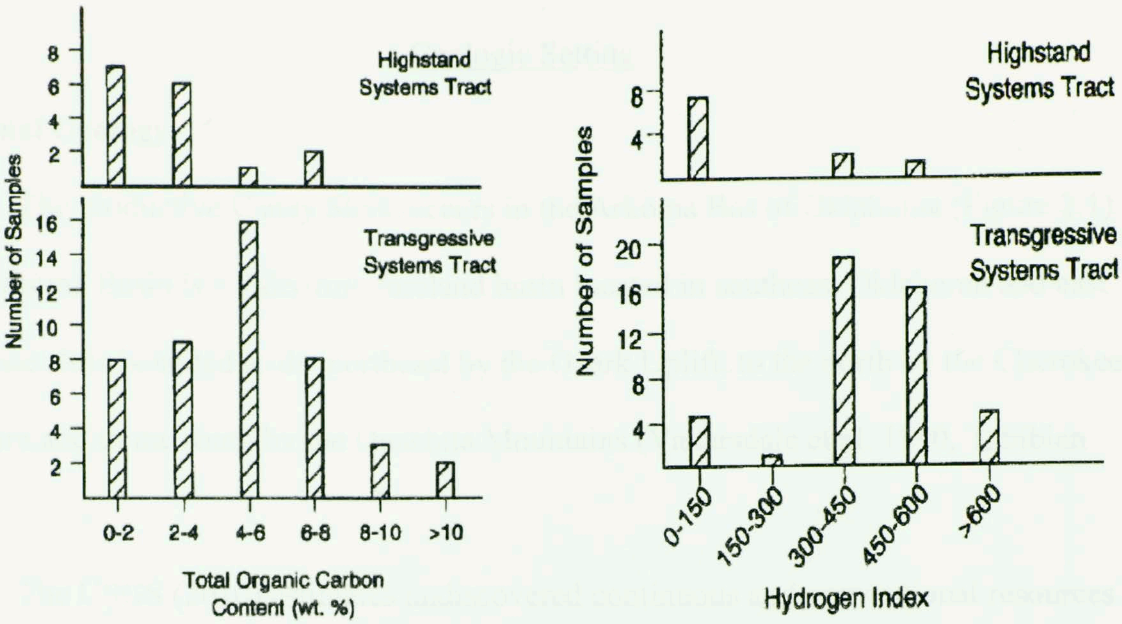


Figure 1.9: Levels of TOC and HI within Highstand (regressive) and Transgressive system tract (after Robinson and Engel 1993).

CHAPTER 2

Geologic Setting

Regional Geology

The productive Caney Shale occurs in the Arkoma Bas of Oklahoma (Figure 2.1). The Arkoma Basin is a Paleozoic foreland basin located in southeast Oklahoma and east Arkansas. It is bounded to the northeast by the Ozark Uplift, to the north by the Cherokee platform and to the south by the Ouachita Mountains (Vanarsdale et al. 1990, Tabibian 1993).

The USGS (2010) estimates undiscovered continuous and conventional resources in the Arkoma basin and Ouachita Thrust Belt to be 38 trillion cubic feet of gas (TCFG), 159 million barrels of natural gas liquids (MMBNGL) and around 0.5 million barrels of oil (MMBO). 70 percent of the 38 TCFG of gas comes from undiscovered shale-gas. The Caney is estimated to contain 1.1 TCFG of that 70% (USGS 2010).

The evolution of the Arkoma basin and related Ouachita Mountains demonstrate features of the Wilson Cycle. The development of a passive margin along the southern edge of North America followed initial Precambrian rifting of the Ouachita trough. During the Ordovician, an ocean basin opened and created an active margin with a subduction zone (Houseknecht et al. 1991, Tabibian 1993, Lambert 1993, Golonka et al 2006, Branch 2007). Continental convergence and basin closure began with the northern movement of the subduction complex in the Late Mississippian/Early Pennsylvanian (Figure 2.2). Vertical loading caused the paleo-shelf to subside and a foreland basin developed (Tabibain 1993). During the Mississippian/Mid Pennsylvanian,

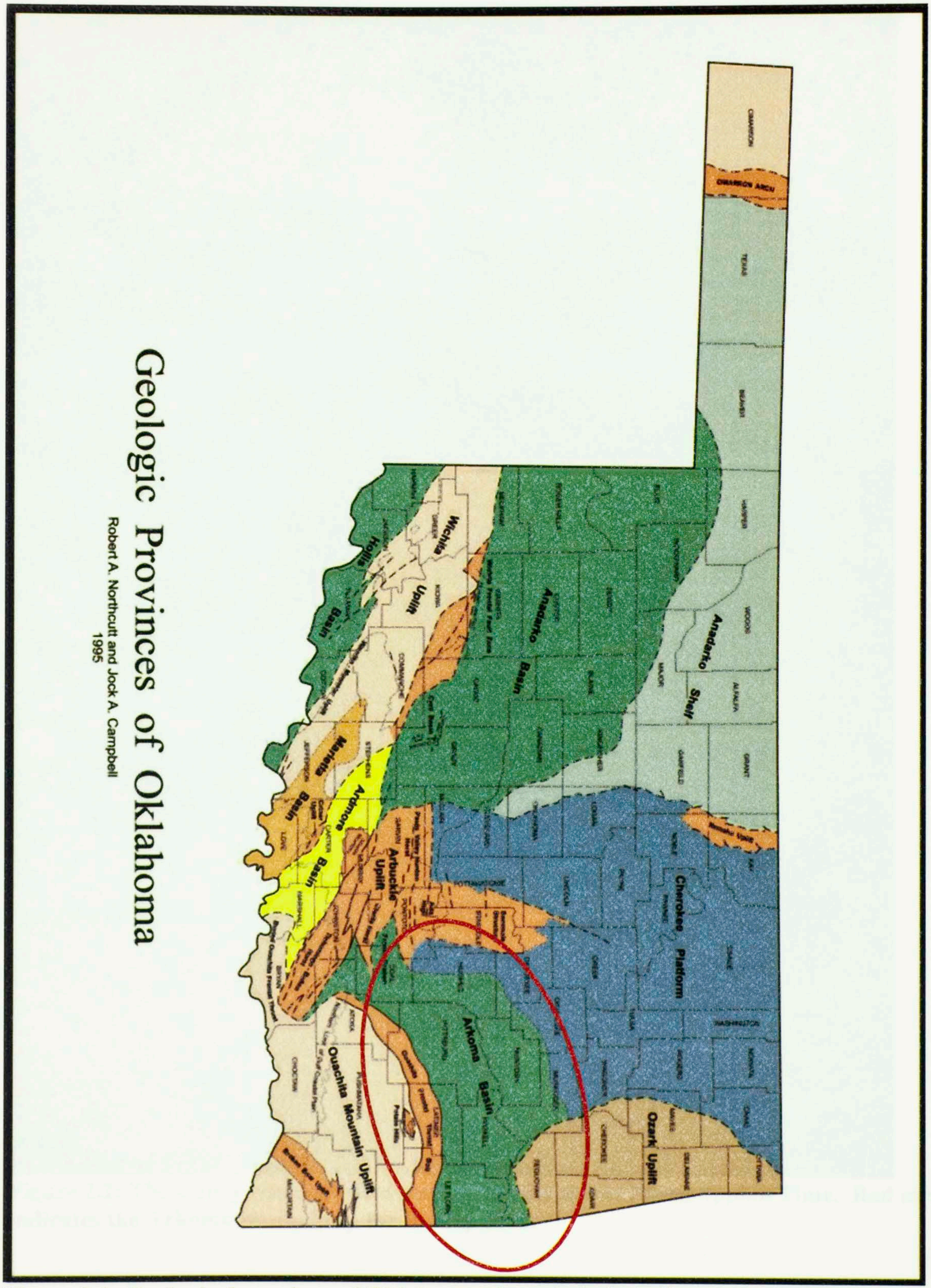


Figure 2.1: Geological province of Oklahoma, the red circle indicates the Arkoma Basin From Northcutt et. al, 1995.

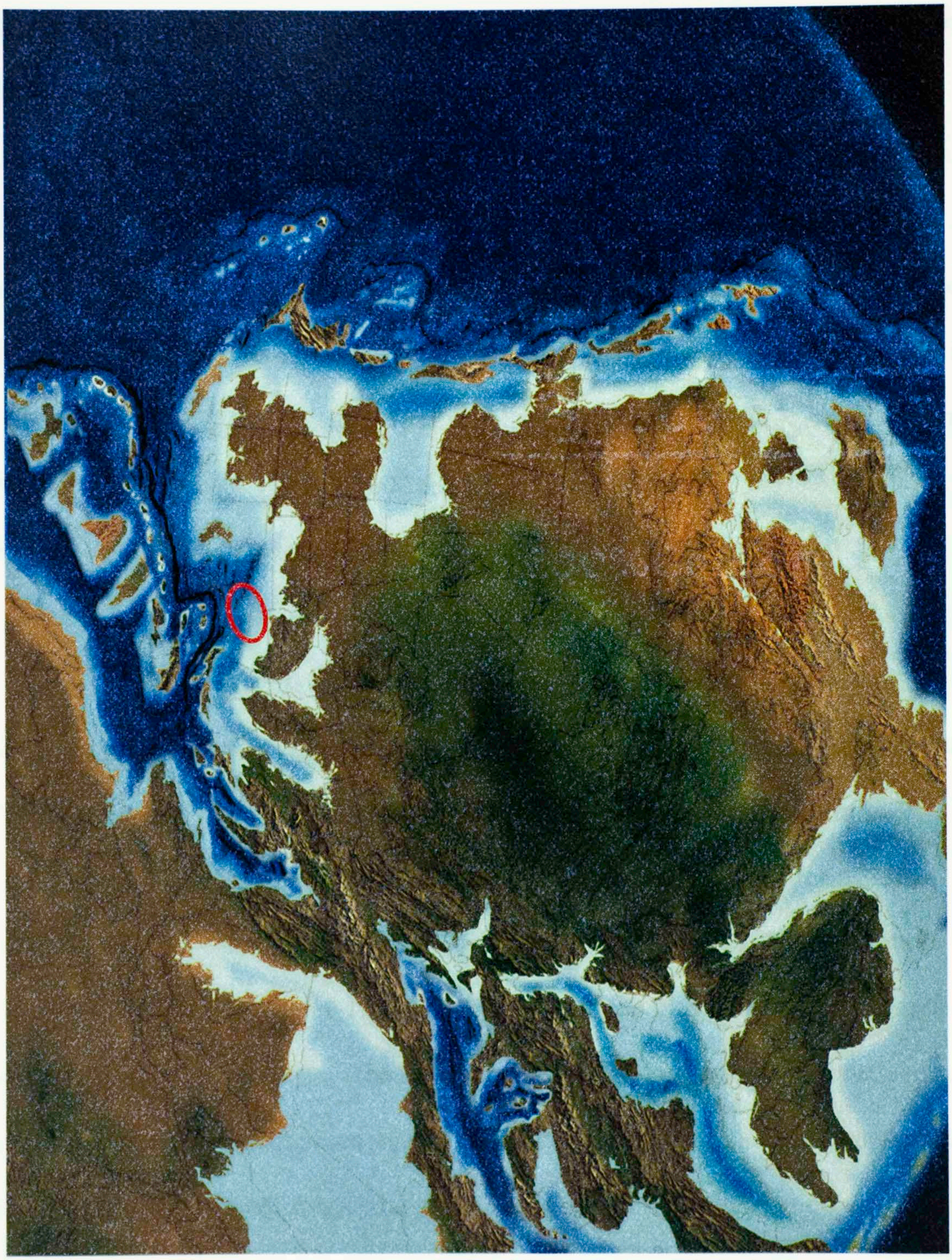


Figure 2.2: The Caney was deposited during Middle to late Mississippian Time. Red circle indicates the Arkoma Basin. Map for Blakey 2010.

the North American plate was subducted under the South American plate and the ocean basin closed. The subduction complex thrust onto the shelf margin. Subsequently, the South American plate collided with the subduction complex and the North American plate during the late Pennsylvanian. The collision created the Ouachita Mountains and the Arkoma Basin (Varnsdale et al. 1990, Tabibian 1993, Golonka et al, 2006). The complex compressional structure within the Arkoma Basin resulted from this collision and mountain building. The major structural events yielded Paleozoic sediment ranging from approximately 3,000 to 40,000 feet in thickness (Tabibian 1993).

Sedimentation and Stratigraphy

General

The Caney Shale is the formal formation name in the south-central and southeastern Oklahoma subsurface (Andrews 2007). The majority of the Caney Shale is Meramecian in age [Upper Mississippian, 340-333mya (Elias 1959; Harris 1971; Monaghan 1985; Maughan 2006)]. The Caney is one of a number of formations including the Hunton Limestone, the Woodford, and the Goddard shale [oldest to youngest respectively (Figure 1.1)]. Andrews (2007) divided the Caney Shale into an upper zone and a lower zone. The upper zone includes shale and interbedded siltstone, and the lower zone is composed mainly of fissile shale. Maughan (2006) separated the Caney into three distinct zones based on well log characterization; the upper Caney, lower Caney and basal Caney.

To understand the Caney, it is essential to understand the time of deposition for all parasequences within the package. This relationship describes the Caney's stratigraphic significance and depositional environment. The following paragraphs area a brief description of the parasequences within the Caney.

Description

The Woodford Shale (359-395ma) unconformably overlies the Hunton Group carbonates. Within the northern study in, Muskogee and Sequoyah Counties, the Kinderhook overlies the Woodford, but it pinches out just south of Muskogee County. Therefore the majority of the basin contains the Mayes Shaledirectly overlying the Woodford (Figure 2.3). The Caney overlies the top of the Mayes and bottom and middle Caney are part of the Meramecian series, but the Upper Caney is Chesterian in age (Andrews 2007). The entire Caney strata varies in thickness from 20 to 360 feet. Well log features are similar throughout the basin. From the base, upward is a hot Gamma Ray organic rich Woodford shale followed by the Mayes RST. Then the Caney TST which is capped by the Goddard formation RST.

Structure

The Arkoma basin is a Paleozoic foreland basin extending 205 miles. The Basin is bounded by the Ozark uplift (northeast), Cherokee platform (north) and the Ouachita Mountains (south) (Tabibian 1993). Normal faults in the south-southwest affect rocks older than Pennsylvanian. Thrust Faults early Pennsylvanian and younger. Within the study area, the Caney is very continuous. The majority of the major structures and faults occur to the south as the Ouachita Thrust. More structurally complexity occurs on the border of Oklahoma and Arkansas from the Ozarks uplift.

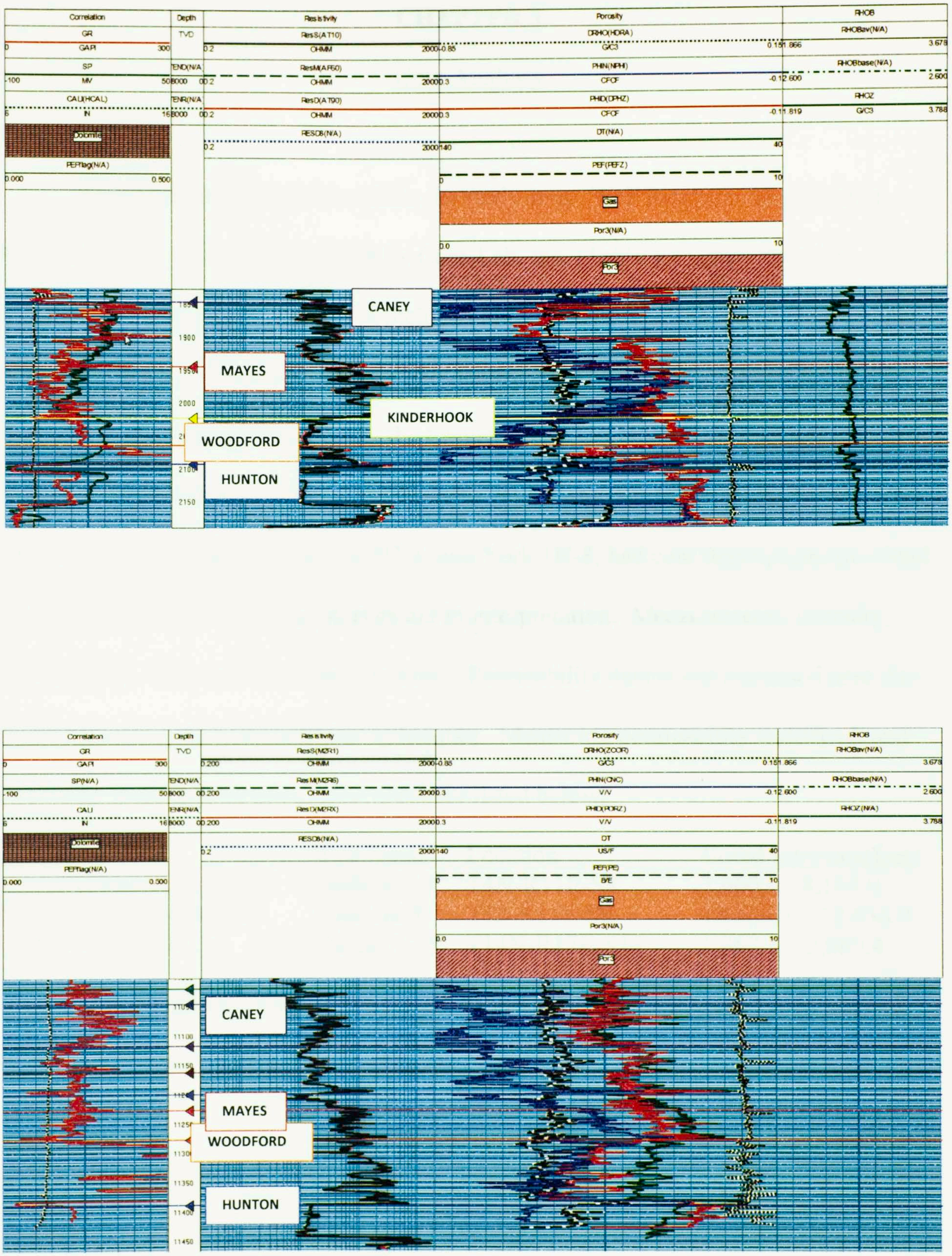


Figure 2 3: Type logs of the overall stratigraphic sections with Arkoma basin. The upper well log is the standard for the North rim and the lower well log is the main stratigraphic section throughout the remaining basin.

CHAPTER 3

Core Analysis

General

Four cores were available within the study area. Well locations are shown on figure 3.1. The cores were provided by Core-Lab, Inc. (Table 1.1), only the core description for the Cometti 2H-13 is included in this thesis. Data provided from all four cores were used in additional analysis and identification of parasequences. Due to the length (680 ft.) and total coverage of the Cometti 2H-13, it became the primary core of interest. A detailed description of the Cometti 2H-13 was completed (Plate I). The other three wells; Muskogee 1-15, Cattle 5H-8, and York 1H-8, had core descriptions provided by Core-Lab, Inc. that were used as an aid in interpretation. Measurements: porosity, permeability, TOC, and vitrinite reflectance. Permeability data is not discussed here due to the uncertainty in measurements techniques. Measuring permeability is difficult and inaccurate in shale reservoirs. The cores are listed below:

Operator	Well Name	Location	Cored Intervals(feet)
Newfield Exploration Co.	Cattle 5H-8	T4N-R11E-S8	7,660.0 - 8,164.0
Newfield Exploration Co.	York 1H-8	T1S-R11E-S8	12,505.5 – 12,636.0
Crown Muskogee Co.	Muskogee 1-15	T14N-R17E-S15	1,862.5 – 2,069.4

The Newfield Exploration Co., Cometti 2H-13 in T2N-R11E-S12, and a cored interval from 11035-11685.5 feet is described below.

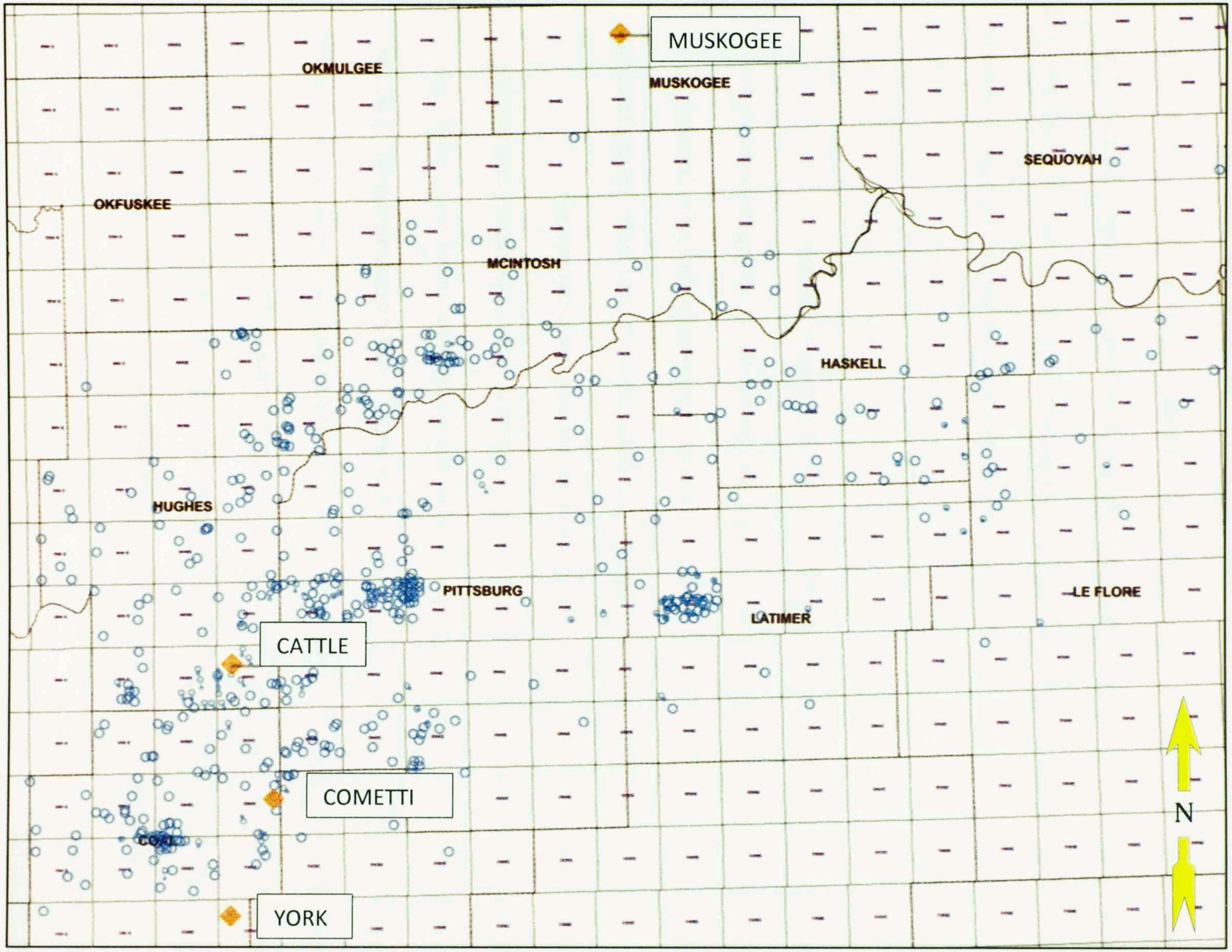


Figure 3.1: Location of core wells in Orange.

Description

Cattle 5H-8

Newfield drilled the Cattle 5H-8 in June of 2007. Core was taken from the Hunton Formation (8,182 ft.) stratigraphically up to the Goddard Formation (7,661ft), including the Woodford, Mayes, Caney, and False Caney (Figure 3.2). Core Lab describes the Caney within the Cattle well as a black to dark grey, silty shale/claystone. The base of the Caney has more silty stringers with limestone/dolomite beds. Moving upward in the core are both muddy claystone and fissile shale occurs with some thin calcareous stringers towards the middle of the section. Many phosphate nodules and pyrite occur further up section and the nodules become more calcareous.

The Cattle well average TOC is 2.4% based upon 32 core plug. Hydrogen index is <50 mgHC/g Corg indicating type IV kerogen. The average gas filled porosity is 2.1%. After being dried a porosity of 6.2% was measured. Core lab measured Sw of 64.4%. Sw in the upper Caney from 7721' to 7661' is 80.2 percent.

