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# The Shelf to Basin Transition and Tectonostratigraphy of the Atoka Formation (Lower Pennsylvanian) in the Arkoma Basin, Northwest Arkansas

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The Shelf to Basin Transition and Tectonostratigraphy of the
Atoka Formation (Lower Pennsylvanian) in the Arkoma Basin,
Northwest Arkansas

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Master of Science in Geology

by

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This thesis is approved for recommendation to the Graduate Council.

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## *Abstract*

The east-to-west oriented Arkoma Basin is a peripheral foreland basin or depositional trough that developed during the Carboniferous Period. This formation covers an aerial extent of approximately 33,800 square miles and spans from west-central Arkansas into southeastern Oklahoma (McGilvery, Manger, and Zachry, 2016; Perry, 1995). The Atoka Formation, deposited during the early Pennsylvanian, is the largest Paleozoic formation by aerial extent in the state of Arkansas and is located within and comprises the bulk of Arkoma Basin sediments (McFarland, 2004; Nance, 2018). This formation has been informally divided into three divisions, the lower, middle, and upper, based on their stratigraphic response to differing tectonic processes.

A tectonostratigraphic interpretation was made for each division of the Atoka Formation using high resolution cross sections; correlated using well log, seismic, and surface data. Five condensed regional transects were constructed that aided in the development of a cross section "grid" meant to represent the deep marine to shallow marine depositional hinge lines.

Each of the three Atoka divisions have a different dominant depositional force. The Lower Atoka deposition was dominated by eustasy, and with sediment supply from the start of Arkoma Basin tectonics, the middle division was dominated by tectonic subsidence and the upper was dominated by sediment supply. The transition between the Atoka divisions and the magnitude of migration between each deep marine hinge line indicates the progradation of the Upper Atoka depositional cycles occurred more rapidly than the retrogradation of the Middle Atoka. The maximum flooding of the formation occurred within the Middle Atoka's uppermost informal member, the Morris Member. The Lower Atoka was deposited on an extensive tectonically stable structural platform, which is supported by no lithostratigraphic transition to

deep marine deposits within this project's study area. The deep marine deposition is characterized by shales encapsulating tumultuously distributed and isolated sandstone complexes. These sandstone complexes are not correlated to the shallow marine sandstones by anything but a condensed geologic timeline.

## *Acknowledgements*

Like any student earning a master's degree, I've gone through peaks and valleys but all of it had cumulated to be the greatest time of my life. At the University of Arkansas, I've expanded my knowledge and understanding of geology and matured as an adult. Making it through classes, stubborn students, job hunting, and crazy geologists couldn't have been done without the support of friends, family, and colleagues.

First, I wanted to thank my advisor, Mac McGilvery. You've taught and helped me grow as a person through tough love. Along with my advisor, I want to thank Jamie Woolsey for her assistance keeping Petra™ running and Robert Liner for generosity sharing his knowledge of Atokan geology. I also appreciate the willingness by all staff within the geosciences department to assist me when I needed help. My experience with University faculty has been unquestionably excellent.

The people that I owe the most to, is my family. Thank you, Dad, for your career advice and helping me work towards a great future. You consistently gave me the ability to put my best foot forward when looking for employment and investment opportunity. Thank you, Mom, for supporting me through tough times and helping me when down. Jake, thanks for listening to my ranting about stocks, science, and football. Pulling off working, teaching, staying sane, and finishing a master's degree would have been near impossible without you all.

Next, I owe my passion for geology to my Granddad. He is who inspired me to pursue this field of study. He is unrelentingly passionate about, not just geology, but the pursuit of learning. A majority of the time, I don't believe there is a topic that he doesn't know at least something about.

I owe my sanity here in Fayetteville to the friends I’ve made along the way. While going to school at this great university, I’ve made more connections and met more like-minded people than at any other point in my life.  Building real relationships makes me truly happy and I feel so grateful to have managed so many during my time here.  The experiences I’ve had will stay with me for a lifetime and I couldn’t be happier with my decision to attend the University of Arkansas.

Finally, I want to thank God for leading me down this path.  Like many geologists, making it in the industry can be difficult, but I ended up exactly where he needed me to be.  Woo Pig forever!

## *Table of Contents*

## *Introduction*

This work focuses on the Atoka Formation in west-central Arkansas which has the largest areal extent in the region (McFarland, 2004). The Atoka Formation, deposited during the early Pennsylvanian, is located in the Arkoma Basin which is a structural and topographic depression that extends from west-central Arkansas into southeastern Oklahoma. The Arkoma Basin is a peripheral foreland basin that developed in association with the Ouachita Orogeny during the Carboniferous and covers an area of approximately 33,800 square miles (McGilvery, Manger, and Zachry, 2016; Perry, 1995). The basin is an east-west oriented, south-west plunging depositional trough that lies between the Ozark Dome to the north and the Ouachita Mountains to the south (Figure 1). The Ozark Dome is a cratonic uplift and the Ouachita Mountains are an accretionary prism developed during the collision of Gondwana and Laurasia and formation of the super continent Pangea during the latest Pennsylvanian and Permian (Houseknecht, 1983; McGilvery, Manger, and Zachry, 2016). Sedimentation of the Atoka Formation was heavily influenced by eustasy, tectonic subsidence, and variable sediment supply leading to complex sandstone and shale cyclicity within the Atoka Formation. This study in conjunction with those of Woolsey (2007) and Denham (2018) demonstrates that deposition of the Lower Atoka was largely dominated by eustatic sea level changes, the Middle Atoka was dominated by tectonic subsidence, and the Upper Atoka was dominated by high sediment supply. Many of the internal depositional cycles informally referenced as members within the Atoka record the transition from shallow to deep marine deposits. The location of the shallow marine to deep water (upper slope) transition through time helps determine the magnitude and rate of shoreline and shelf edge migration. This migration reflects changes in the dominant forcing mechanism through time which include eustacy, subsidence, and sedimentation rate.  This study focuses on the northern edge of the deep marine deposits as it shifted through geologic time.