Muskogee 1-15

The Muskogee 1-15 was drilled by Crown Energy in January of 2006. Core was taken from the Hunton formation (2,101.5 ft) through the Caney formation (1,842ft). The Muskogee well only recovered less than half of the total interval length. It missed the upper Mayes and the lower part of the Caney, but included the Kinderhook Shale. The Kinderhook Shale is a light grey, highly laminated, calcareous silty shale. The Upper

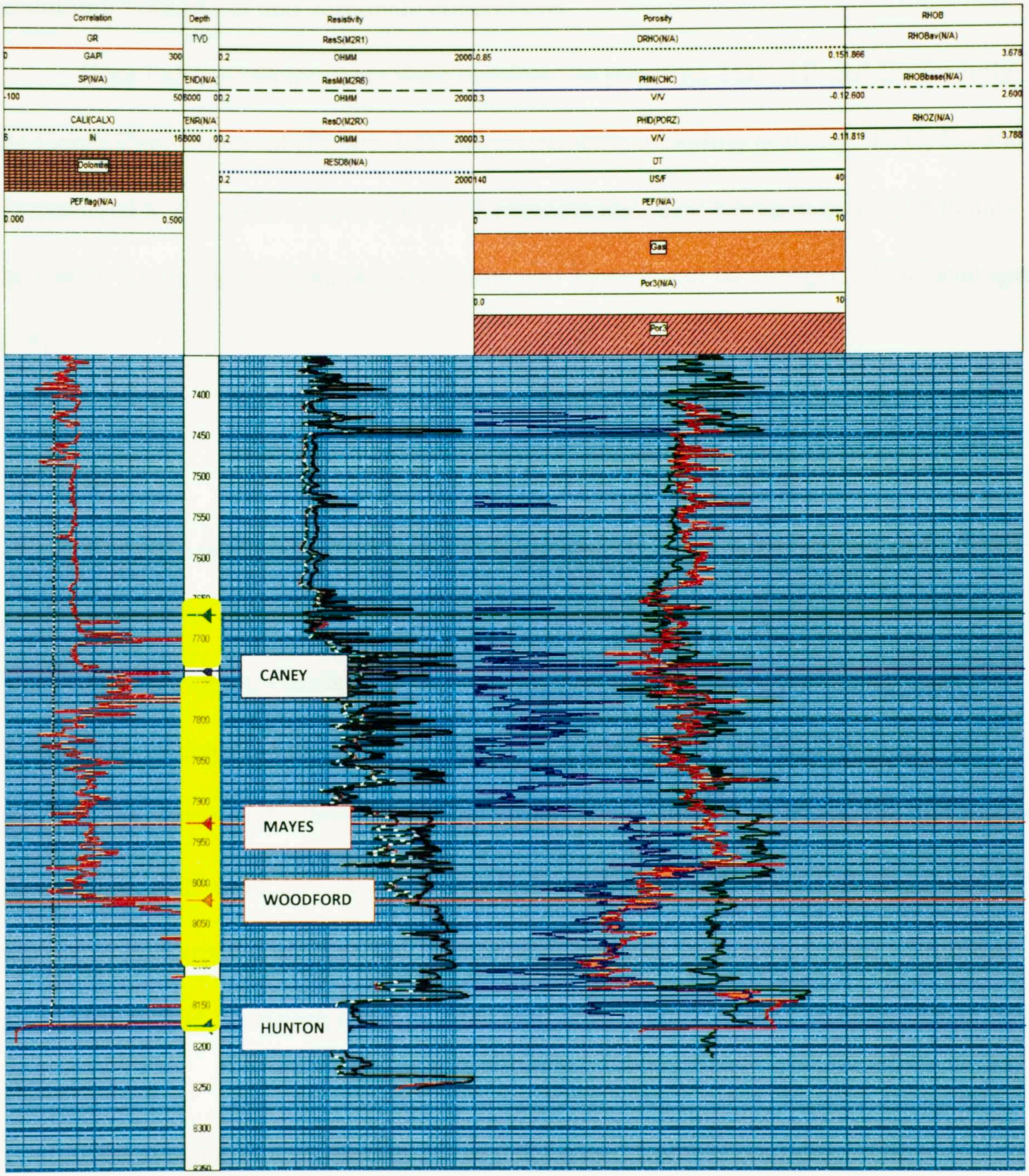


Figure 3.2: The Newfield Exploration cattle 5H-8 yellow rectangles indicate the cored interval.

Caney here is described as a black to dark grey shale, with planar laminations, and containing both pyrite and carbonate concretions.

Core Lab's measurements were restricted to porosity, TOC, HI and Ro for only the Upper Caney interval (Figure 3.3). Measurements including porosity, TOC, Ro and HI averaged 8.9%, 3.83%, 0.95% and 212 respectively. The Kerogen quality indicates the Caney was in the Oil/Gas prone window and Type II and III kerogen. TOC averages 4.6%.

York 1H-8

Newfield drilled the York 1H-8 in December of 2006. Core was taken from the Hunton Formation (12,700 ft) through the Caney Shale (12,433ft). The Caney, Mayes, Woodford and Hunton Formations were cored, but the entire Caney was not cored (Figure 3.4). According to Core Lab report, the Caney within the York core is a dark grey, muddy, laminated siltstone and silty shale. Glauconite, shell fragments that formed lag deposits, algal cysts and carbonaceous material throughout. Core Lab also noted a number of slickensides and vertical mineralized fractures, indicating a fault within this core. This should be expected because the well is very close to the Ouachita Thrust Belt (figure 1.5)

The average TOC is around 3% as determined from 20 core plug. Other measurements include porosity (5.5%), gas filled porosity (1.3%), water saturation (74%) and Ro (1.77%) The hydrogen index indicates a Type IV dry gas prone with measurements between 70 -50 mg HC/g C org.

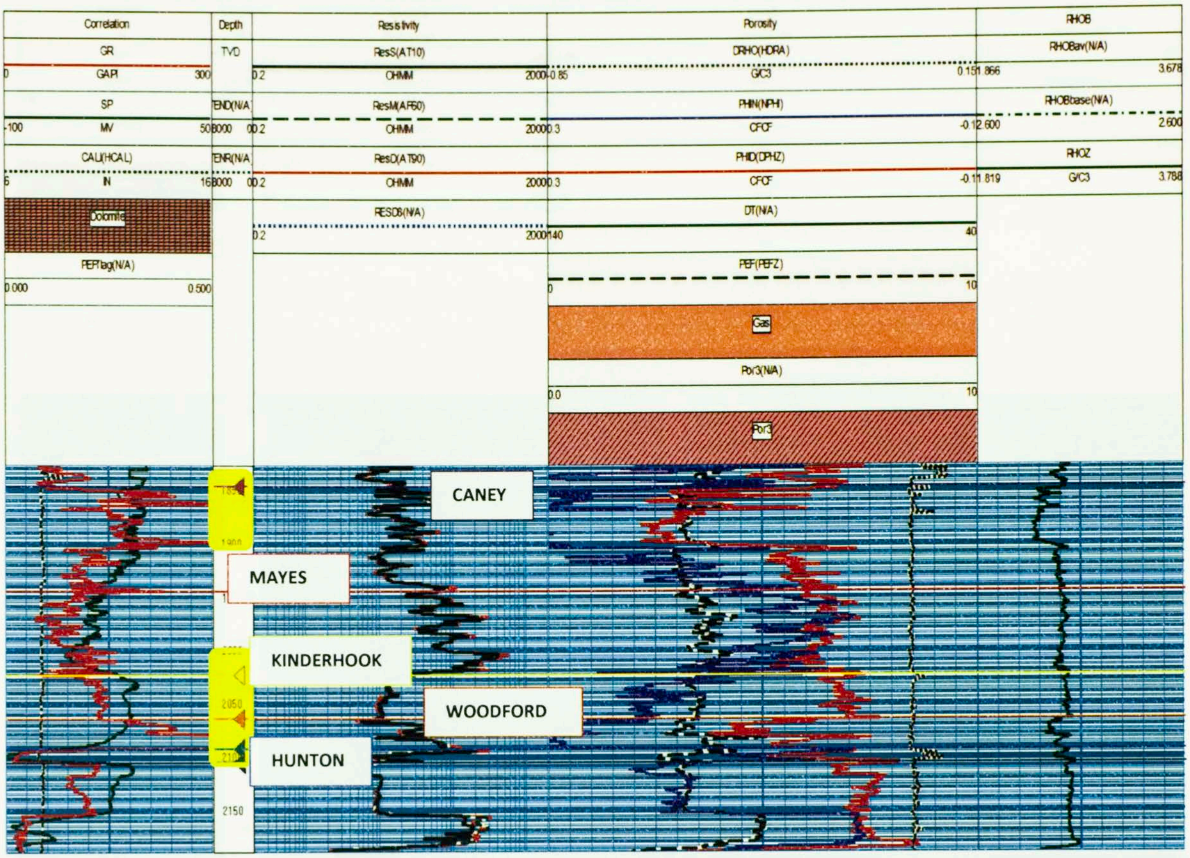


Figure 3.3: The Crown Energy Muskogee 1-15. The yellow rectangle indicates cored intervals.

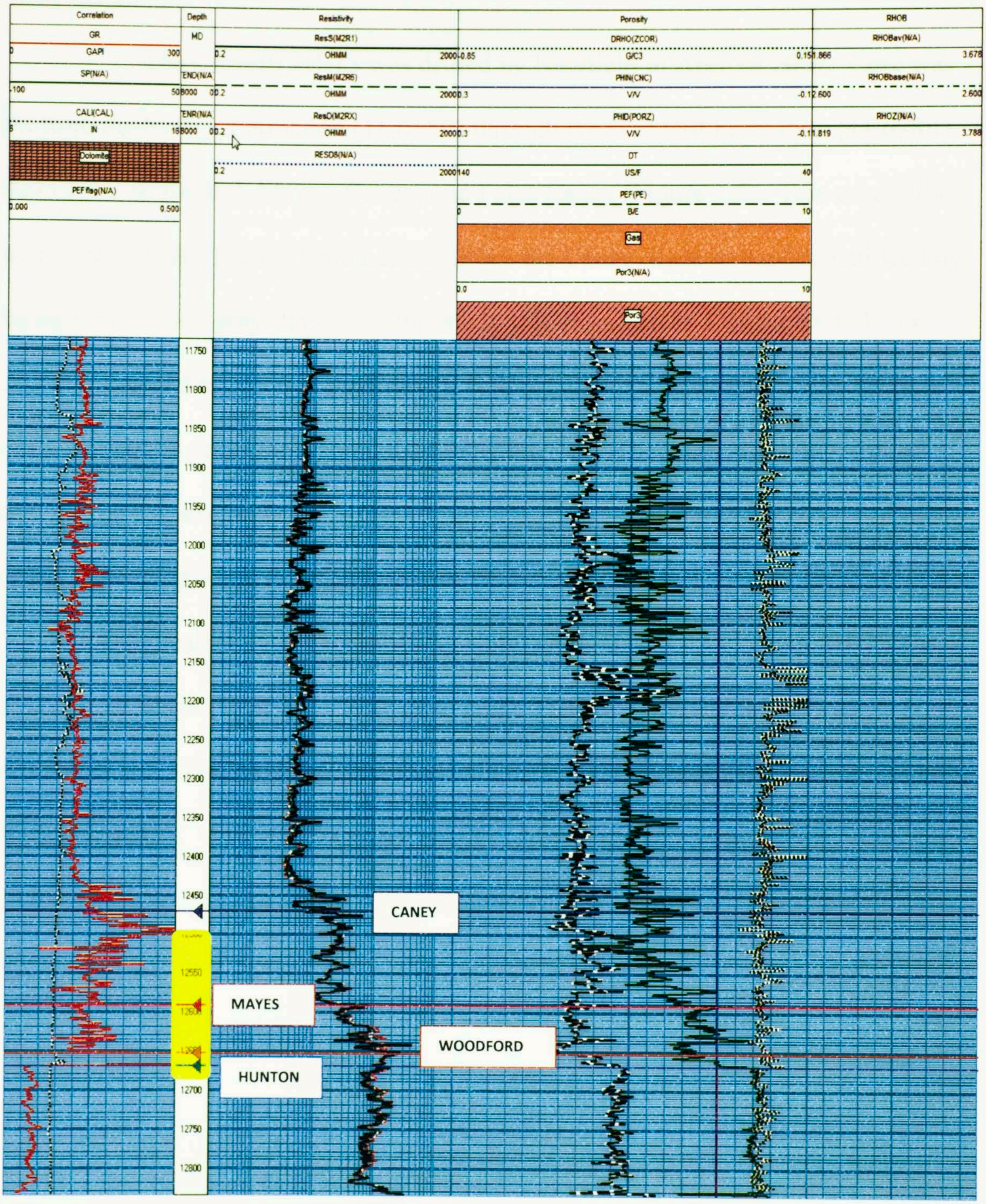


Figure 3.4: The Newfield Exploration York 1H-8 well yellow rectangle is the cored interval.

Cometti 2H-13

The Cometti 2H-13 was drilled by Newfield in April of 2007. Core was taken from the Sylvan Formation (11,015ft) through the Goddard Formation (11,698ft), including the Woodford, Mayes, Caney, and False Caney (Figure 3.5). This core is the primary focus of this thesis. Core Lab describes the Caney Shale in the Cometti well as medium grey to dark grey shale. For this study it is classified as a dark grey to black shale. The Caney formation in the Cometti well is more of a shale than a silty shale. Pyrite Concretions occur throughout the Caney interval. There are also thin strips of pyrite. Pyrite has also replaced fossils (figure 3.6). Core Lab and I also noted carbonate laminae, algal cysts, shell fragments and lag deposits (figure 3.7).

Geochemical analysis performed by CoreLab indicated the Cometti 2H-13 was a dry Gas Prone Shale (Type IV). With an average TOC of 3.5% and Ro between 1.5-2%. Clay content is > 32%, 44% was composed of quartz, feldspar and carbonate, around 8% contain kerogen.

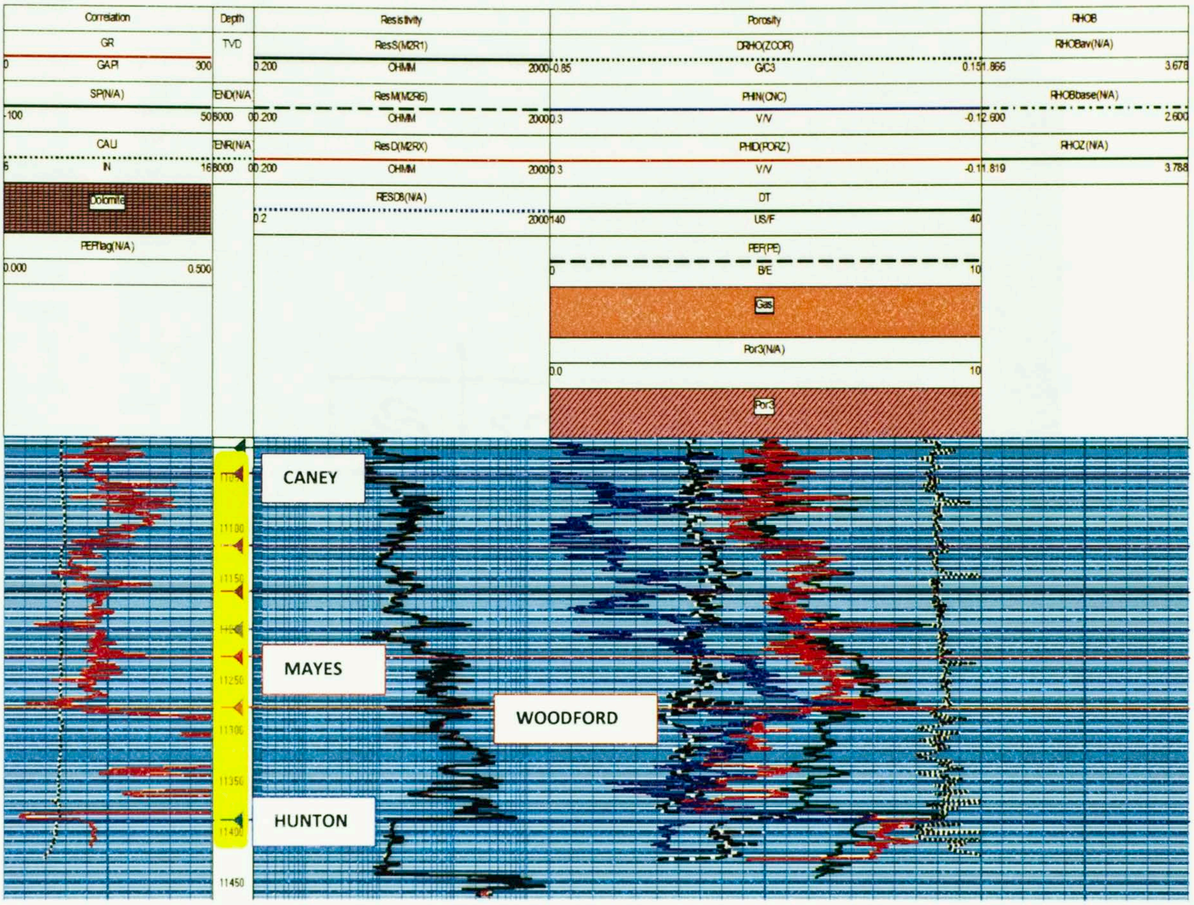


Figure 3.5: The Newfield Exploration Cometti 2H-13. The Cored interval is indicated by the yellow rectangle.

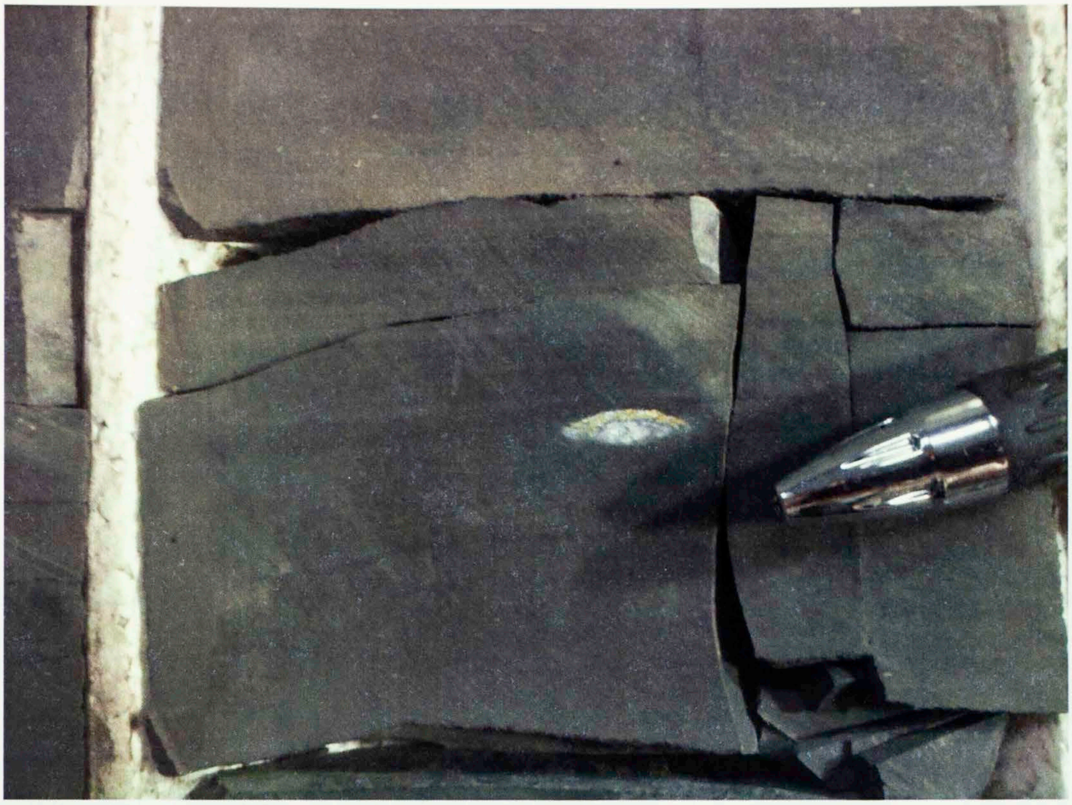


Figure 3.6: Fossil replaced by pyrite. Note pen for scale.

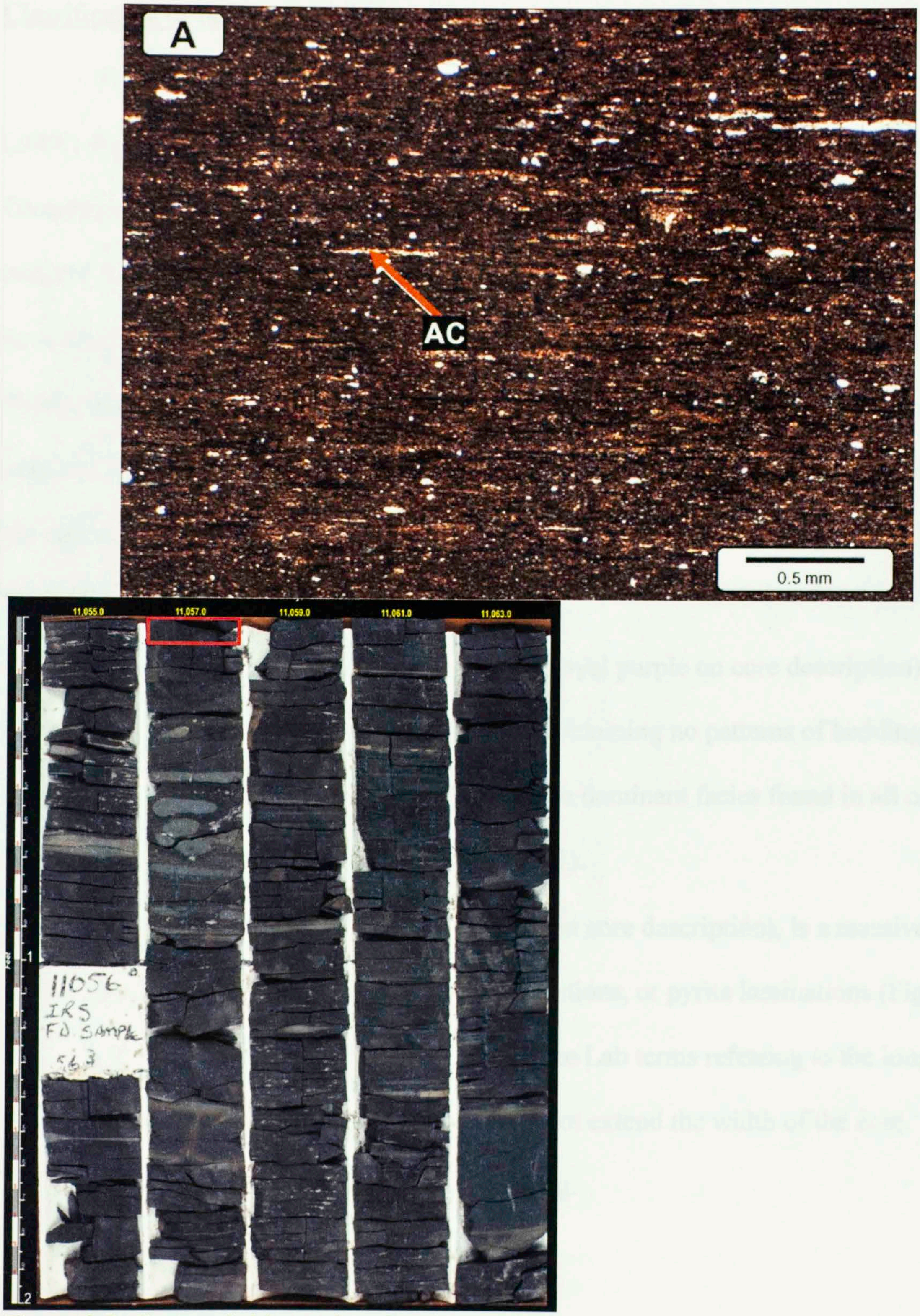
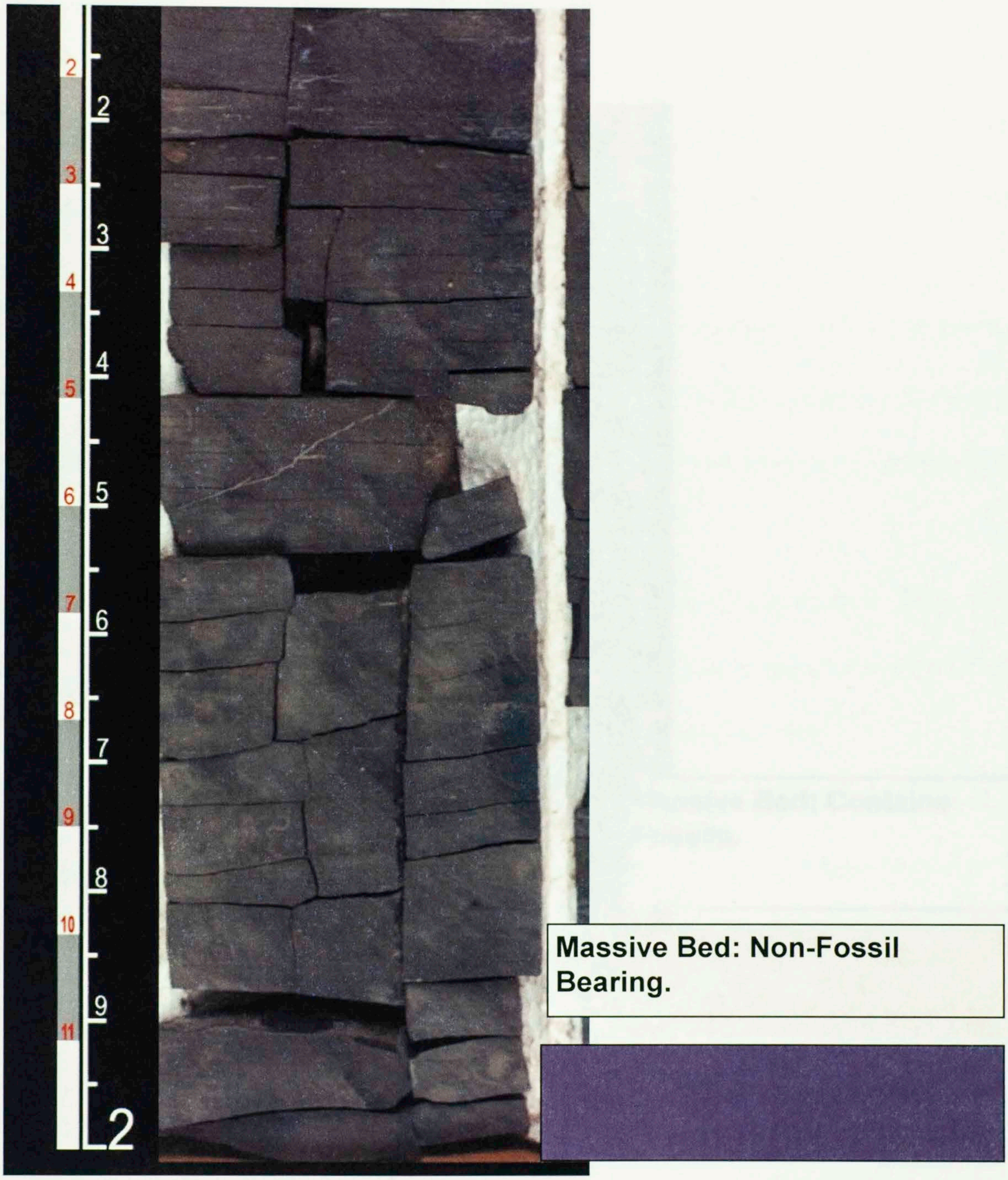


Figure 3 7: Core and thin section showing carbonate laminae, algal cyst (AC) in thin section Red rectangle are of then section sample. Photos provided by Core_Lab, Inc.

Classification of facies

There have been many shale core interpretations based on lithology. Signh (2008) divided the Barnett shale into 9 different lithofacies, Hasley (2011) divided the Greenhorn Basin Shales into 8 different lithofacies. They both were able to establish patterns from lithology that explained the sequence stratigraphy. Geomechical studies have shown that bedding patterns can help explain zones of interest for enhanced drilling. Brittle strata are more facturable than ductile, stata, but the later usually contains the majority of hydrocarbons. Therefore, identifying different bedding patterns throughout the core and establishing well log patterns for sequence stratigraphy was a key this study. Six different facies identified in this core:

- Massively bedded, Non-Fossil Bearing: (royal purple on core description). This facies is a solid dark grey to black shale containing no patterns of bedding, concretions or fossils (Figure 3.8). It is the dominant facies found in all of the cores including the Cometti core (Plate 1.1).
- Massively bedded, Fossil Bearing: (pink on core description), is a massive shale, dark grey to black, but with fossils, concretions, or pyrite laminations (Figure 3.9). Note that Pyrite laminations is a Core Lab terms referring to the long, cylindrical pyrite, that often- times does not extend the width of the core. They are not laminations in reference to bedding.



Massive Bed: Non-Fossil Bearing.

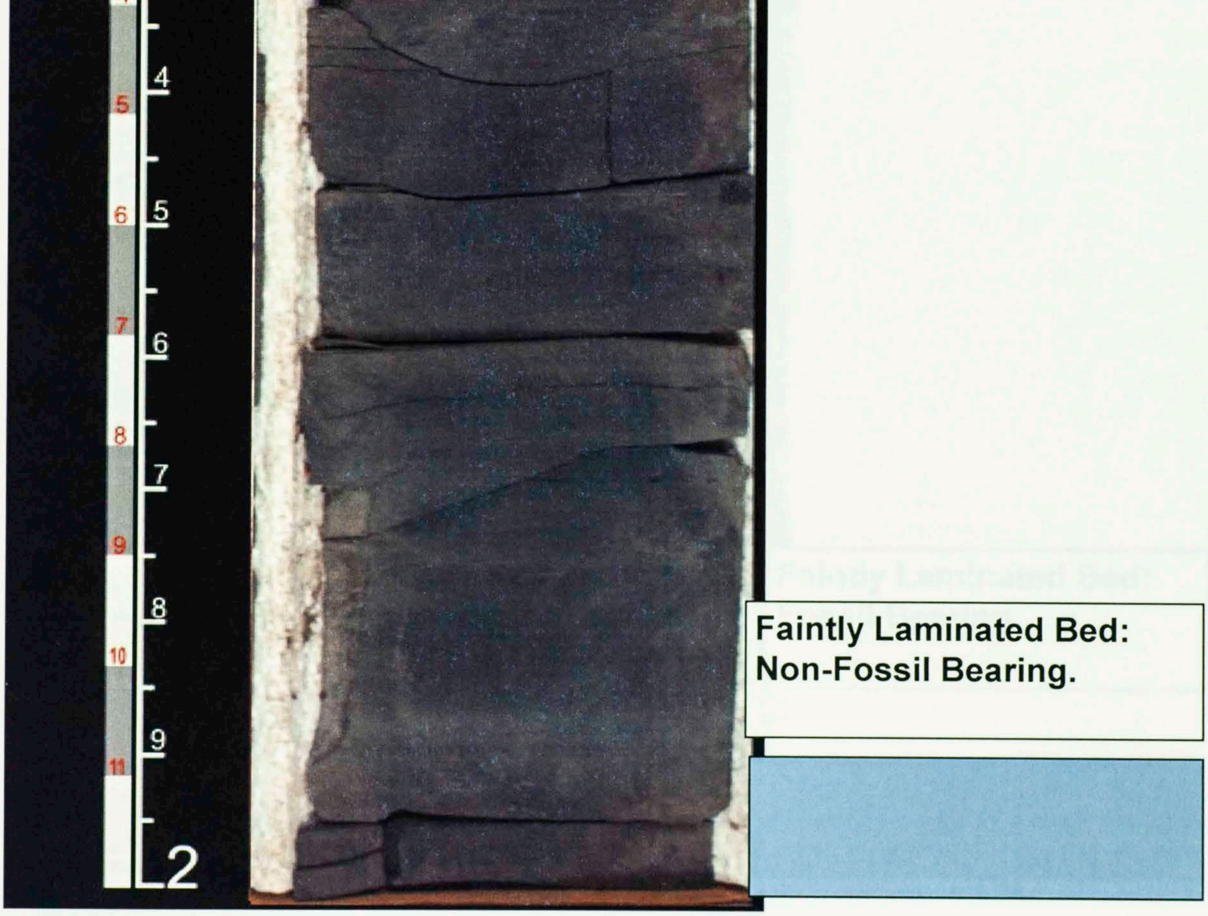
Figure 3.8: Massive Bed: Non-Fossil Bearing example. Grey and white scale: inches. Photos provided by Core_Lab, Inc.

Figure 3.9: Massive Bed: containing fossil. Grey and white scale: inches. Photos provided by Core_Lab, Inc.

- Faintly Laminated beds non-fossil bearing (Light blue on core description), include those beds with subtle bedding features. Wetting the core surface display features. Faintly laminae include small flows, widely spaced laminations or those that appear to have escape features (Figure 3.10). This category however does not include beds with fossils, or concretions.
- Faintly laminated bed, fossil bearing: (green on core description) is very similar to previous facies however contains fossils. Many of the fossils are within the flows and small bedding features of this group (Figure 3.11). A number of the fossils are still intact and have not been broken.
- Highly laminated bed, non-fossil bearing: (orange on core description). Beds that are laminated as well as beds with flows features that can be seen without wetting the core (Figure 3.12). Most of these beds appear lighter in color.
- Highly laminated beds, fossil bearing (Yellow on core description) included all of the same bedding patterns, but with the presences of fossils. These beds also appear lighter in color than the previous four facies types (Figure 3.13).

Depositional Environment Interpretations

Based upon previous studies, the location of the shelf is known to be located on the north-northwest rim of the basin (Figure 3.14). Cored well information indicates the southern portion of the Arkoma basin where the York, Cometti, and Cattle cores are located is within a shelf to basin transition. The York, located furthest south it this area is more of a basinal shale and with into a transition zone toward the north-northwest.



Faintly Laminated Bed:
Non-Fossil Bearing.

Figure 3.10: Faintly Laminated bed: Non-Fossil Bearing example. Grey and white scale: inches. Photos provided by Core_Lab, Inc.

Figure 3.11: Faintly Laminated: Fossil Bearing bed. Grey and white scale: inches. Photos provided by Core_Lab, Inc.

Figure 3.8: Highly laminated Beds: Non-Fossil bearing example. Grey and white scale: inches. Photos provided by Core_Lab, Inc.

Figure 3.13: Highly Laminated Beds: Fossil bearing examples. Grey and white scale: inches. Photos provided by Core_Lab, Inc.

The Kinderhook is a key indicator that the shelf was located in the North part of the basin, within Muskogee, Sequoyah and Crawford Counties. The majority of unconventional shales with higher carbonate content are associated with shallow marine (shelf) environments and siliciclastic clays are associated with relatively deeper water (Slatt et al., in press; Slatt and Rodriguez, in press). The Caney contains both carbonate contents and siliciclastic clays therefore the Caney was deposited in a transition zone.

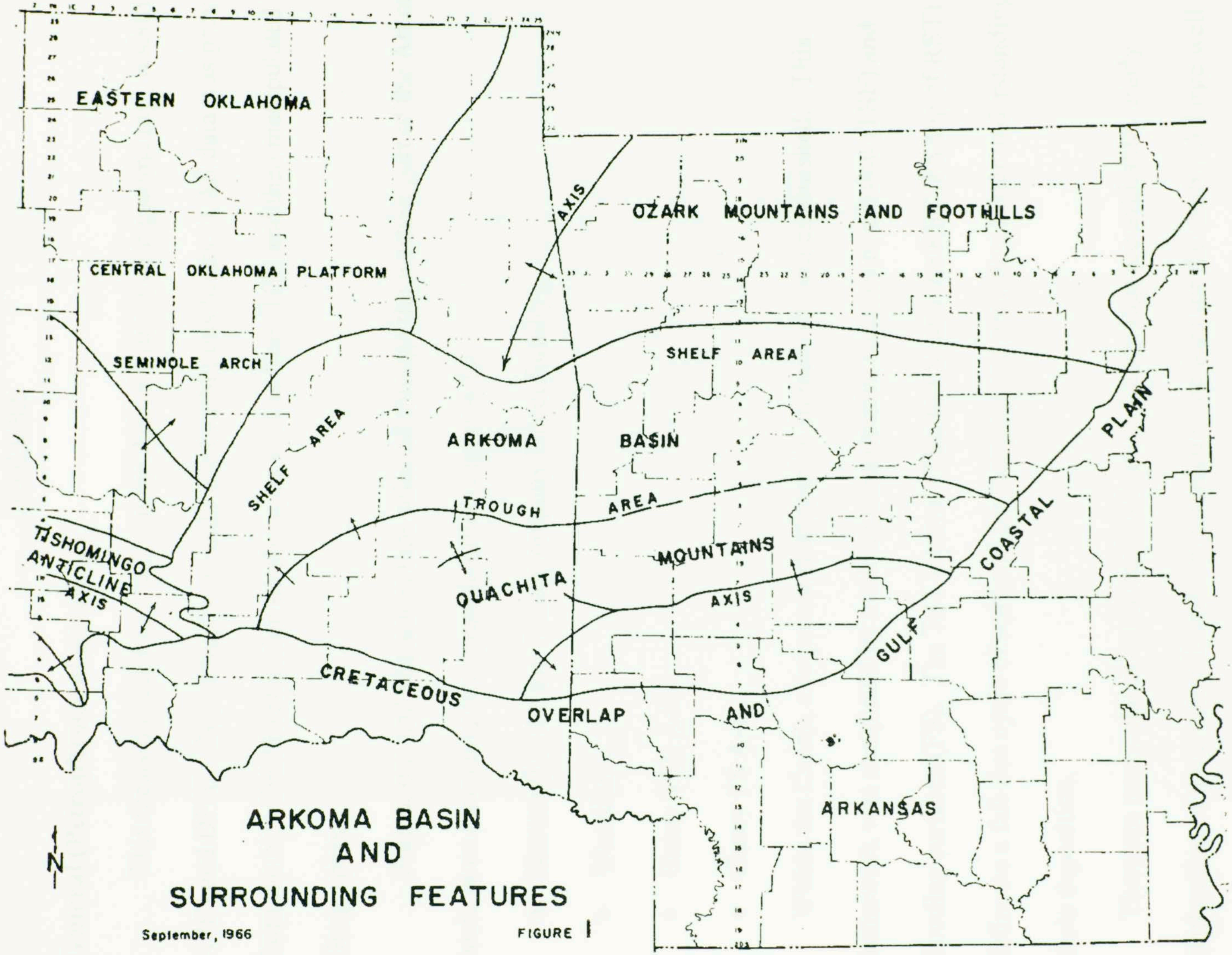


Figure 3.14: Map of Arkoma Basin and Location of the shelf area. From Branan 1968.

CHAPTER 4

Well Logs

General (Petrophysics of gas shale)

This thesis included 555 wells in the Arkoma Basin with gamma ray , resistivity, NPHI and DPHI. Digital logs were only used within this thesis. LAS data was provided from the Newfield Exploration database, as well as from TGS and then manipulated in Geographix.

Formations and sequences tops selected through the western part of the Arkoma basin in an ascending stratigraphic order (Figure 4.1):

- Hunton (i.e. the top Hunton orogeny Unconformity),
- Woodford,
- Caney TSE A-J,
- Caney FS A-J

Within the Caney, a sequence stratigraphic framework was established. This framework was completed by marking transgressive surfaces of erosion (TSE) and flooding surfaces (FS). The TST interval (TSE to FS) and the RST (FS-top of RST) delineate a fall-rise cycle of sea level for mapping and provide a better understanding of shale deposition.

There are many places in the basin where no Caney logs are available. Early exploration of the Hunton limestone provided some logs for the study. A large well log data based was available from Woodford exploration. The data base does not contain many specialty logs because the Woodford play developed quickly. Only now are operators realizing that all shale plays are not the same and each requires its own

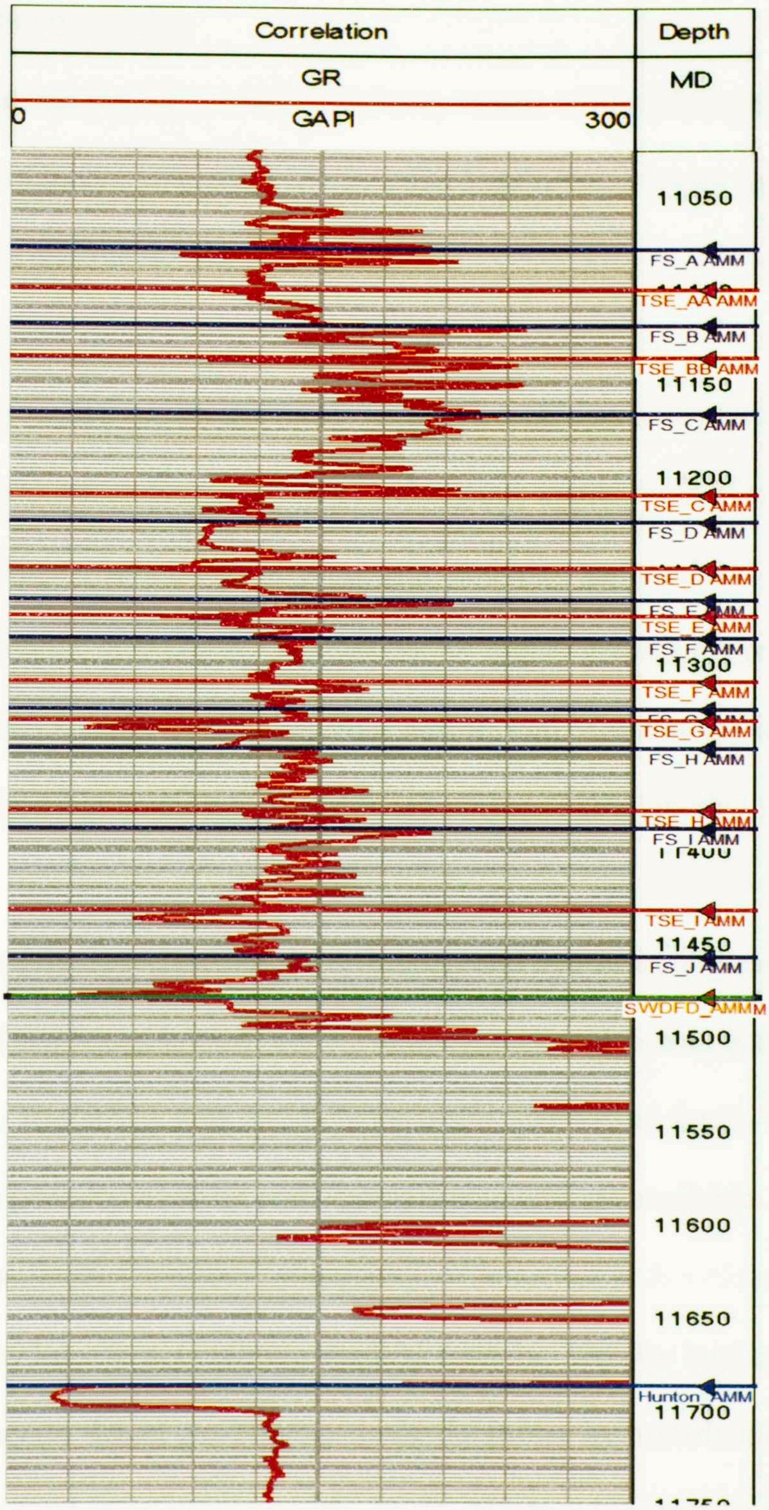


Figure 4.1: Stratigraphic Column of the Devonian/Mississippian formations in Arkoma Basin.

reservoir characterization study. Consequently, more specific well logs are now being taken in newer wells.

The gamma ray log provided a primary means of identifying sequences throughout the Caney. Resistivity and porosity logs were also very useful, especially for wells without a gamma ray log.

Gamma Ray

A Gamma Ray log by definition records a rock's naturally emitting gamma radiation. Shales are composed of clays and organic matter, both of which tend to accumulate radioactive isotopes of potassium, uranium, and thorium. High amounts of these three elements in shales are responsible for higher gamma ray responses. Shales are also great markers for correlating from well to well. Gamma ray logs in this study were used to interpret facies relationships and sequence stratigraphy in the study area.

Resistivity

A resistivity log identifies water-bearing and hydrocarbon-bearing zones. The resistivity tool sends an electrical current into the rock and measures the current as it exits the formation. Resistivity logs also help determine permeable zones. Also, resistivity can determine porosity when no porosity measurements are available.

Porosity Logs

Porosity logs do not measure porosity directly. Density logs can identify evaporate minerals, detect gas-bearing zones, determine hydrocarbon density and evaluate shaly-sand reservoirs (Asquith, 2004). Neutron logs measure hydrogen within the formation and can determine if pore spaces are filled with water or oil. In a shale reservoir water-bearing matrix clays lead to a much higher neutron porosity value than is real. In this study the neutron porosity log aided correlation. If gamma ray or resistivity logs were missing within the well, porosity logs help detect the tops of each formation.

Well Log Characteristics

Sequence stratigraphic features within the study are include: TST (Transgressive systems tract), RST (Regressive systems tract), FS (flooding surface), TSE (Transgressive surface of erosion), and SB (sequence boundary).

A summary of facies relationships of each gamma ray log response is described below.

A TSE is produced during a rise in sea level as the shoreline migrates landward, further eroding the falling stage sequence boundary.

The fining upward TST is interpreted as representing deposition during a rapid rise in sea level. Shelf, shoreface deposits and condensed sections are deposited during this time interval. The TST contains the majority of the organic rich zones, are especially condensed sections.

The RST is identified by a cleaning- upward, progradational pattern due to continuing rise of sea level but at a slower rate. Shales within the HST are lower in TOC, and thus have a lower API gamma ray response.

Each system's tract within the Caney is associated with a characteristic gamma ray log pattern (Figure 4.1) as follows:

- TST is characterized by a fining upward sequence or an increase in gamma ray API values (Woodford).
- RST is characterized by a coarsening up or a decrease in gamma ray pattern.

- SB and TSE within this study are the same surface formed during different parts of a sea level cycle. TSE occurs at the base of a TST.
- FS occurs at the highest API gamma ray reading, at the top of a TST.
- The MFS occurs at the top of a condense section. It is characterized by the highest API reading and the finest grained shale.

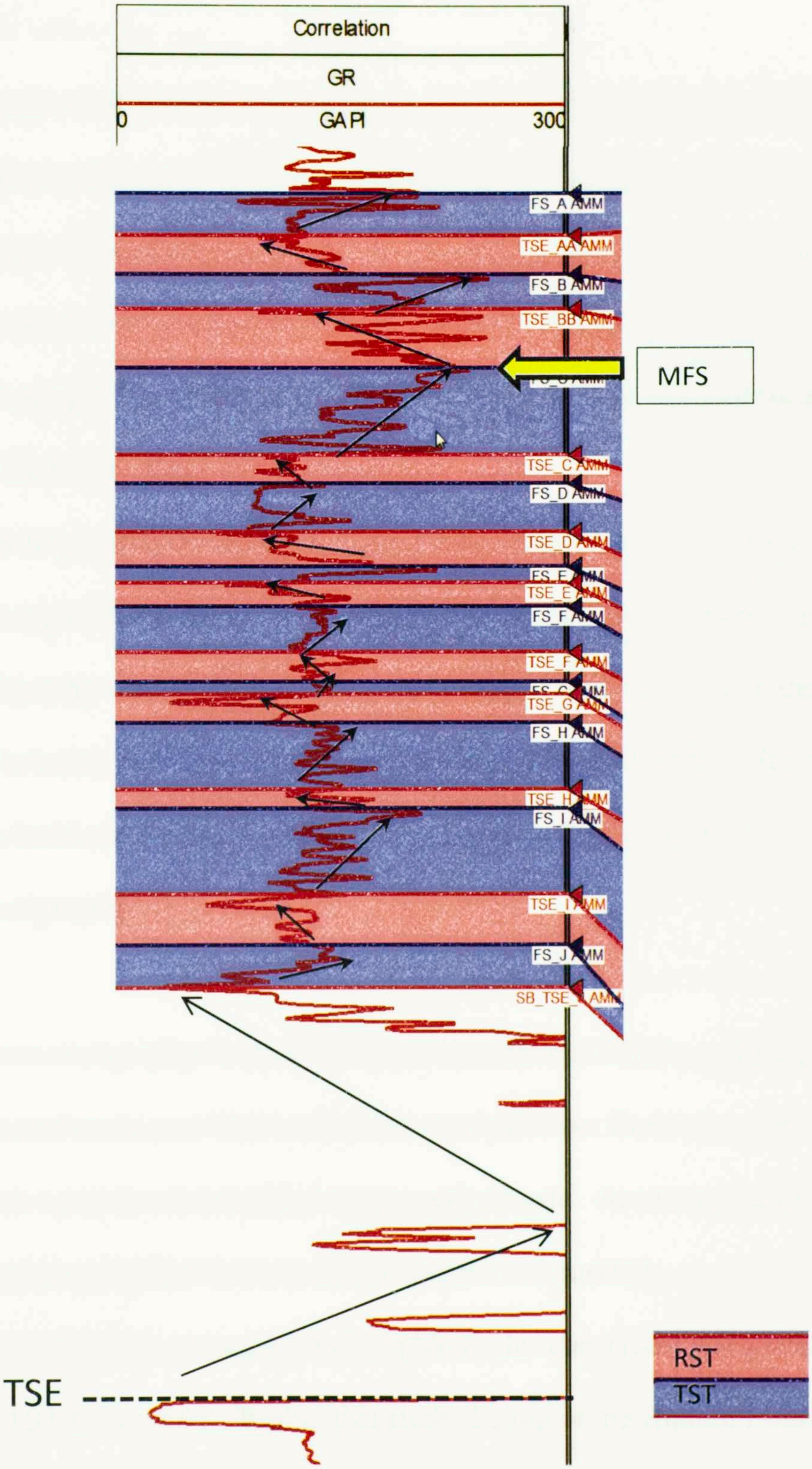


Figure 4.2: Well Log showing sequence stratigraphy features.

CHAPTER 5

Sequence Stratigraphy and Well Log Cross Sections

General

A sequence stratigraphic framework for the Caney Shale was established from correlating digital well logs on 25 cross sections (Figure 5.1). Five cross sections were constructed along strike of the Arkoma Basin (slightly northeast-southwest) and twenty cross sections were constructed parallel to the dip of the Arkoma basin (northwest-southeast). Creating a large framework allowed for an excellent regional stratigraphic framework of the Caney Shale within Oklahoma.

In order to properly correlate the Caney from well to well, 10 flooding surfaces (FS) and 10 transgressive surfaces' of erosion (TSE) stratigraphic makers were picked. A sequence stratigraphy was developed after cross sections were datumed on the unconformity between the Hunton Limestone and the Woodford Shale. The stratigraphic makers for the basin can be found within the Cometti 2H-13 (Figure 4.1).

Sequence Stratigraphy

General

Sequence stratigraphy is the subdivision of sediment fill into genetic packages bounded by unconformities or their correlative conformities. Controls on the strata include extrinsic controls of tectonics, eustasy, and climate. Accommodation space is also a factor and is controlled by tectonic subsidence and eustasty.

A shale's complete sequence stratigraphic cycles consists of a regional sharp TSE, followed by a TST then a RST. Within this study the top of the Hunton Limestone is where the TSE occurs, followed by a 2nd order TST (the Woodford shale). At the SB above the Woodford starts a detailed 3rd order sequence stratigraphy. That depicts the remaining RST and TST throughout Mayes and Caney time. Nine RST's and 10 TST's were correlated within the basin.

Picking these additional sequences was not difficult, especially with the large amount of data in this study area. Correlations can be performed in a relatively short amount of time using the software package Geographix and a complete digital log data base. Therefore, all shale plays should be correlated this way to properly understand and visually depict shale deposition.

Depositional History

To understand the depositional history of the Caney a general sequence stratigraphic model for gas shales must be discussed first. Generally, less organic-rich RST are thicker landward and downlap basinward onto the underlying organic-rich condense sections (CS). The further seaward the strata, the greater the difference in thickness between the SB/TSE and FS, at least in theory. Therefore, RST should be thickest landward and TST thickest seaward (Figure 5.2).

As seen from cross section dipline's D and L and Strikeline C (Figures 5.3, 5.4, and 5.5) it is relatively difficult to determine the exact landward vs. seaward direction. In order to better determine the direction of land and direction of sediment movement, each RST and TST were mapped and will be further discussed in the next chapter.

Each sequence is deposited during a different time period and different types of facies may be associated with each systems tract. The facies referred to in this section are those established from core analysis from Chapter 3.

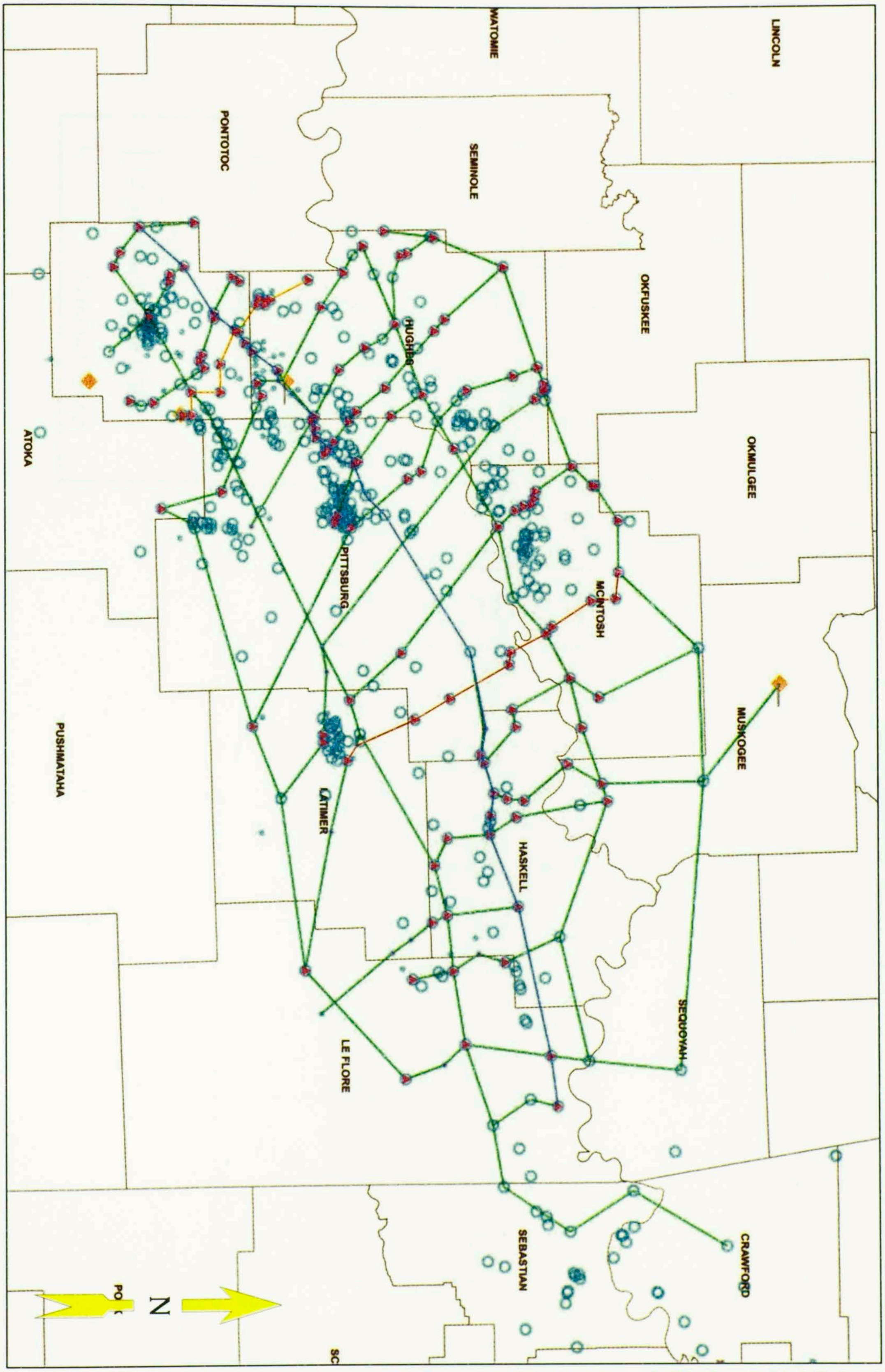


Figure 5.1: Cross section grid location. Dipline L highlighted in red, Dipline D highlighted in orange, Strikeline C highlighted blue. Pink triangles: Wells in cross section, blue circles: digital wells used and orange diamonds: cored wells.

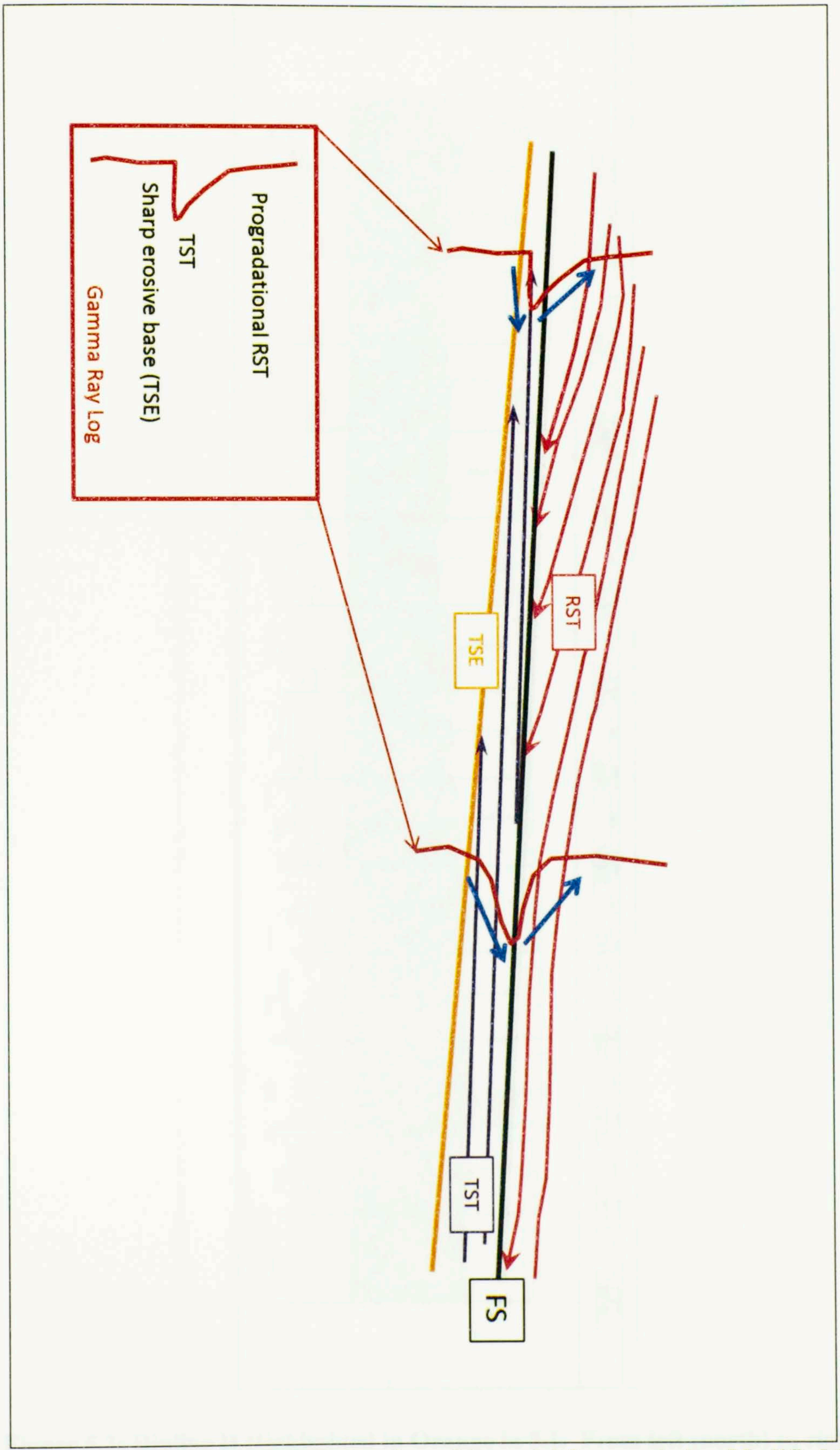


Figure 5.2: General Sequence stratigraphic model for gas shales. Modified from Slatt and Rodriguez (in press).

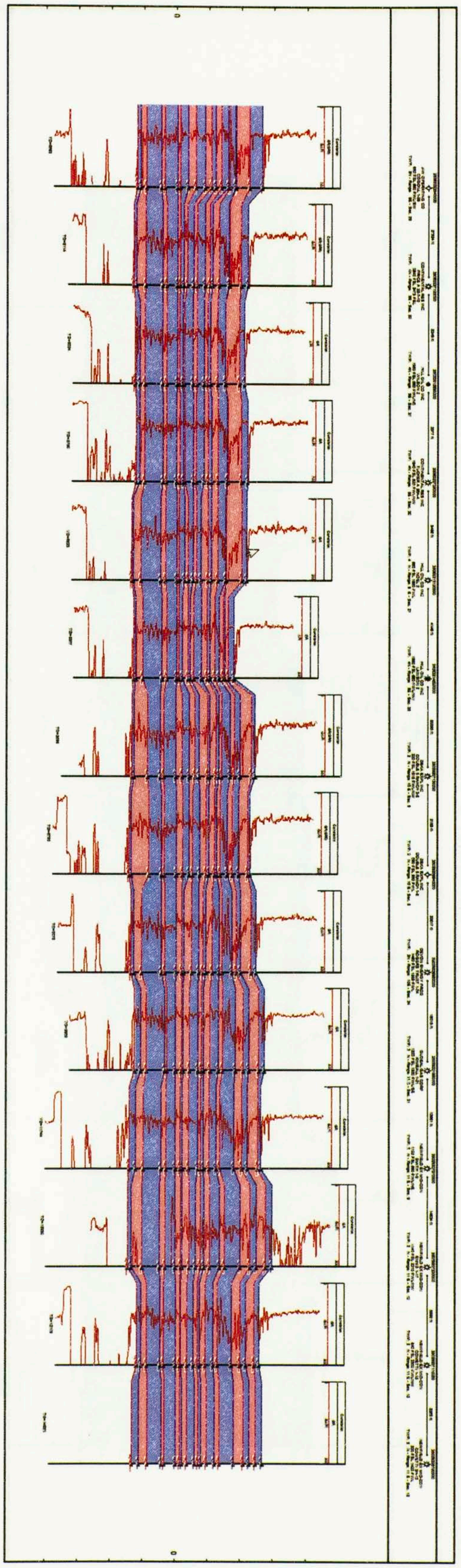


Figure 5.3: Dipline D Highlighted in Orange in 5.1. From left (north) to right (south)

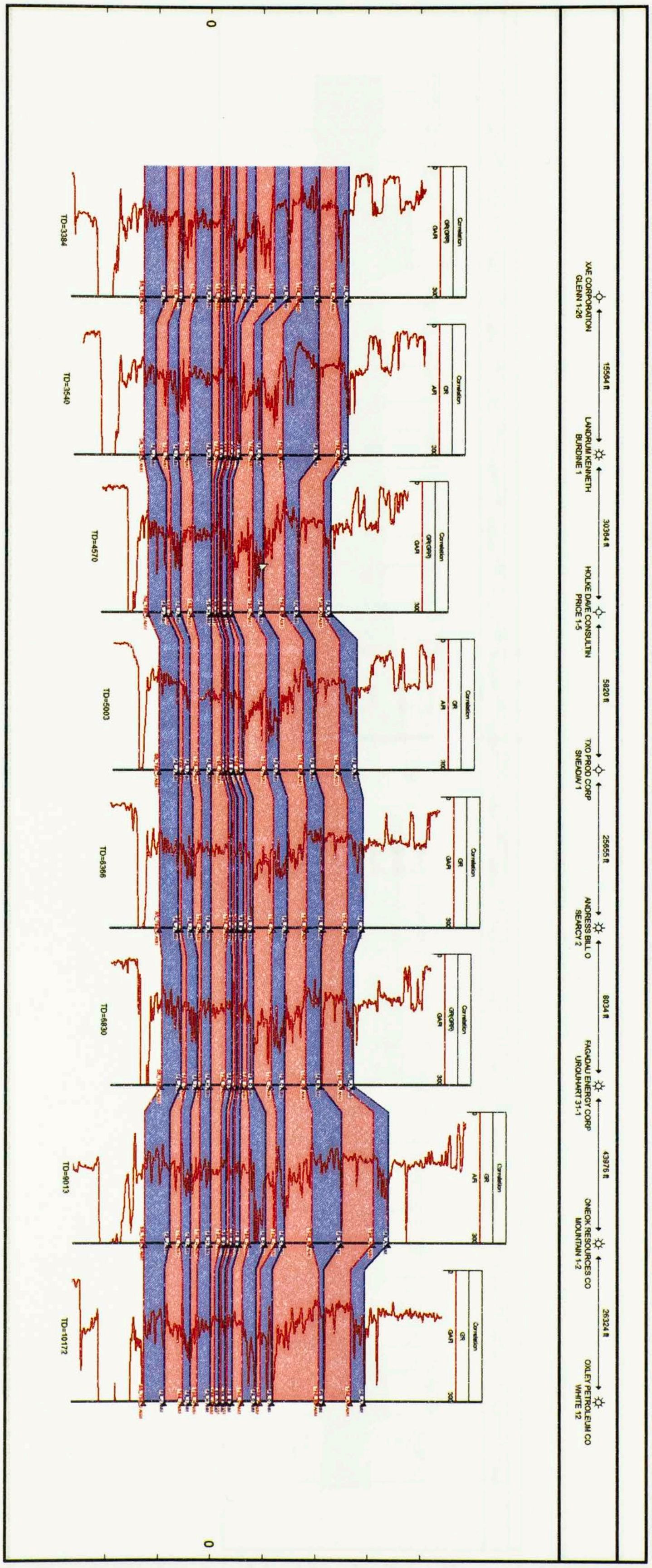


Figure 5.4: Dipline L Highlighted in Red in 5.1. From left (north) to right (south)

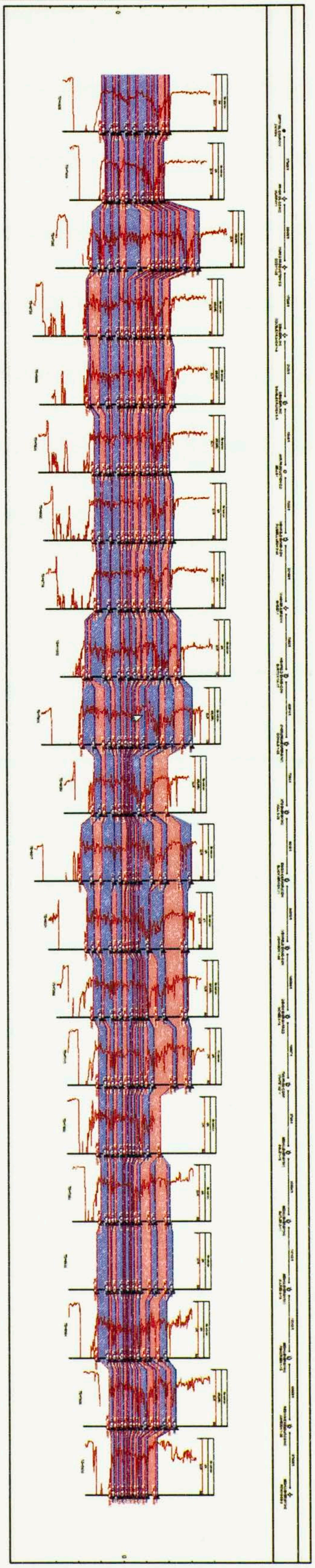


Figure 5.3: Strikeline C Highlighted in blue in 5.1. From left (west) to right (east)

The core facies analysis performed on the Cometti showed an overall trend from the *massive beds: non and fossil bearing* up to the *highly laminated beds: non and fossil bearing,* indicating a progression from quiet water to shallow water, higher energy environments with more event deposits. This cycle occurs twice within the core (figure 5.6). Due to scale difference, correlation between facies and each systems tract is difficult to determine just from the gamma ray log. The core facies are at a more detailed scale than what the gamma ray can resolve. A closer look at these two cycles from core facies is further discussed in the next chapter.

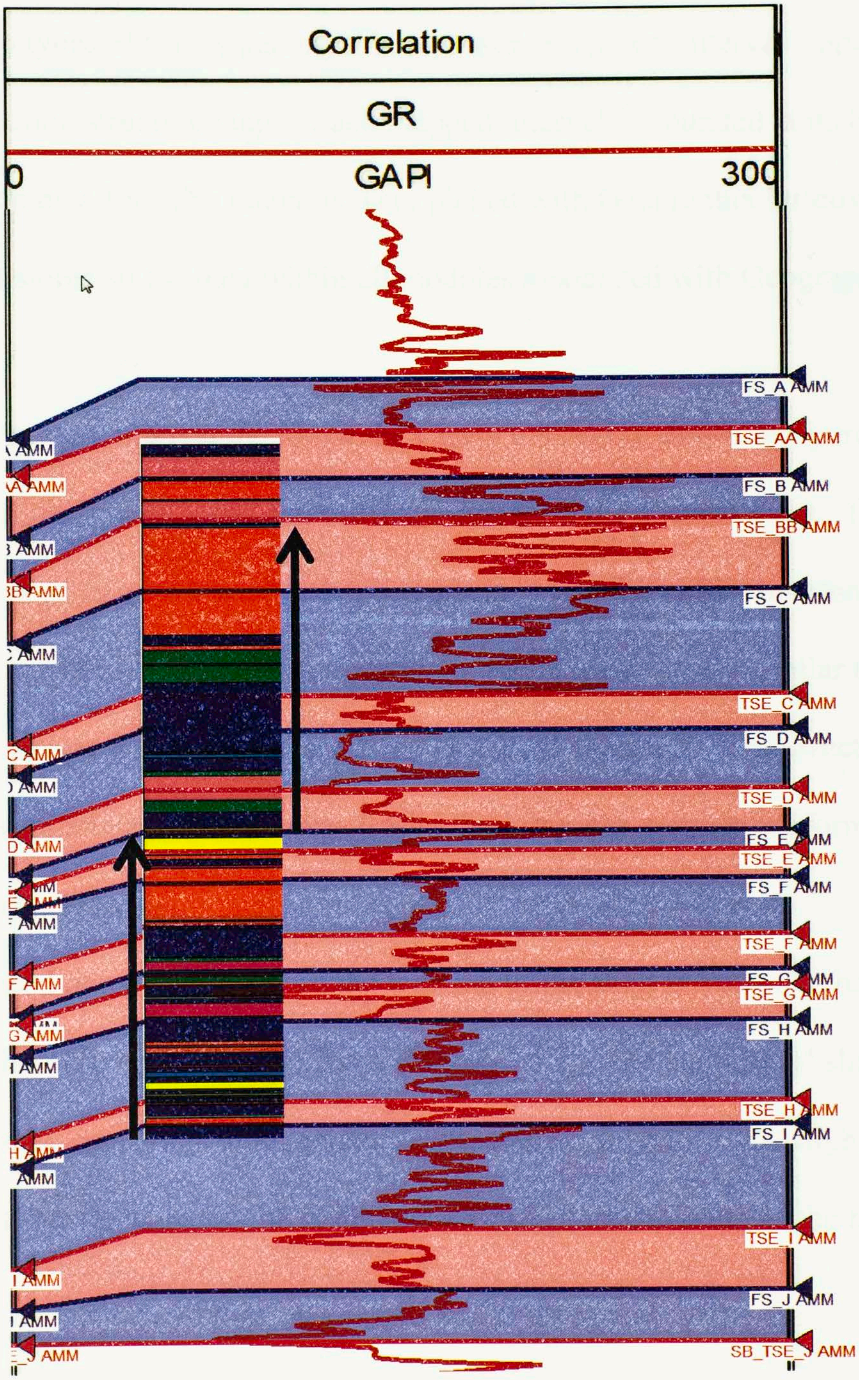


Figure 5.6: Cometti 2H- 13 well log with core facies. Note the two massive to highly laminated cycles indicated by the two arrows.

CHAPTER 6

Geological Maps

General

Two types of Caney geological maps were prepared: interval isopach maps and top of formation structure maps. Each mapped interval is bounded at its base by a TSE and at its top by a FS. The intervals were picked with Geographix Discovery: Xsection tool, which stores all the data within all modules associated with Geographix.

Structure

A structure map on the top of the Caney interval is shown in figure 6.1. The red indicates the shallowest areas and the blue represents the deepest areas. The top of the Caney was used as a structural datum because it is was the most consistent marker throughout the basin. The overall structure of the Hunton is very similar to that of the Caney--- shallowest towards the north and deeper to the south. The structure formed early in development of the Arkoma Basin, therefore, the majority of formations have similar structural trends.

Based on previous studies the location of the shelf is known to have been located on the north-northwest rim of the basin (Figure 3.15). The majority of shales are located within the shelf transition zone and the deeper part of the basin. The slightly higher areas would allow for the transport of sediments towards the deep areas of the basin.

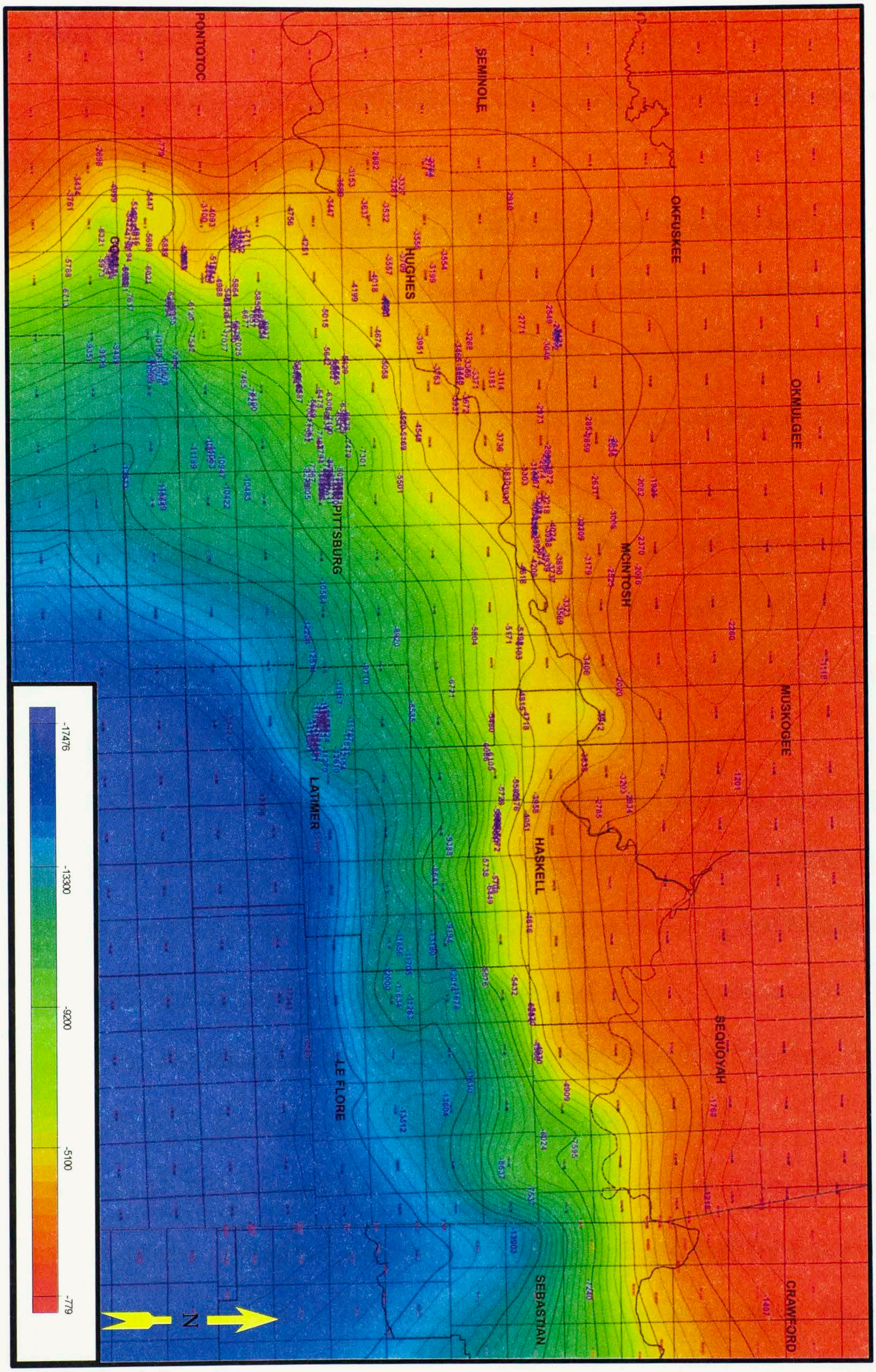


Figure 6.1: Structure Map of the Top of the Caney. Data points are in purple. Contour interval 500 feet.

Interval Isopach

Nineteen intervals were determine to be bounded by TSE and FS, and were then mapped. They include the following:

- TST J: TST J isopach is from SB/TSE J (Top of the Woodford) to FS J. Figure 6.2, shows two narrow, thick intervals trending northwest-southeast. One thick is located within southern Muskogee, northeast McIntosh, northeast Pittsburg and eastern Haskell Counties. The second thick occurs to the west of the first, through Hughes and Pittsburg Counties.
- RST I: RST I isopach (FS J to TSE I) has one major thick interval trending northwest-southeast (figure 6.3). This lobe is slightly east of TST J. Covering most of Pittsburg, eastern McIntosh, northern Latimer and western Hughes Counties.
- TST I: TST I isopach (TSE I to FS I) continues the northwest-southeast trend seen in the previous two maps (Figure 6.4). This interval's thick has shifted slightly to the east. The thickest interval occurs in Hughes, Pittsburg and Latimer Counties.
- RST H: RST H isopach (FS I to TSE H) trend is very similar to RST I (Figure 6.5). The thick in this interval occurs throughout most of Pittsburg, eastern McIntosh, northern Latimer and western Hughes Counties.
- TST H: TST H isopach's (TSE H to FS H) thickest area trends northwest-southeast. Figure 6.6, shows this interval to be distributed more as a blanket than a narrow valley-fill (RST I and H) covering McIntosh, Pittsburg, Hughes, and Coal Counties.

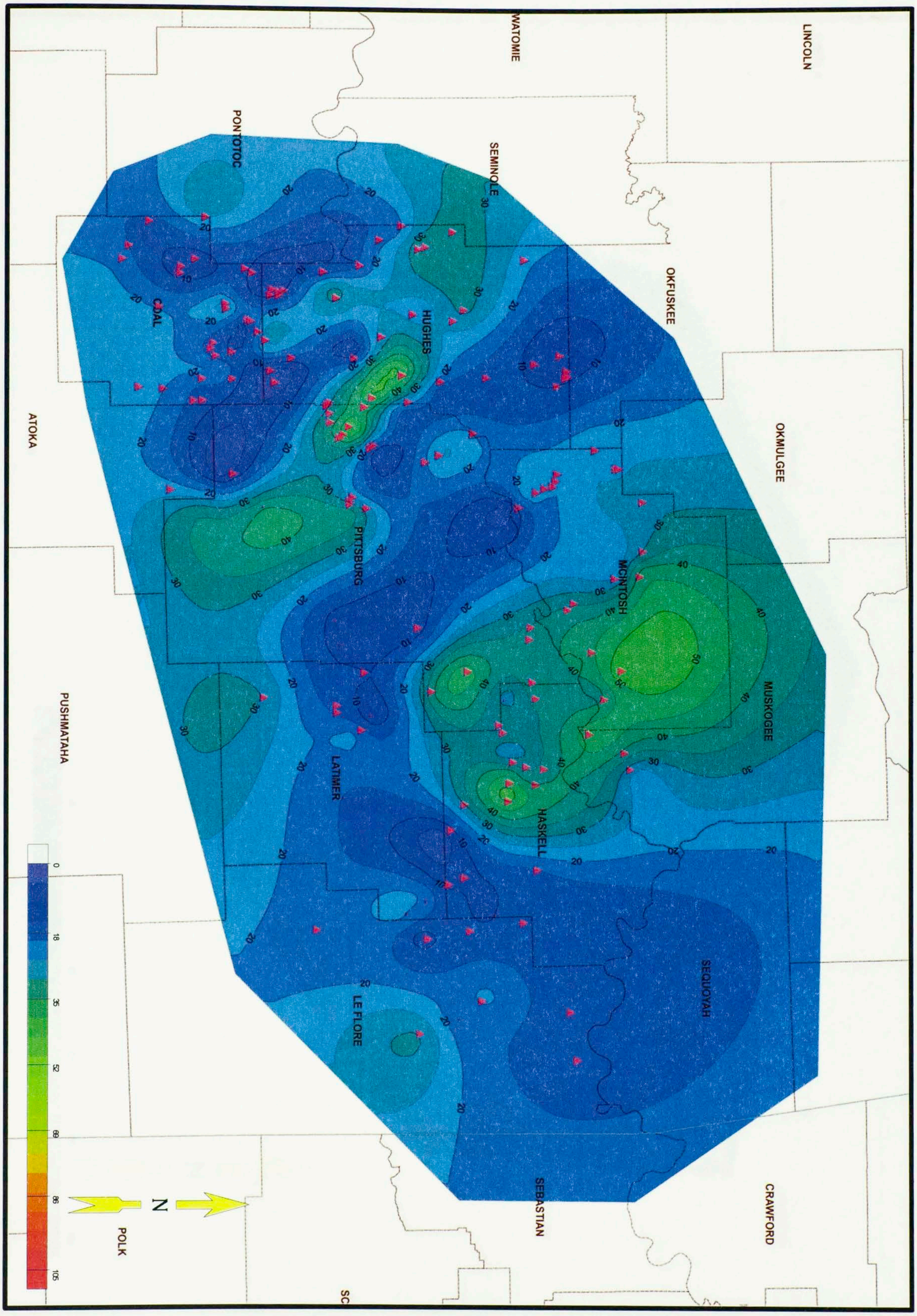


Figure 6.2: TST J isopach from Top of Woodford (TSE J to FS J) displays a thick trend northwest-southeast. CI. 5ft

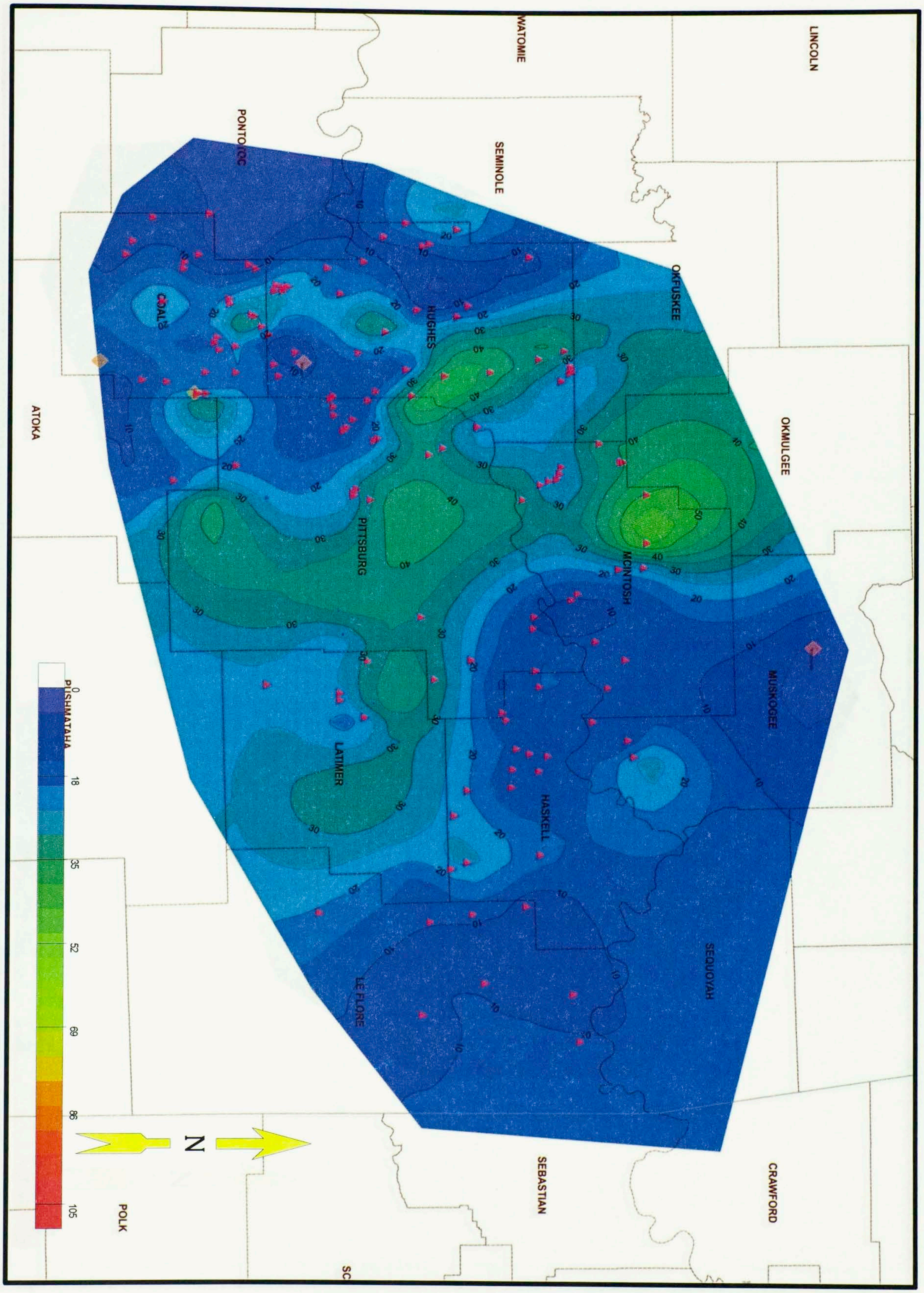


Figure 6.3: RST I isopach from FS J to TSE I displays a thick trend northwest-southeast. CI. 5ft

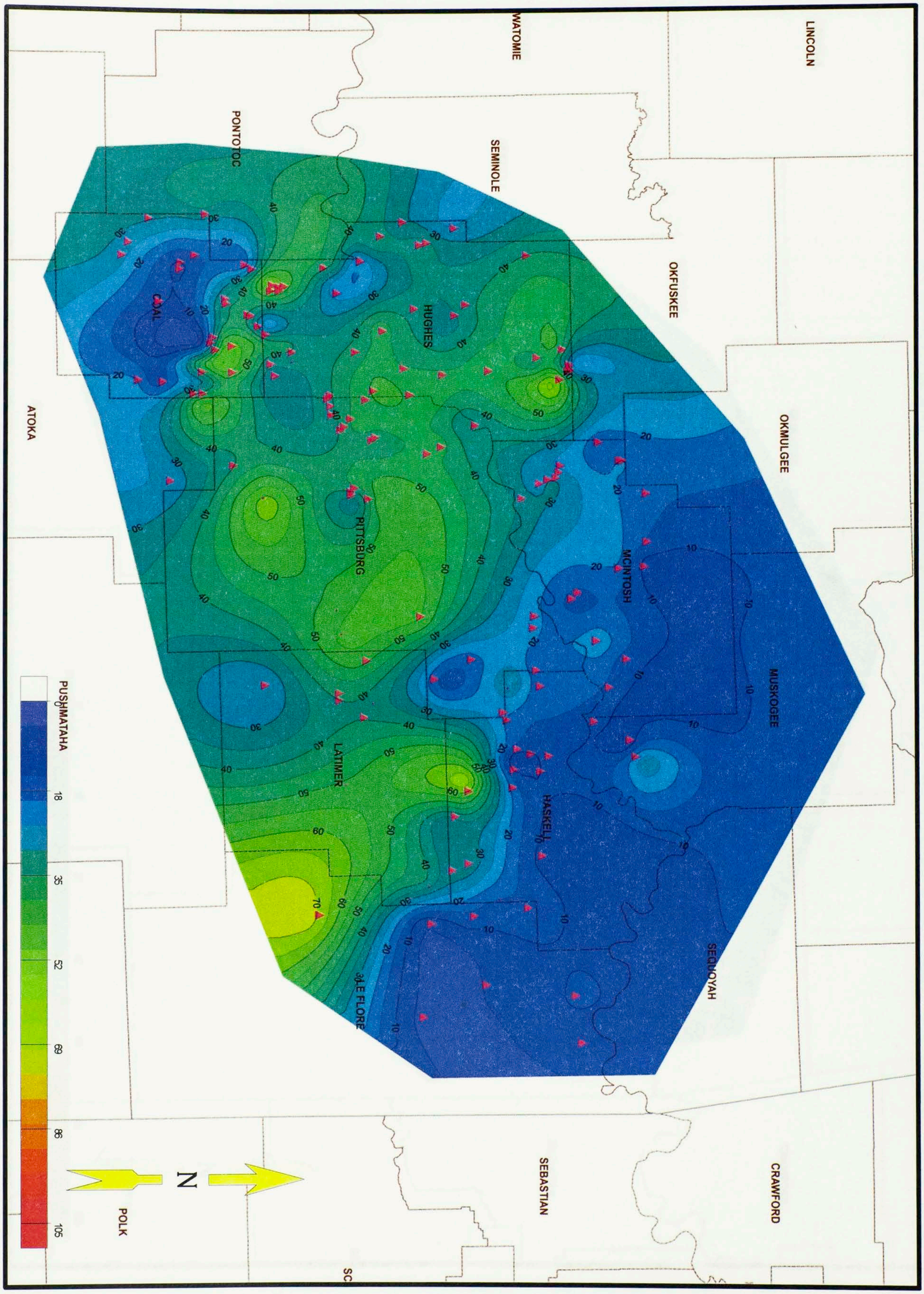


Figure 6.4: TST I isopach from TSE I to FS I displays a thick trend northwest-southeast. CI. 5ft

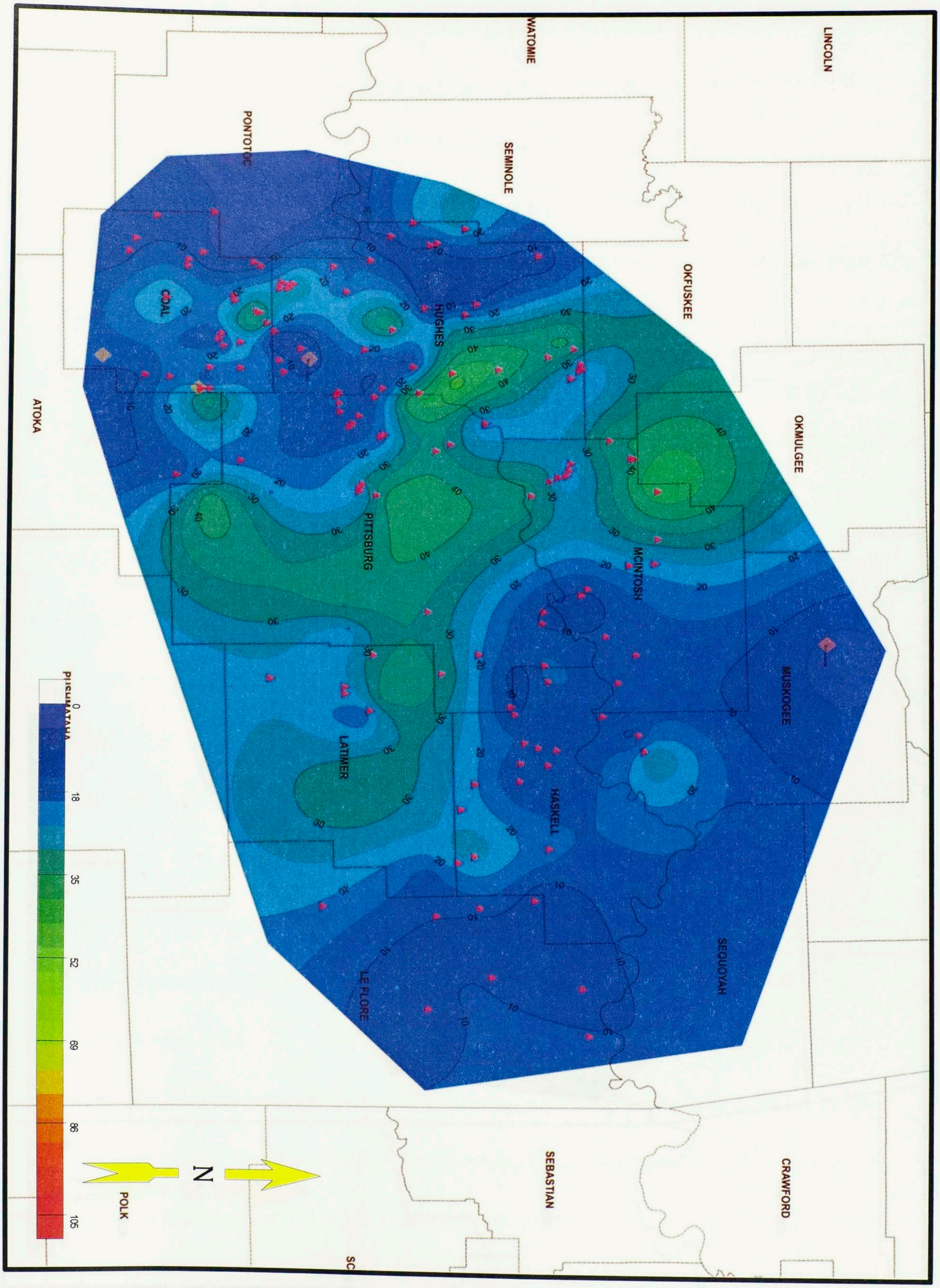


Figure 6.5 RST H from FS I to TSE H isopach displays a thick trend northwest-southeast. CI. 5ft

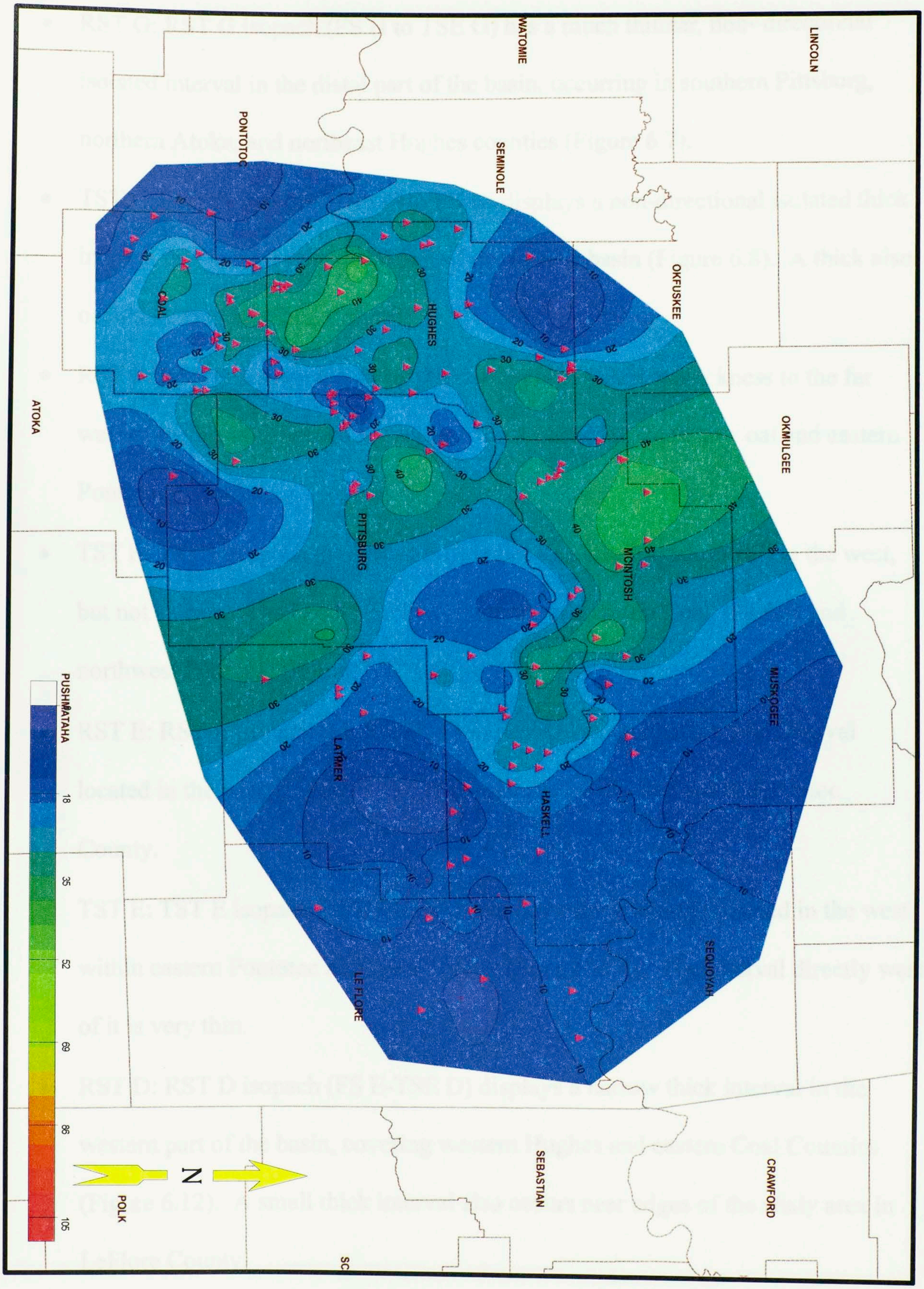


Figure 6.6 TST H from TSE H to FS H isopach displays a thick trend northwest-southeast. CI. 5ft

- RST G: RST G isopach (FS H to TSE G) has a much thinner, non- directional isolated interval in the distal part of the basin, occurring in southern Pittsburg, northern Atoka, and northeast Hughes counties (Figure 6.7).
- TST G: TST G isopach (TSE G to FS G) displays a non-directional isolated thick interval that includes the distal part of the eastern basin (Figure 6.8). A thick also occurs in southern Coal County.
- RST F: RST F isopach (FS G to TSE F) displays a shift in thickness to the far west of the basin (Figure 6.9), where a thick occurs in southern Coal and eastern Pontotoc Counties.
- TST F: TST F isopach (TSE F –FS F) indicates a thick location still in the west, but not as narrow as in RST F. This interval falls within Coal, Hughes and northwest Pontotoc (Figure 6.10).
- RST E: RST E isopach (FS F-TSE E) indicates a thick blanket- like interval located in the west (Figure 6.11). The majority of it is located in Pontotoc County.
- TST E: TST E isopach (TSE E-FS E) also has a thick interval located in the west within eastern Pontotoc and Coal County (Figure 6.11). The interval directly west of it is very thin.
- RST D: RST D isopach (FS E-TSE D) displays a narrow thick interval in the western part of the basin, covering western Hughes and eastern Coal Counties (Figure 6.12). A small thick interval also occurs near edges of the study area in LeFlore County.

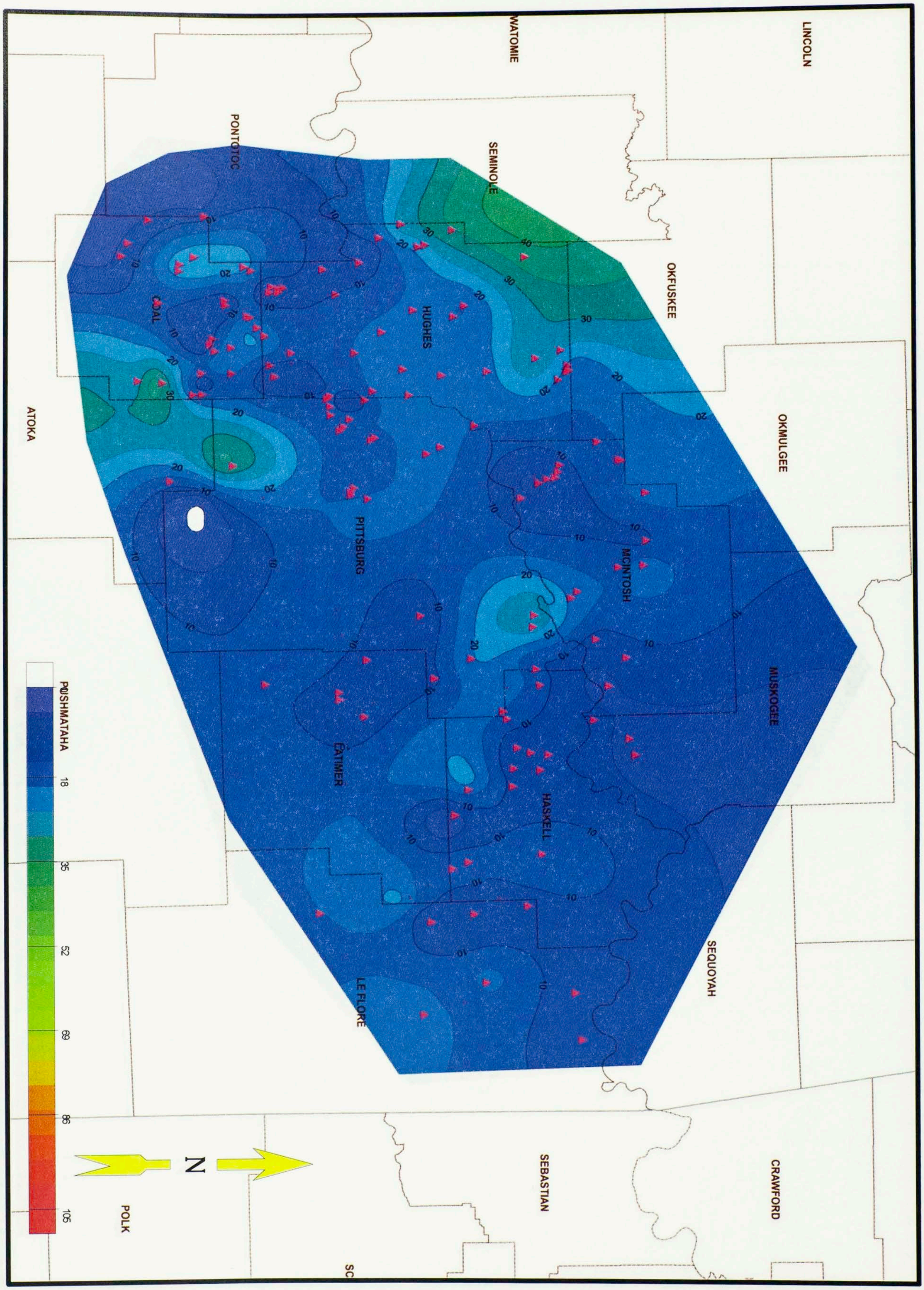


Figure 6.7: RST G from FS H to TSE G non-direction isolated thick in the western part of the basin. CI. 5ft.

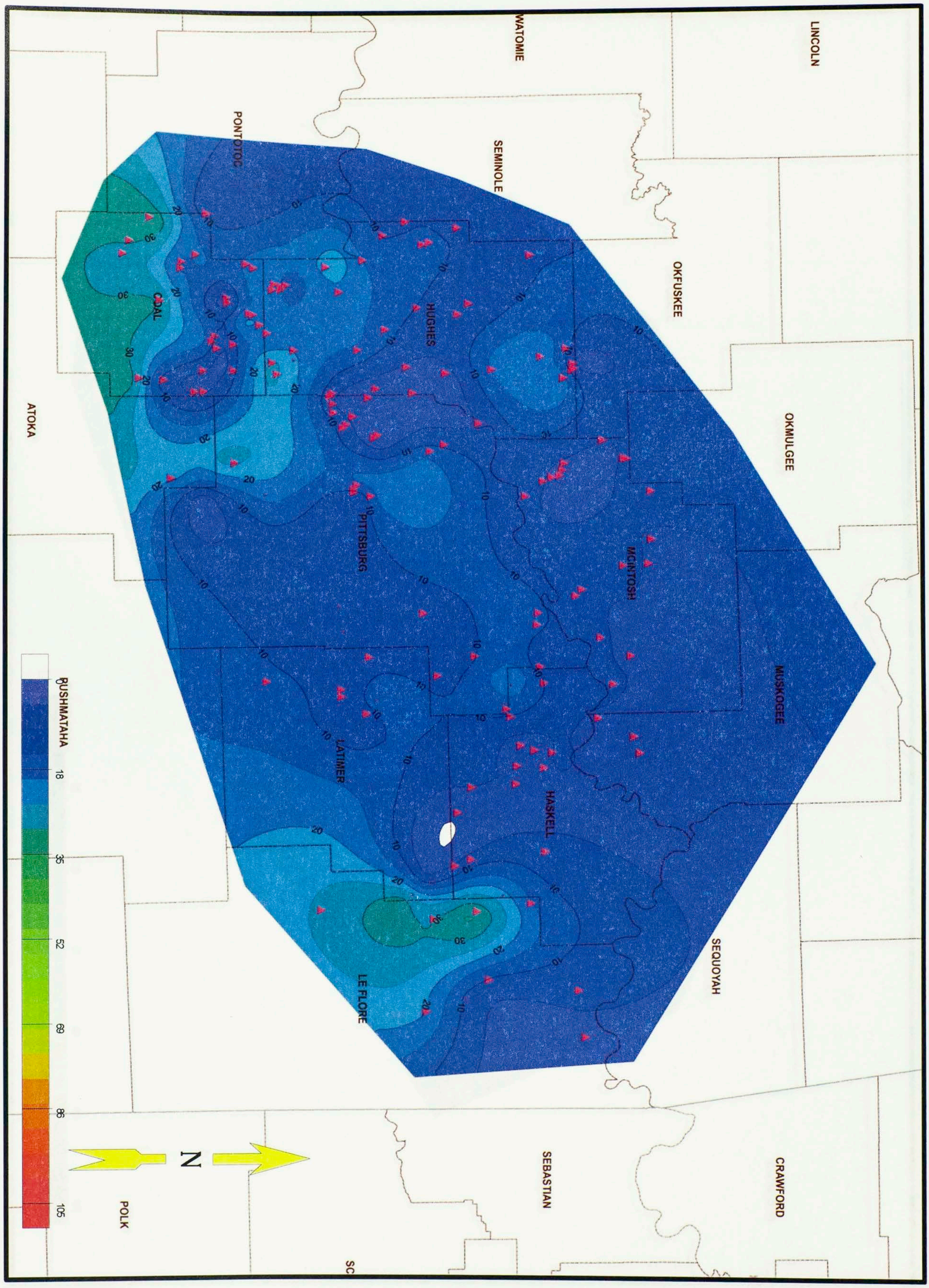


Figure 6.8: TST G from TSE G to FS G non-direction thick in the western and south eastern parts of the basin. CI. 5ft.

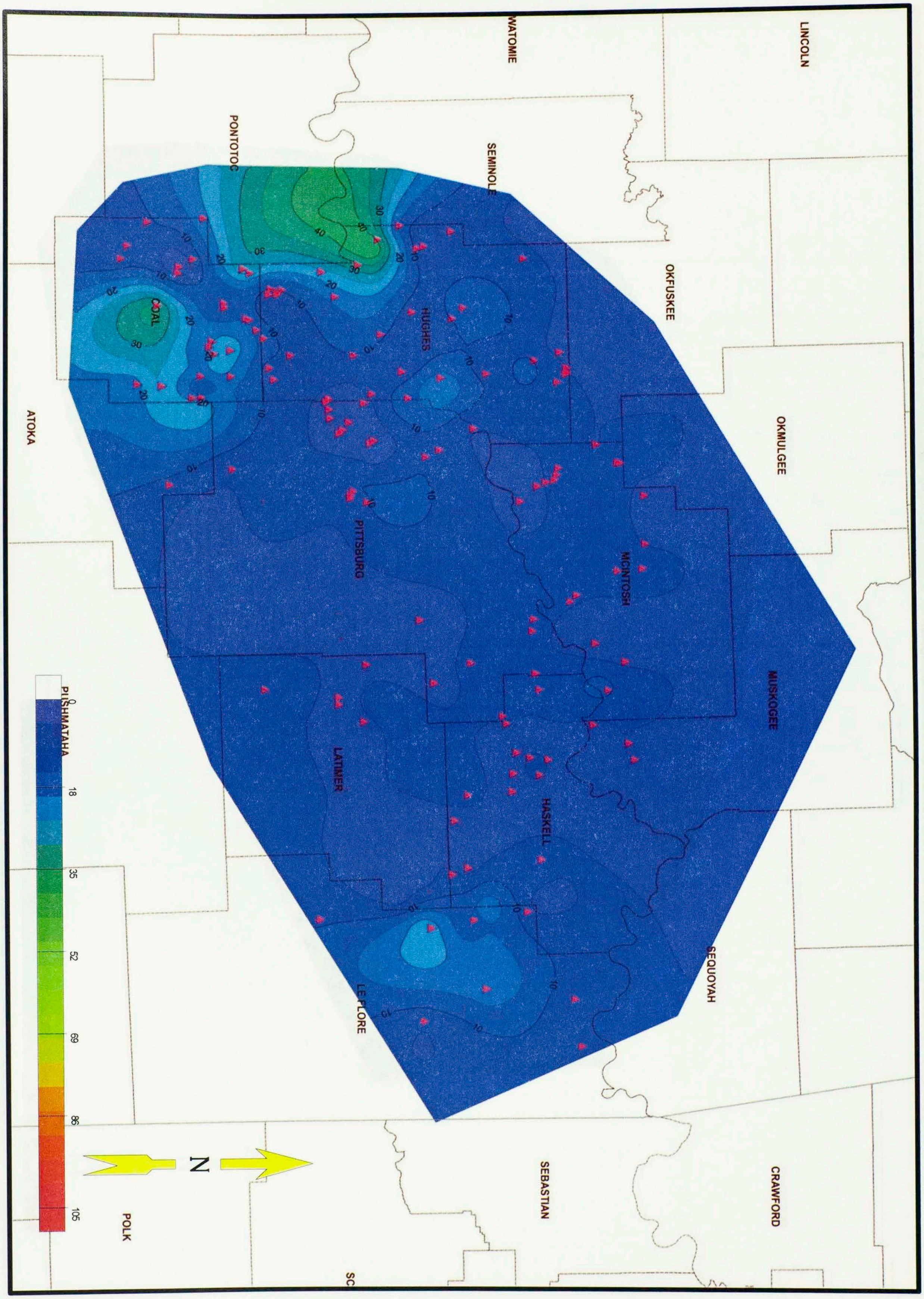


Figure 6.9: RST F isopach from FS G to TSE F map displays a shift in thickness to the far west part of the basin. CI. 5ft.

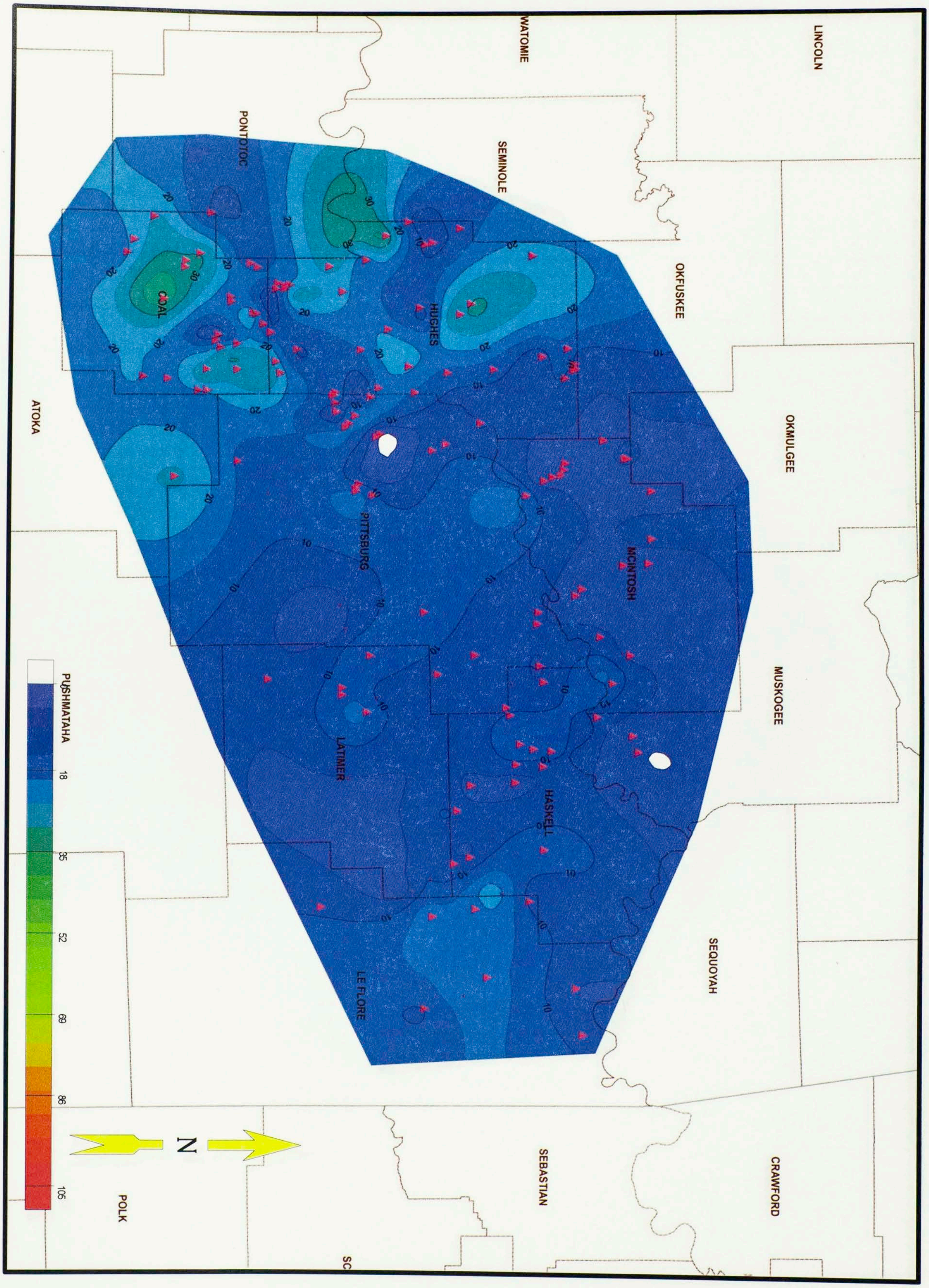


Figure 6.10: TST F isopach from TSE F to FS F thickness continues to develop in the west. CI. 5ft.

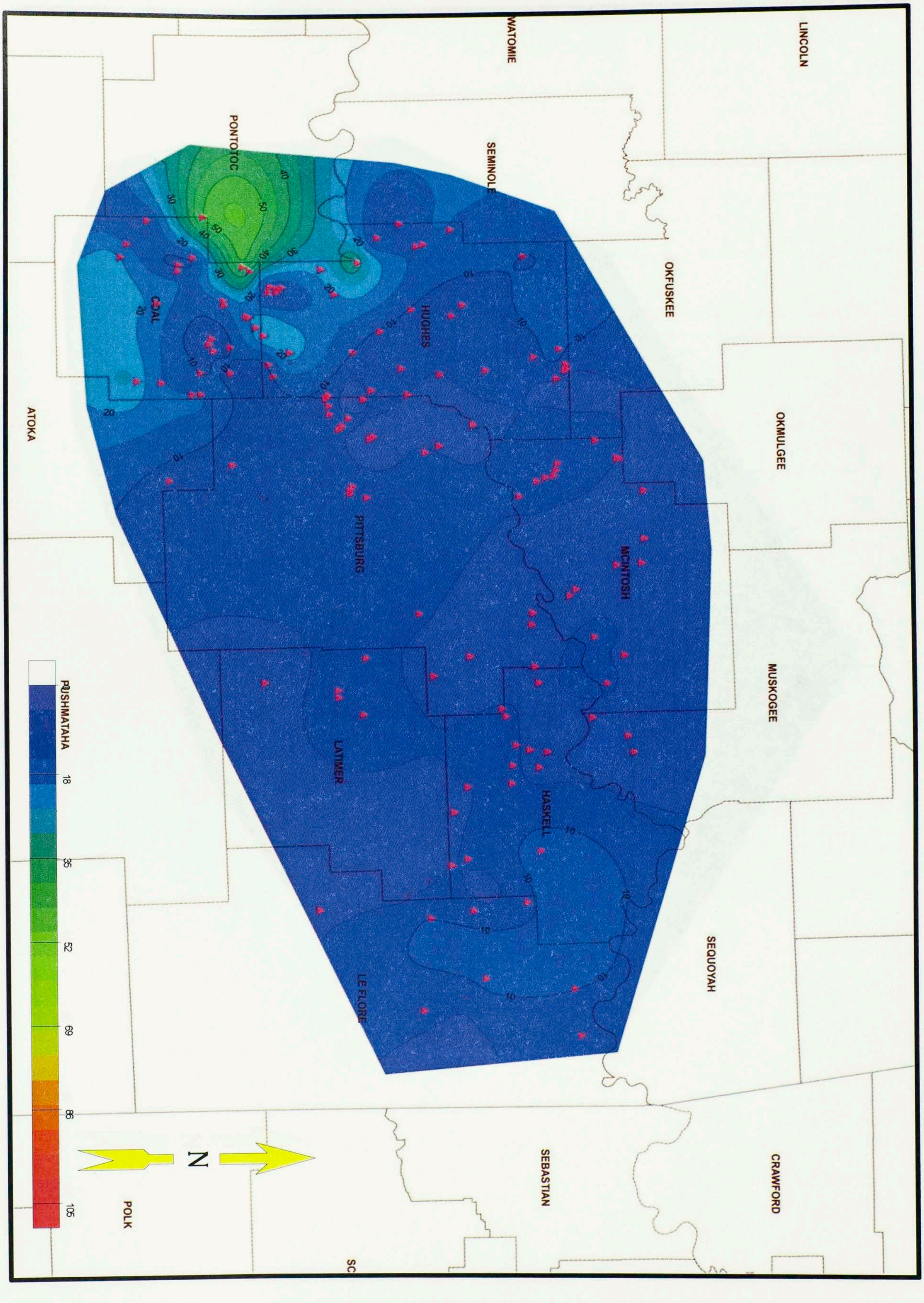


Figure 6.11: RST E isopach from FS F-to TSE E displays a thick sheet located in the west. CI. 5ft.

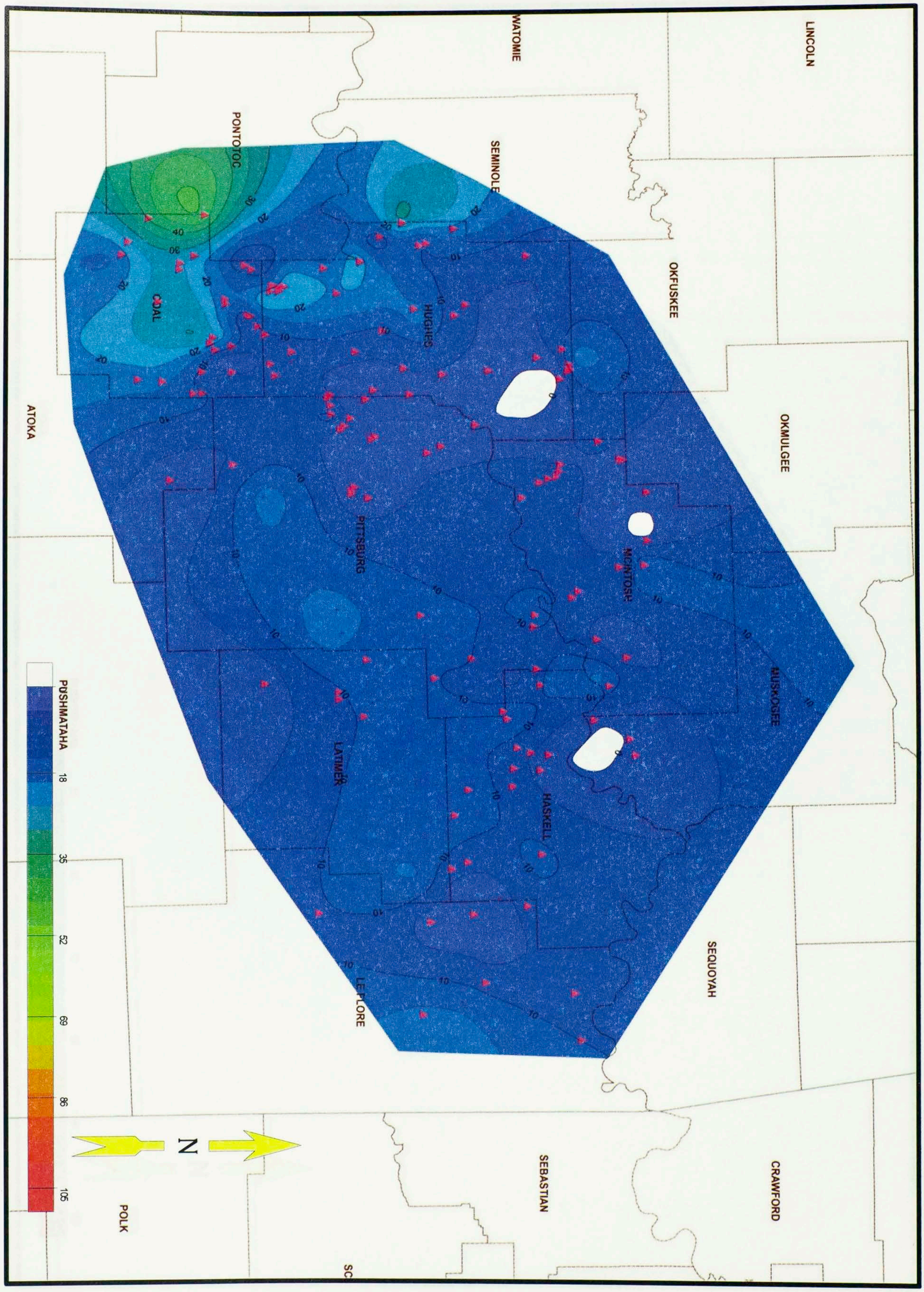


Figure 6.12 TST E isopach from TSE E- FS E thick trend still in the western part of the basin. CI. 5ft.

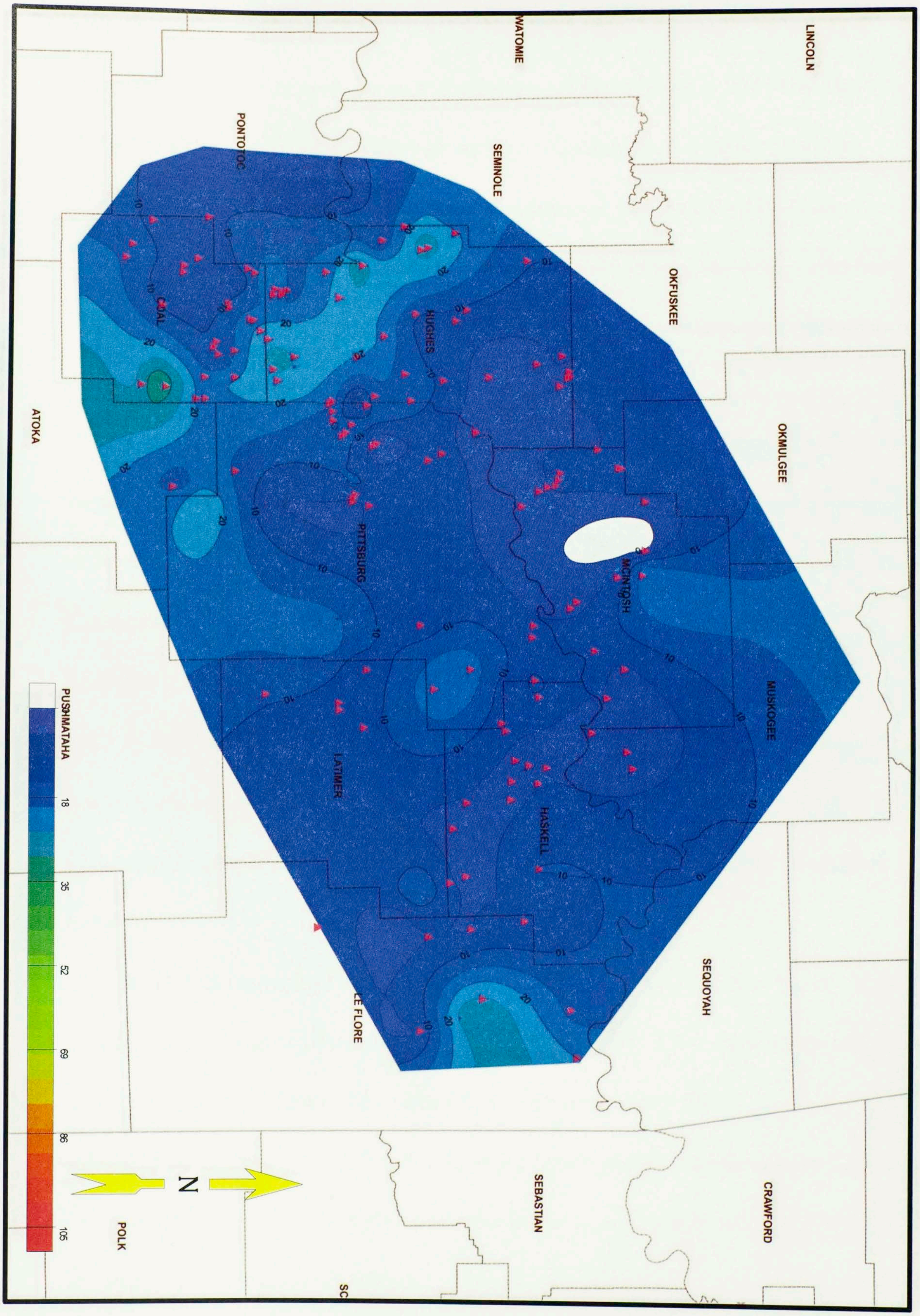


Figure 6.13 RST D isopach from FS E to TSE D narrow thick in western part of the basin as well as a think in Leflore County have developed. CI. 5ft.

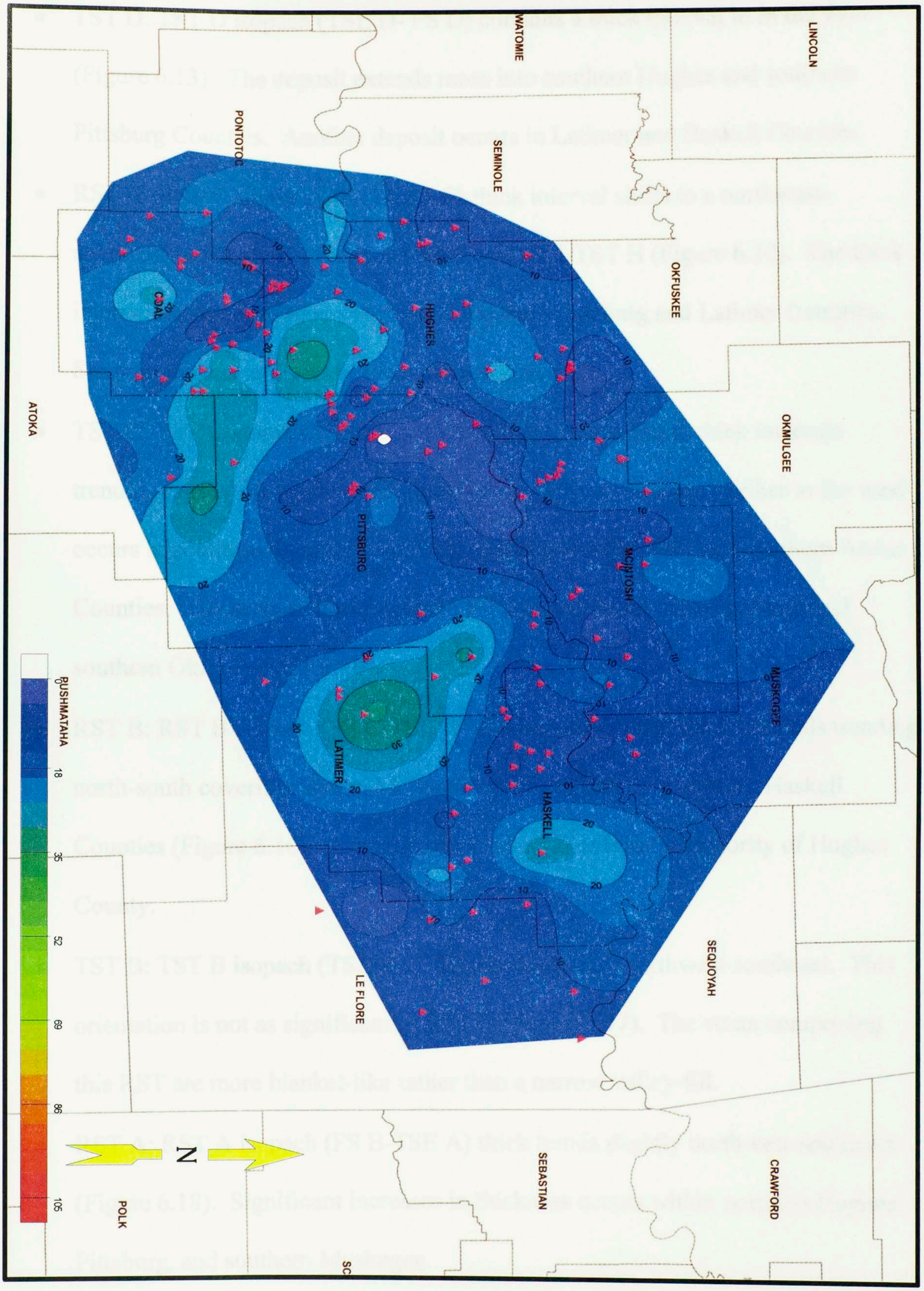


Figure 6.14 TST D isopach from TSE D to FS D displays a thick interval still in the west as well as a thick in northwest Latimer County. CI. 5ft.

- TST D: TST D isopach (TSE D- FS D) contains a thick interval to in the west (Figure 6.13). The deposit extends more into southern Hughes and southern Pittsburg Counties. Another deposit occurs in Latimer and Haskell Counties.
- RST C: RST C isopach (FS D-TSE C) thick interval shifts to a northwest-southeast trend which is pronounced than TST J-TST H (Figure 6.14). The thick interval occurs in southern McIntosh, northern Pittsburg and Latimer Counties. Strata in the western part of the basin are now thin.
- TST C: TST C isopach (TSE C-FS C) includes two separate thick intervals trending northwest-southeast (Figure 6.15). One narrow thick further to the west occurs in southern Seminole, Hughes, southeastern Pittsburg and northern Atoka Counties. The second thick occurs to the east, within eastern McIntosh and southern Okmulgee Counties.
- RST B: RST B isopach (FS C-TSE B) displays significant thick intervals trending north-south covering eastern McIntosh, northern Pittsburg, eastern Haskell Counties (Figure 6.16). A smaller thick interval covers the majority of Hughes County.
- TST B: TST B isopach (TSE B-FS B) trends slightly northwest-southeast. This orientation is not as significant as RST B (Figure 6.17). The strata comprising this RST are more blanket-like rather than a narrow valley-fill.
- RST A: RST A isopach (FS B-TSE A) thick trends slightly northwest-southeast (Figure 6.18). Significant increases in thickness occurs within northern Hughes, Pittsburg, and southern Muskogee.

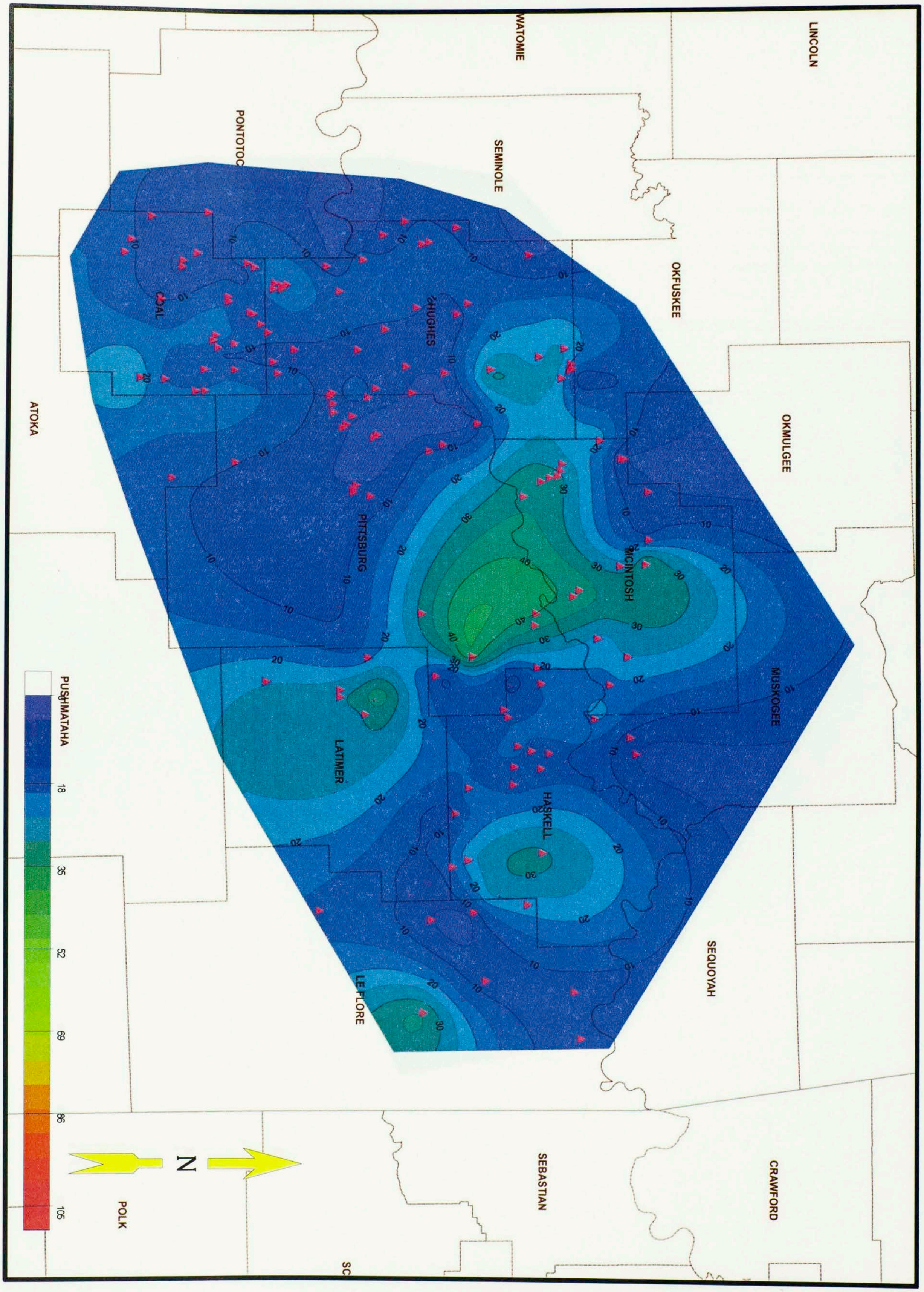


Figure 6.15 RST C isopach FS D to TSE C displays a shift in thickness back to a slight northwest-southeast direction. CI. 5ft.

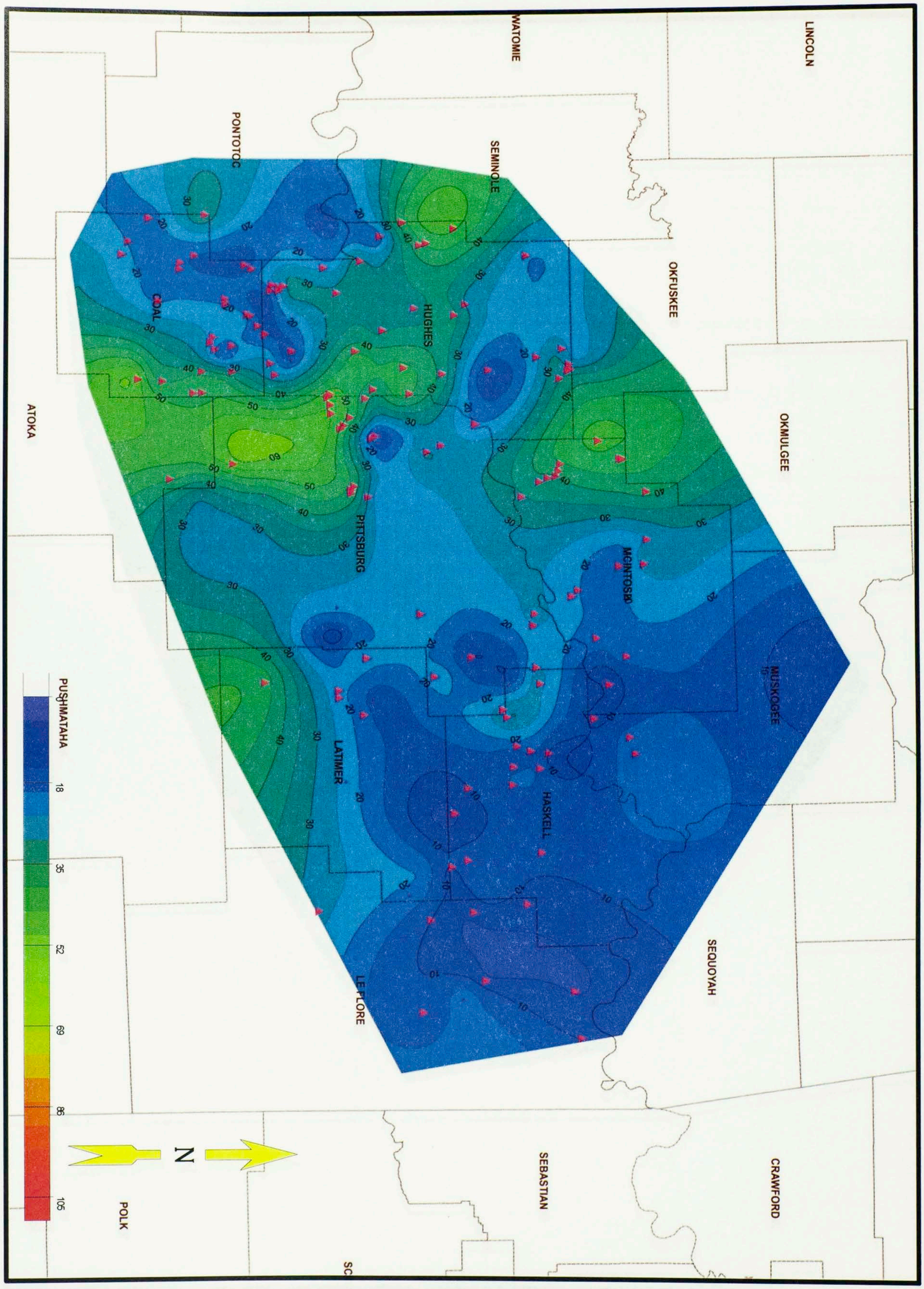


Figure 6.16 TST C isopach TSE C to FS C thick continues in a northwest-southeast trend. CI. 5ft.

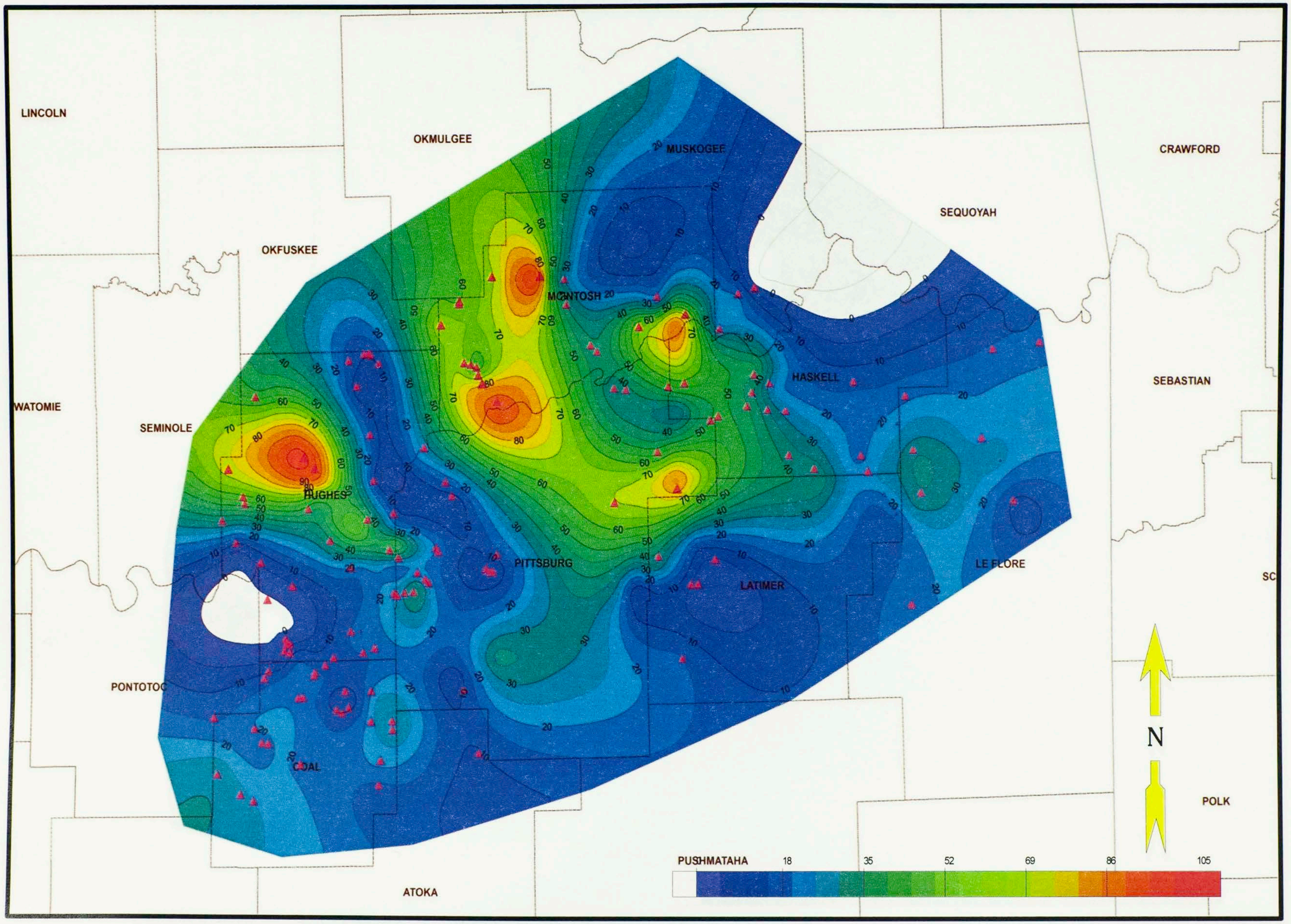


Figure 6.17: RST B isopach TSE B to FS B trends north-south. CI. 5ft.

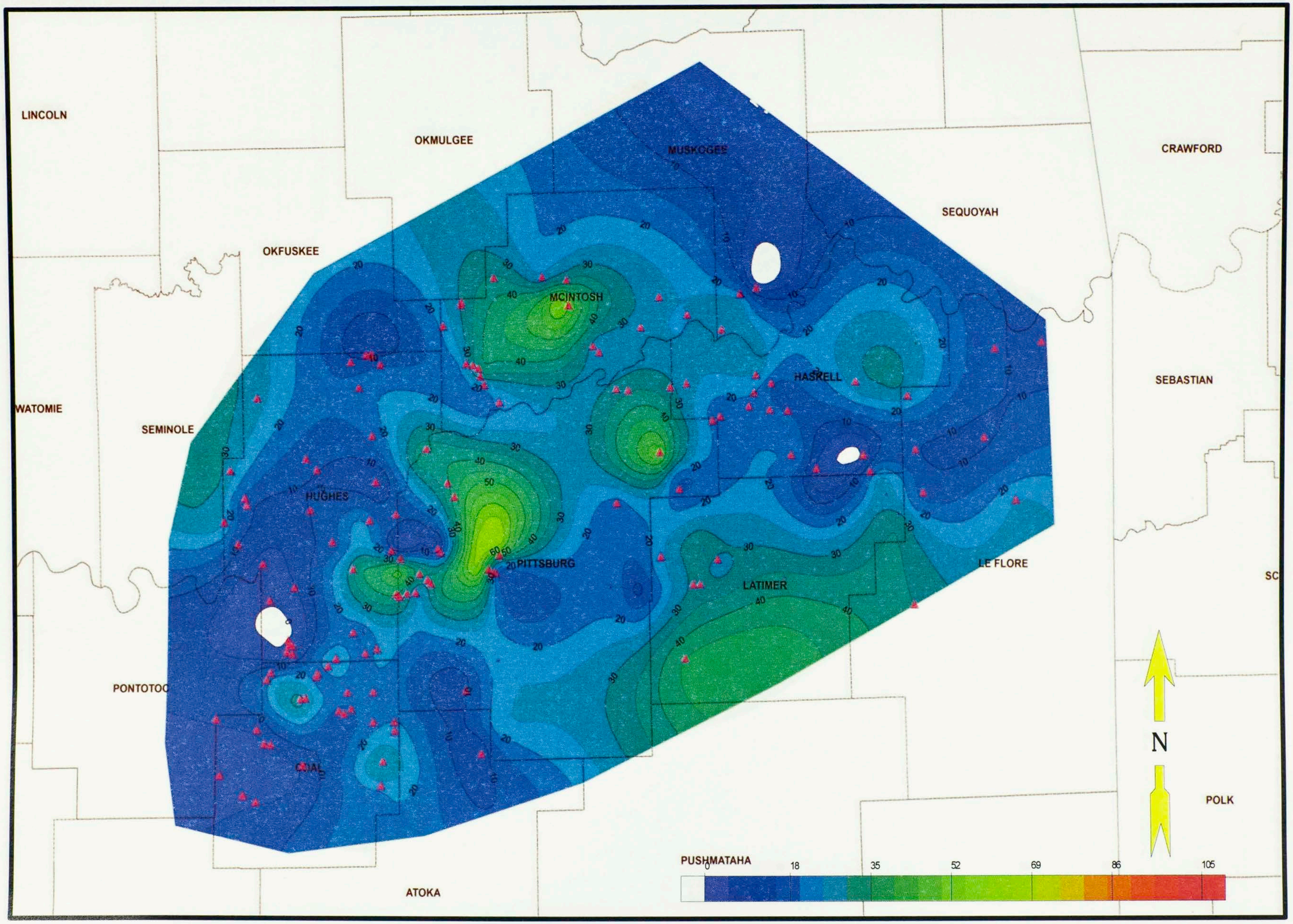


Figure 6.18: TST B isopach TSE B to FS B slightly northwest-southeast. CI. 5ft.

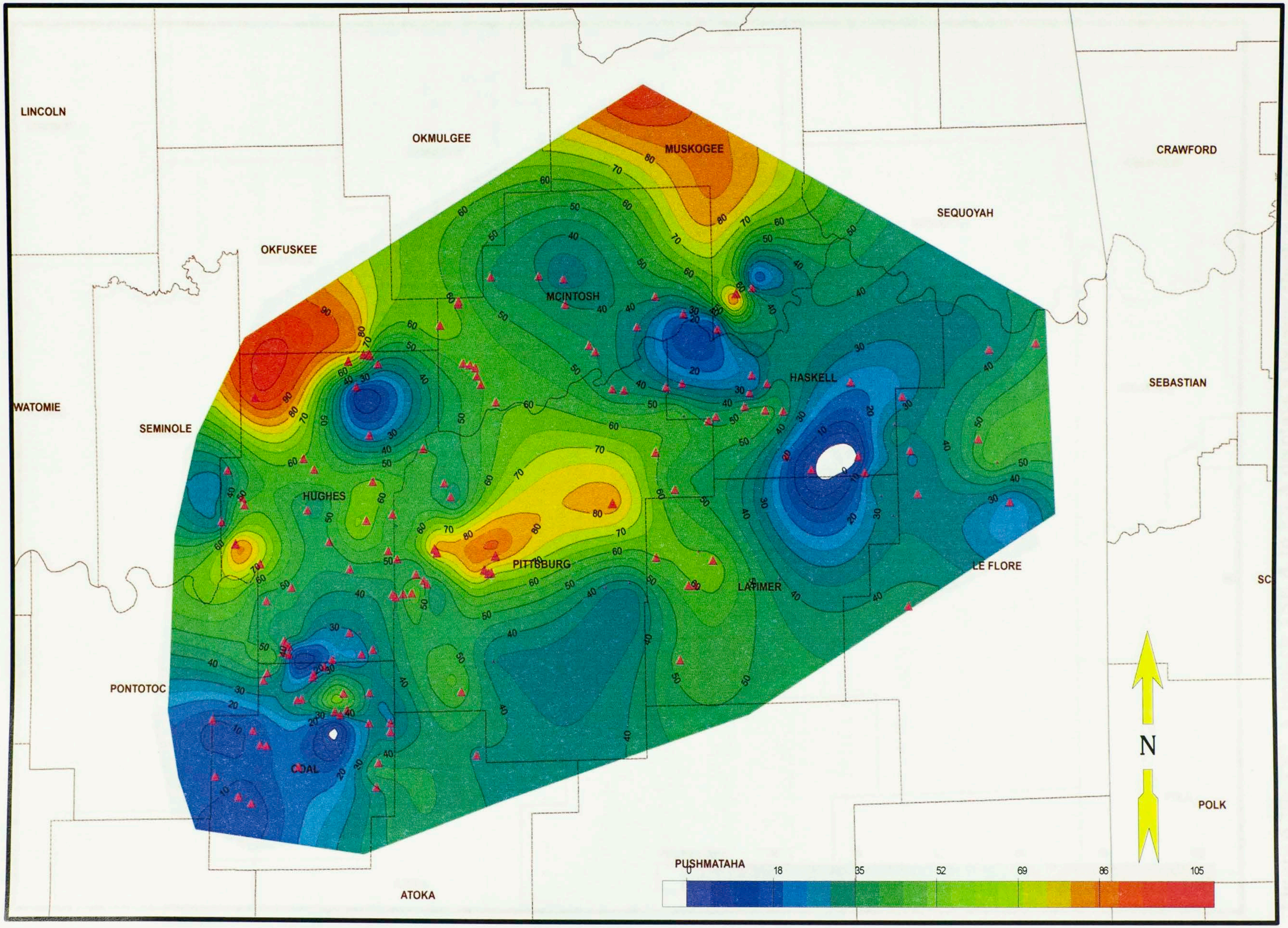


Figure 6.19: RST A isopach from FS B to TSE A slightly northwest-southeast. CI. 5ft.

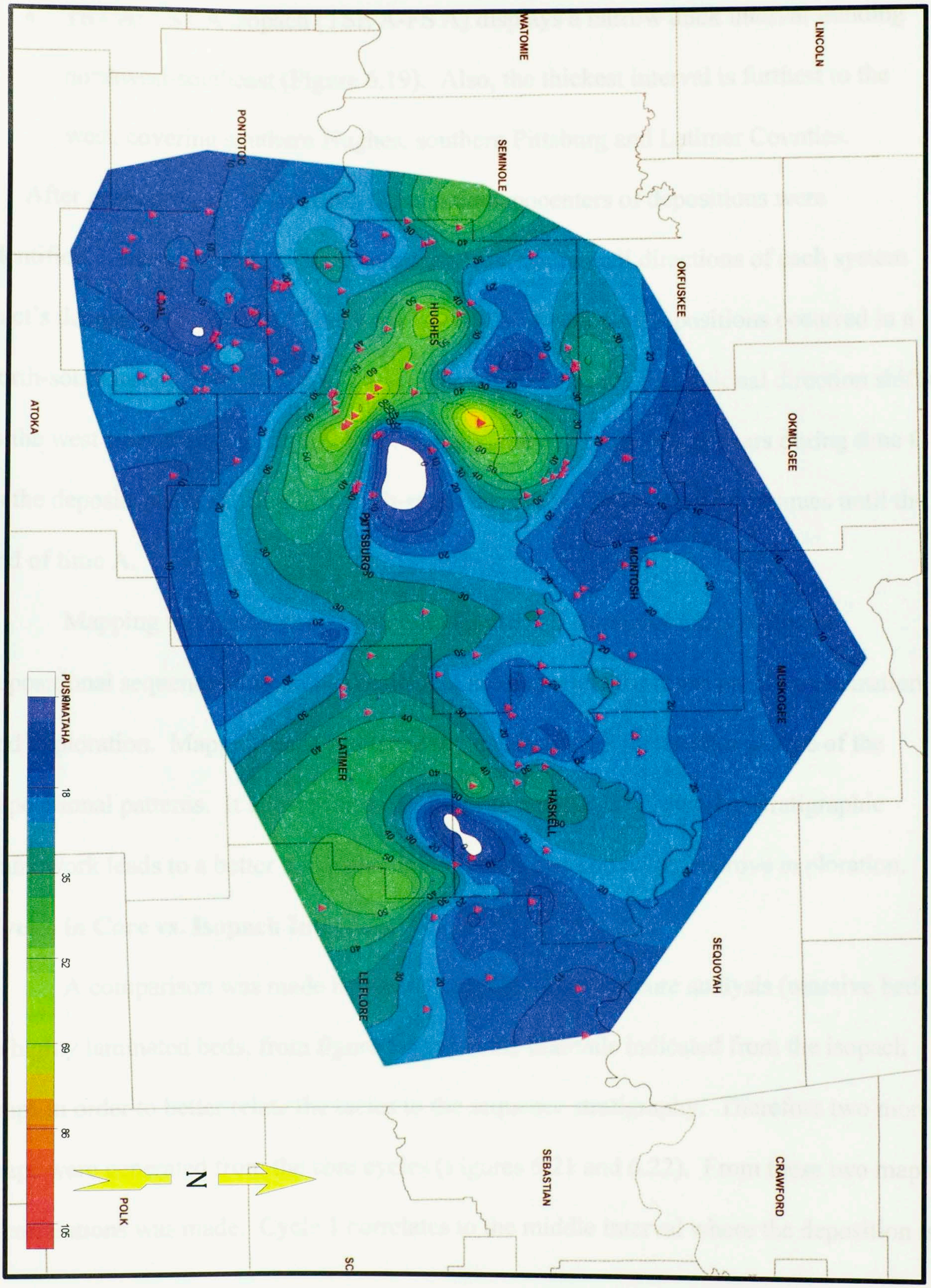


Figure 6.20: TST A isopach TSE A to FS A displays a narrow thick northwest-southwest trend. CI. 5ft.

- TST A: TST A isopach (TSE A-FS A) displays a narrow thick interval trending northwest-southeast (Figure 6.19). Also, the thickest interval is furthest to the west, covering southern Hughes, southern Pittsburg and Latimer Counties.

After generating all 19 isopachs three main depocenters of depositions were identified. These intervals were determined from the overall directions of each system tract's deposit (Figure 6.20). The lower interval's direction of depositions occurred in a north-south trend, up to the top of FS H. The middle interval depositional direction shifts to the west from RSTG to TST D time. Finally, the upper interval appears during time C as the deposits starts shifting in a north-south direction. This interval continues until the end of time A.

Mapping the Caney as one continuous interval, combines many different depositional sequences and omits details that are important for reservoir characterization and exploration. Mapping each sequence separately allows for a better picture of the depositional patterns. It allows for more accurate mapping. A detailed stratigraphic framework leads to a better understanding of reservoirs and helps improve exploration.

Cycles in Core vs. Isopach Intervals:

A comparison was made between the cycles from the core analysis (massive bed to highly laminated beds, from figure 5.6) with the intervals indicated from the isopach maps in order to better relate the facies to the sequence stratigraphy. Therefore two more maps were generated from the core cycles (Figures 6.21 and 6.22). From these two maps a correlations was made. Cycle 1 correlates to the middle interval where the deposition is

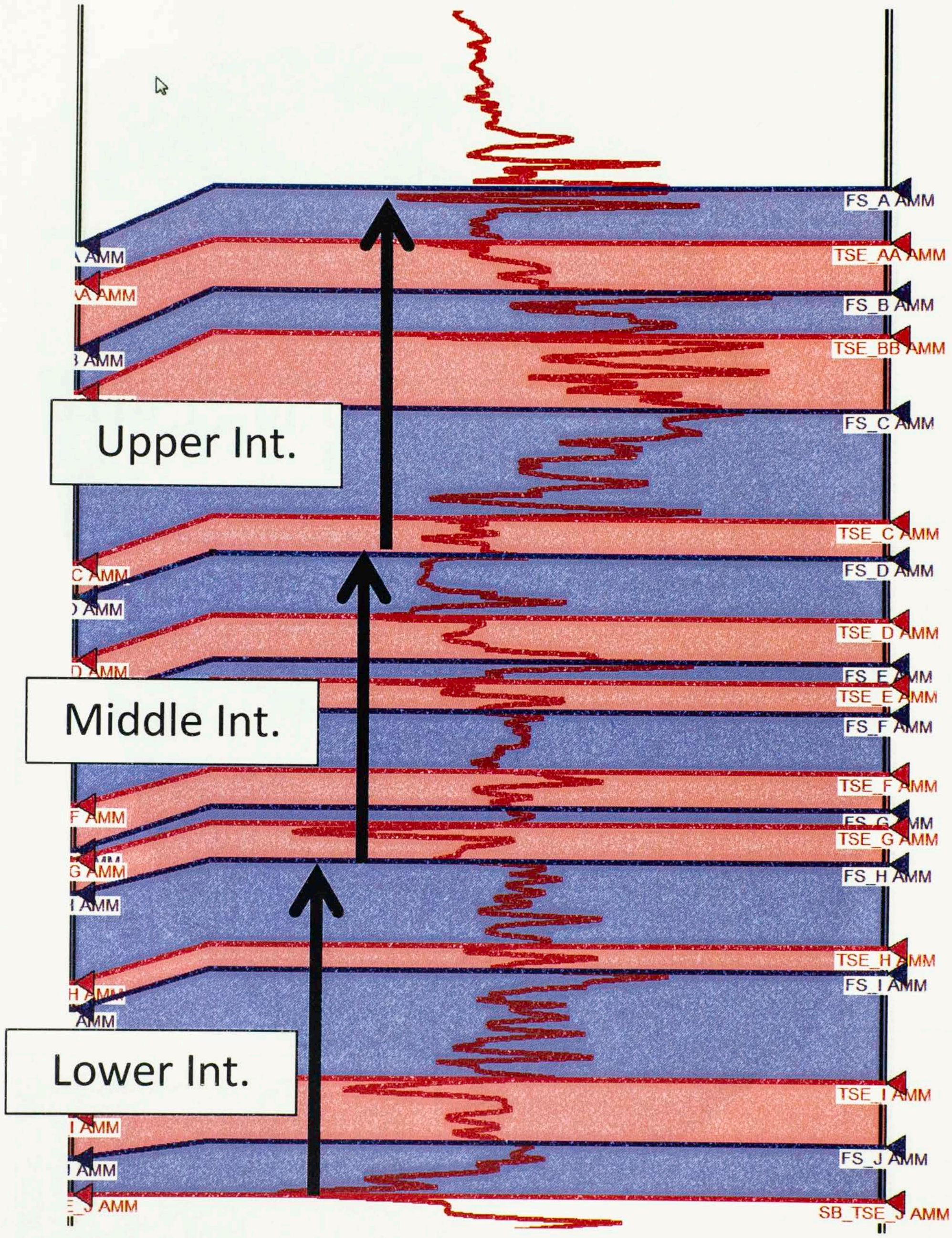


Figure 6.21: Three main interval of deposition identified from the overall direction of each system tract's thick. Gamma Ray Log

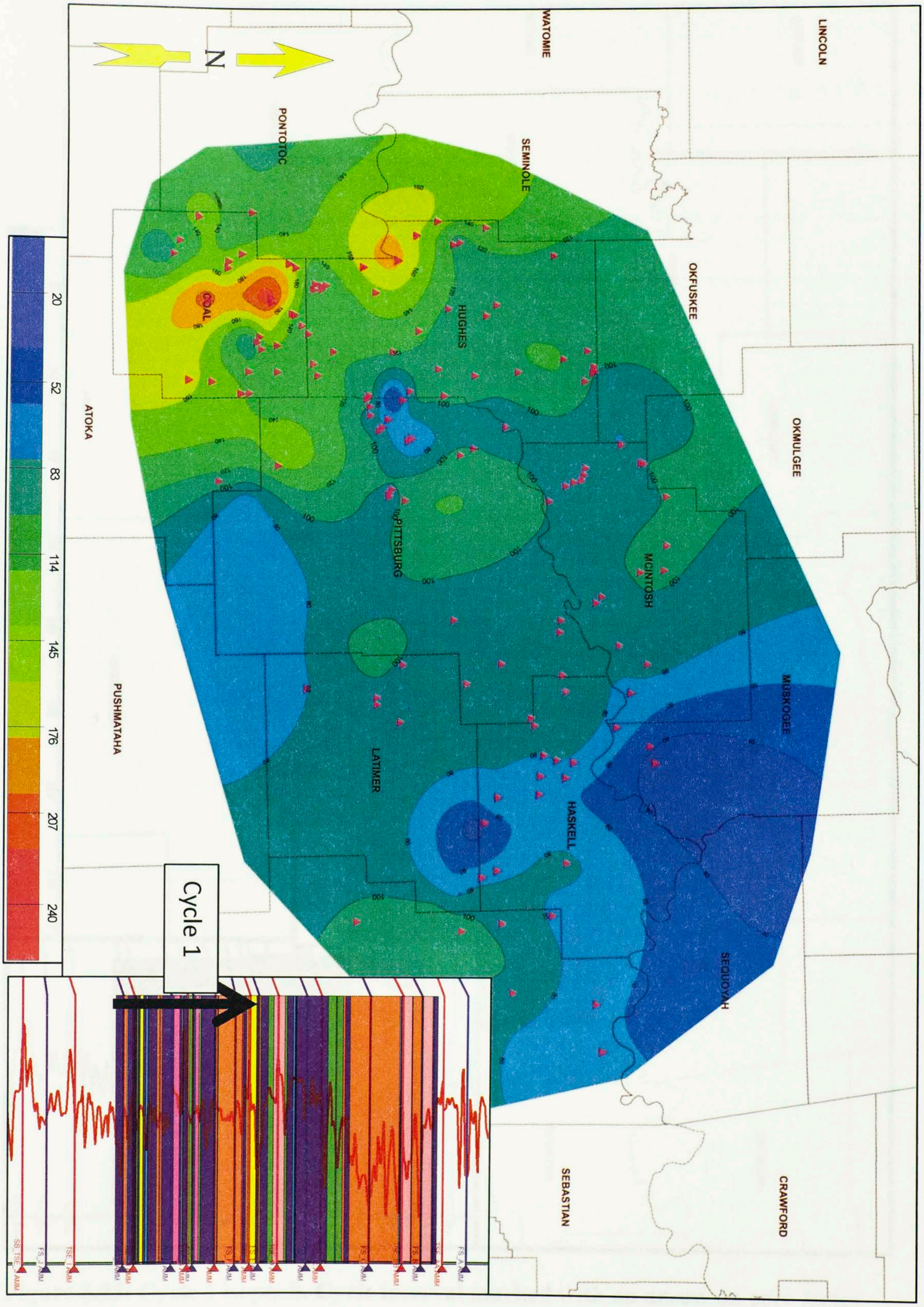


Figure 6.22: Cycle 1 isopach. Cycle interval marked with an arrow on core facies gamma ray log. CI. 20ft

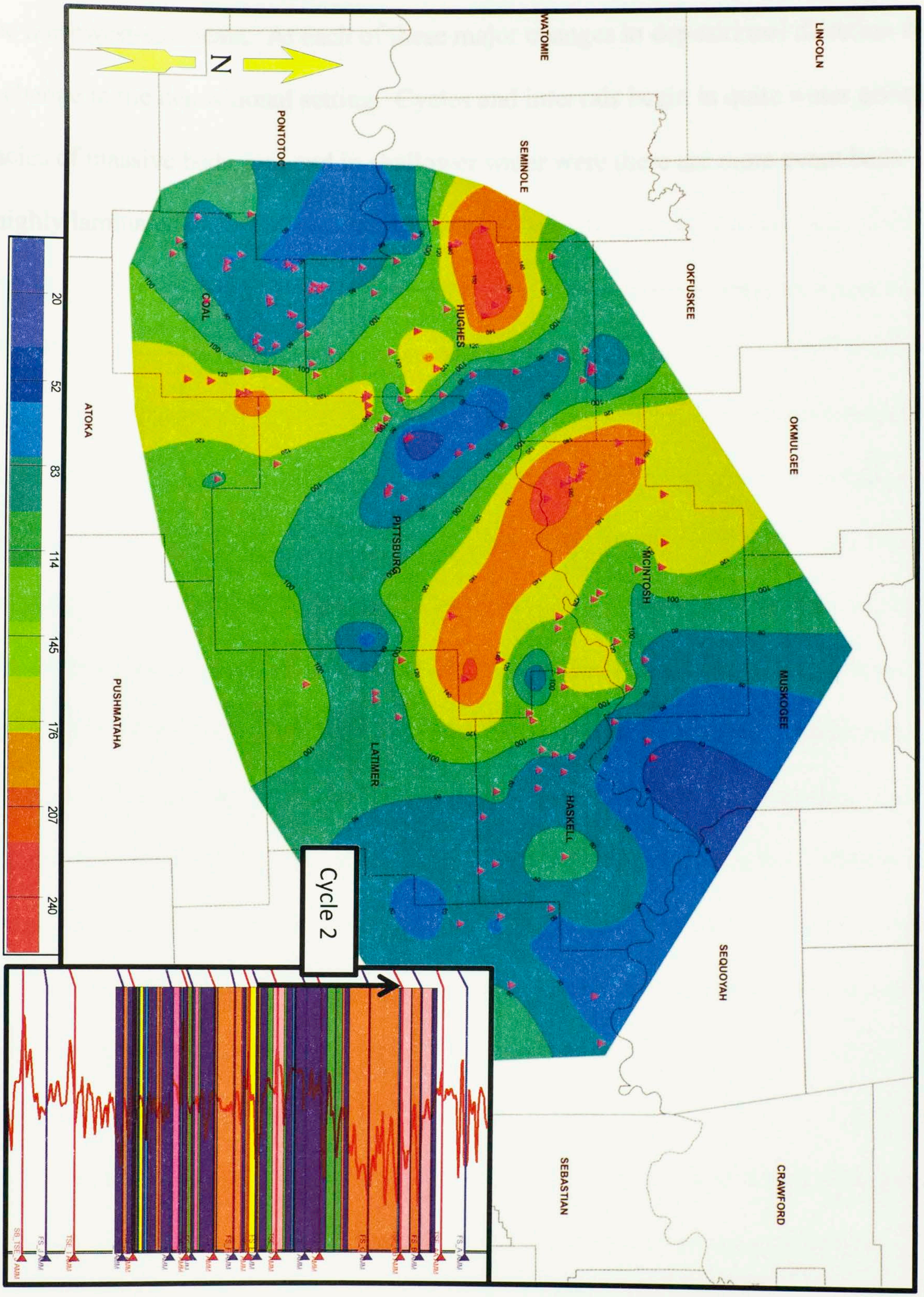


Figure 6.23: Cycle 1 isopach. Cycle interval marked with an arrow on core facies gamma ray log. CI. 20ft

comes from the west. Cycle 2 correlates with the upper interval the deposition was from the northwest-southeast. At each of these major changes in depositional direction there is a change in the depositional setting. Cycles and intervals begin in quite water giving a facies of massive beds, and end in shallower water were there are more event beds (highly laminated).

CHAPTER 7

Discussion

General

The purpose of this thesis was to develop a stratigraphic framework of the Caney Shale in order to better understand the Caney Shale distribution throughout the Oklahoma portion of the Arkoma Basin. This framework creates an analog for future exploration and development within the basin. Sequence stratigraphy was accomplished from analyzing the cored wells and well logs, thereby creating six standard facies classification based on bedding patterns, and providing a general characterization of every type of facies seen within a Caney Shale. The correlation between facies patterns and systems tract provided a better understanding of expected bedding patterns with each sequence. It also helped develop a strong interpretation and understanding of the Caney Shale. Creating the framework established marker for well log correlation and developed a complete 3rd order sequence stratigraphy of three intervals of 2nd order cycles. The Caney Shale is interpreted as a black to dark grey shale, deposited in two different time intervals. The third time interval is equivalent to the Mayes formation. Depositional direction was determined from core well measurements, well log character, basin history and patterns from geological mapping.

Uncertainties in Interpretation

As with any study that incorporates many different kinds of data from many different sources, uncertainties in interpretation can exist. Sequence stratigraphy is an analytical tool that aids interpretations. Additional research could identify and decrease any potential interpretive error as well as provide new information. Other data would be useful if time permitted and had been available. Seismic data, formation micro-image (FMI), biostraigraphic data, and XRD data would have provided additional information to aid in making a more precise interpretation.

Future Studies

Shale's are becoming a prime target for exploration. The better they are understood, the better the plays will be developed. Even though this study built a stratigraphic framework, it was still based on regional mappable intervals events (3rd order cyclicity). Therefore, there are a number of topics that still need to be evaluated. The first is to develop a regional study of the Fayetteville that links it with the Caney. This evaluation could determine weather the Caney and Fayetteville are indeed the same shale, with different names based on location. Another study would include how many sequences of shales are similar, since the Fayetteville is economical and the Caney is not. A linkage could be the key for the development of a Caney Play.

A number of field studies could be done, for example taking maps that were completed in this thesis and focusing on specific zones in specific areas of interest. Regional work on the TSE C, a possible large SB/TSE boundary similar to the Woodford SB/TSE interval could lead to a better understanding of depositional settings. Structural mapping the TSE C surface separately could display locations for incised valleys and lead to the discovery of sweet spots. A number of different geochemical studies could be performed for a chance to better understand the reservoir's kerogen quality and maturity. A diagenetic study could help determine locations of brittle strata for perfing and fracking. That would aid in finding better areas for perfing and fracking. From an engineering background, a geomechical analysis of the Caney would help improve development of the wells and, thus, production.

CHAPTER 8

Conclusions

The Stratigraphic framework of the Caney Shale in southeastern Oklahoma of the Arkoma Basin was established from four cored wells, (with a primary focus on the Cometti 2H-13) and from digital well logs. The sequence stratigraphy provided the basis for creating well log cross sections, structure and isopach maps. The main conclusions of this thesis are as follows:

1. The Caney is a black to dark grey weakly calcareous shale including nodules and concretions with varying composition. Many nodules are phosphate and concretions tend to be pyritic or calcareous. Clay tends to make up around a third of the shale, a little over another third is composed of quartz, feldspar and carbonate, there is usually < 10 percent kerogen and the remaining composition is heavier minerals.
2. The Caney's thickness trend generally follows the shape of the Arkoma Basin. Therefore, the deepest parts of the Caney are located in the south, next to the Ouachita Thrust belt. The shallowest Caney appears in the north near the Ozark uplift and Cherokee Platform.
3. Six different facies classified from the core description of the Cometti 2H-13. They are: (1) Massive bed: Non-Fossil Bearing, (2) Massive Bed: Contains Fossils, (3) Faintly Laminated Bed: Non-Fossil Bearing, (4) Faintly Laminated Bed: Fossil Bearing, (5) Highly Laminated Bed: Non Fossil Bearing, and (6) Highly Laminated Beds: Fossil Bearing.

4. Ten different sequence boundaries (SB) or Trangressive Surfaces' of Erosion (TSE) and flooding surfaces (FS) were identified (J, I, H, G, F, E, D, C, B, and A). Transgressive system tract (TST) intervals are bounded by a lower TSE and upper FS. Regressive or highstand system tract (RST/HST) are bounded at the base by FS and the top by another SB/TSE. These boundaries correlated well to 3rd order eustatic sea level cycles.
5. The majority of the sediment source for the Caney is from the northwest part of the shelf, as determined from two out of the three intervals. The other area for sediment supply comes from the west, leading to the possibility that supply came from the Arbuckle Mountains. Ozark Uplift could be another contributor of sediment spilling into the southwest corner of the basin.
6. The Caney differs from that of the Woodford age and composition. It was also being deposited during the Ouachita Mountain and Arbuckle Mountain uplifts.
7. Each Interval's bedding pattern consists of basal massive bed grading into a highly laminated bed. The depositional setting depicted from this bedding pattern is from quiet water to high energy, shallower water with more events.
8. The majority of the Caney is a Type III and IV kerogen. It is a dry gas prone play. It can be a new unconventional play, once development and fracking of wells is better understood.
9. The Caney Shale marks one of the final Transgressive systems tracts before reaching the Goddard, regressive systems tract. Further, sequence

stratigraphy work on the Goddard could allow for a better understanding of sourcing for the tight gas sand that overlies the shale package.

REFERENCES

Andrews, R.D., 2009, Production Decline Curves and Payout Thresholds of Horizontal Woodford Wells in the Arkoma Basin, Oklahoma: Shale Shaker, The Journal of the Oklahoma City Geological Society, p.103-112.

Andrews, R.D., 2007, Stratigraphy, Production, and Reservoir Characteristics of the Caney Shale in Southern Oklahoma: Shale Shaker, The Journal of the Oklahoma City Geological Society, p.9-25

Asquith, G., and D. Krygowski, 2004, Basic Well Log Analysis, *AAPG Methods in Exploration Series, No. 16. 2nd Edition.*

Bates, R.L., and J.A. Jackson, 1984, Dictionary of Geological Terms: 3rd Edition: Prepared by the American Geological Institute.

Branan, C.B. Jr., 1968, Natural Gas in Arkoma Basin of Oklahoma and Arkansas: in Natural Gases of North America, V. 2, p. 1616-1635.

Branch, A. A, 2007, Comprehensive Characterization of a Core from an Overmature Woodford shale in Leflore County, Oklahoma and Comparison with Data from Other Studies of the Woodford Shale in the Arkoma Basin: unpublished Master Thesis University of Oklahoma, p. 1-9.

Elias, M. K; and C.C. Branson, 1959, Type Section of the Caney Shale: Oklahoma Geological Survey Circular 52, p.3-22.

Ettensohn, F. R., 1998: Compressional tectonic controls on Epicontinental black shale deposition: Devonia-Mississippian examples from North America. In: J. Schieber W. Ximmerle, and p. Sethi (editors), *Shales and Mudstones (Vol. 1O; Basin Studies, Sedimentology and paleontology*, Sewizerbart'sche Verlagscuchhanglung, Stuttgart, p. 109-128.

Fang, H., C. Jianyu, S. Yongchuan, and L. Yaozong, 1993. Application of organic facies tudies to sedimentary basin analysis: a case study from the Yitong Graben, China: Organic Geochemistry, v.20(1), p.27-42.

Forgotson, J.M., 2007, Abstract: Caney Shale, Arkoma Basin, Oklahoma, #90071.

Frantz, J. Jr. and V. Jochen, 2005: Shale Gas. White Paper, p.9.

Golonka, J., A. Slaczka, and F.J. Picha, 2006. The Western Carpathians and Ouachitas: A Comparative Study of Geodynamic Evolution, *in* J. Golonka & F. J. Picha (eds.), The Carpathians and their foreland: Geology and hydrocarbon resources: AAPG Memoir 84, p. 787-810.

Harris, Reginald, 1971, Palynology of Sand Branch Member of the Caney Shale Formation (Mississippian) of Southern Oklahoma: unpublished PhD. Dissertation University of Oklahoma, p.1-4

Houseknecht, D. W. and T.A. McGilvery, 1991. Red Oak Gas Field, Arkoma Basin, Oklahoma. AAPG Bulletin, vol. 75, no. 3, p. 597.

Hunt, J.M., 1996, Petroleum Geochemistry and Geology: W.H. Freeman and Company, New York, p. 743.

Lambert, M. W., 1993. Internal Stratigraphy and Organic Facies of the Devonian-Mississippian Chattanooga (Woodford) Shale in Oklahoma and Kansas, in B. J. Katz & L. M. Pratt (eds.), Source Rocks in a Sequence Stratigraphic Framework: AAPG Studies in Geology 37, p. 163-176.

Maughan, T.J. and D. Deming, 2006. Gas Occurrence in the Caney Shale, Part 1: Shale Shaker, The Journal of the Oklahoma City Geological Society, p. 77-89.

Maughan, T.J. and D. Deming, 2007. Gas Occurrence in the Caney Shale, Part 2: Shale Shaker, The Journal of the Oklahoma City Geological Society, p. 119-135.

Monaghan, P., 1985, The Stratigraphy of Mississippian Pennsylvanian Shale Sequence of southern Oklahoma: unpublished Bachelor Thesis Baylor University p.15-19.

Northcutt, R.A., Campbell, J.A., 1995, Geologic Provinces of Oklahoma: Oklahoma Geological Survey Open-File Report OF5-95, map scale. 1:750,000.

Potter, P.E., J. B. Maynard, and W.A. Pryor, 1980: Sedimentology of Shale. Springer Verlag New York Inc. p. 305.

Robinson, V.C. and M. Engel, 1993: Characterization of the Source Horizon within the Lat Creaceous Transgress Sequence in Egypt. In : Katz BJ, Pratt LM (ed) Source Rocks in a Sequence Stratigraphic Framework. AAPG Studies in Geology 37: p. 101-117.

Schutter, S. R., 1998, Characterization of Shale Deopsition in Relation to Stratigraphic Squence Systems Tracts, *in* J. Schieber, W. Zimmerle, and P. Sehi, eds., Shales and Mudstones I: Stuttgart, Germany E. Schweizerhbart'sche Verlagsbuchhangdlung, p.79-108.

Singh, Prena, 2008, Lithofacies and Sequence Stratigraphic Framework of the Barnett Shale, Northeast Texas. Ph.D. Dissertation, The University of Oklahoma.

Singh, P., R. Slatt, G. Borges, R. Perez, R. Portas, k. marfurt, M. Ammerman, and W. Coffey, 2009, Reservoir characterization of Unconventional gas Shale reservoirs:

Examples from the Barnnstt Shale, Texas, U.S.A., OCGS, The Shale Shaker, July-August-2009.

Slatt, R. M. and N. D Rodriguez,. In Press, Rodriguez Comparative Sequence Stratigraphy and Organic Geochemistry of Unconventional Gas Shales: Commonality or Coincidence?

Slatt, R.M., P.R. Philp, N.O'Brien, Y. Abousleiman, P. Singh, E.V. Eslinger, R. Perez, R. Portas, E.T. Baruch, K.J. Marfurt, and S. Madrid-Arroyo, in press, Pore-to-regional scale, integrated characterization workflow for unconventional gas shales: in J. Breyer, ed., Shale Reservoirs. Giant resources for the 21st century: Amer. Assoc. Petrol. Geol. Mem. 97, 24pg.

Slatt, R.M., P. Singh, P.R. Philp, K.J. Marfurt, Y. Abousleiman, N.O'Brien, and E.V. Eslinger, 2009 Workflow for stratigraphic characterization of unconventional gas shales: Gulf Coast Association of Geological Societies Transaction v. 59, p.699-710.

Tabibian, M, 1993, Natural Gas Stability and Thermal History of the Arbuckle Reservoir, Western Arkoma Basin. Master's Thesis, University of Tulsa, p. 1-251.

U.S. Geological Survey, 2010, Assessment of Undiscovered Natural Gas Resources of the Arkoma Basin Province and Geologically Related Areas: U.S. Department of the Interior: U.S. Geological Survey: Fact Sheet 2010-3043.

Varnsdale, R. B., E. S. Schweig, III.,1990. Subsurface Structure of the Eastern Arkoma Basin: AAPG Bulletin, vol. 74, no. 7, p. 1030-1036.

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