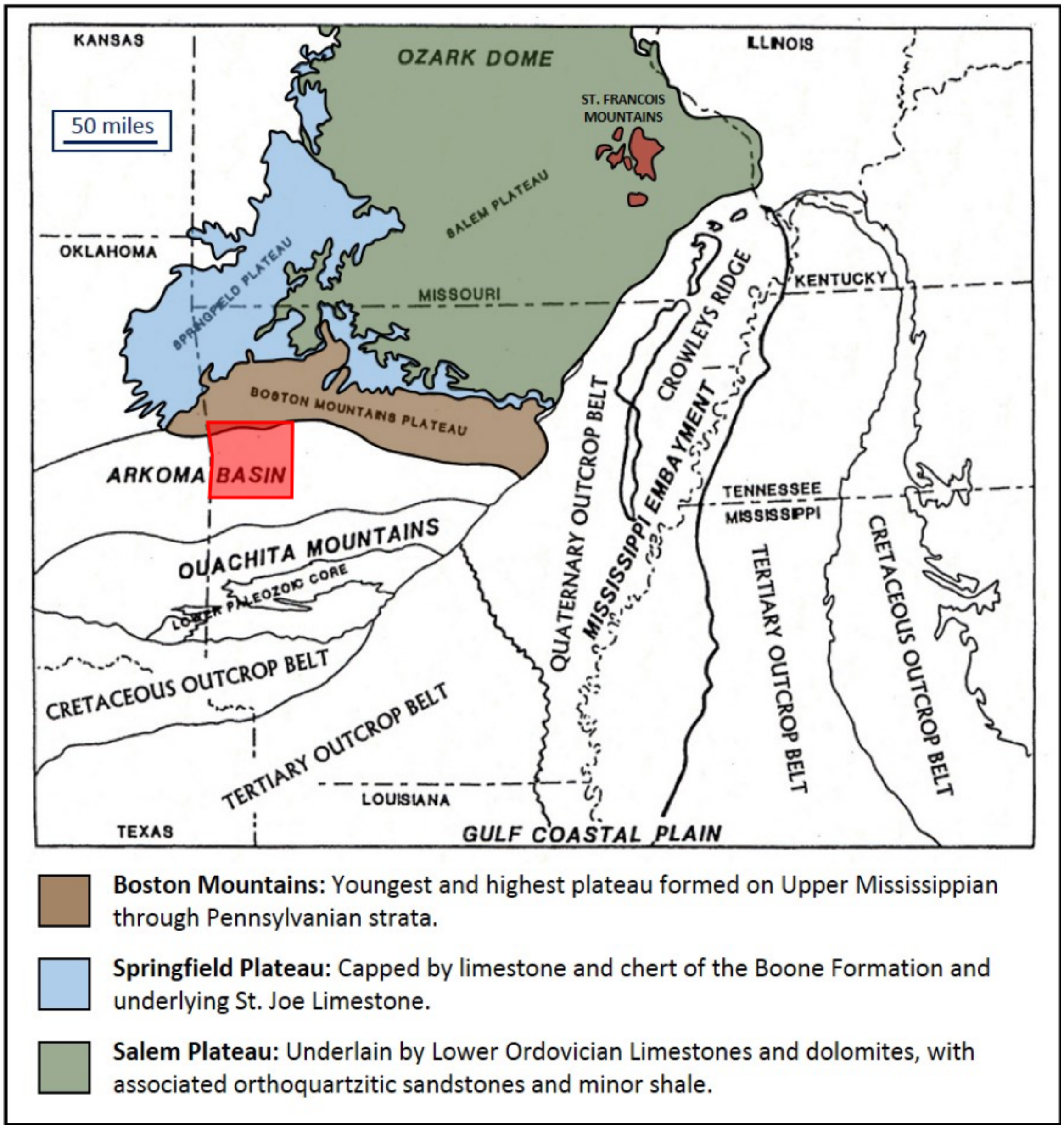


**Figure 1**: Study area in red within the Arkoma Basin and surrounding provinces.  The Ozark Dome to the north and the Ouachita Mountains to the south. (Modified from Manger, Zachry and Garrigan, 1988).

***Statement of the Problem***

The Arkoma Basin and the Atoka Formation have been heavily studied over the course of approximately 120 years. Many of the informal members and all three divisions of the Atoka have been investigated in certain areas of the Arkoma Basin and in many combinations of stratigraphic interval. Despite this, there are many gaps associated with the Arkoma Basin and the Atoka Formation in our scientific literature that need to be addressed.

This project provides a series of regional transects that address the current lack of understanding of the temporal and geographic changes in the transition from shallow to deep marine deposition within the Atoka Formation in response to the tectonic evolution of the Arkoma Foreland Basin. Previous work has tended to focus on more "local" stratigraphic issues. The area north of the Washburn anticline which is characterized by cyclic marginal marine to shallow marine deposits has been studied in great detail (Denham, 2018; Nance, 2018; Wang, 2016; Bahram, 2015; Sutton, 2012). The regional, strike oriented, stratigraphic cross section publish by the Ft. Smith Geological Society (1988) provides a key reference for the stratigraphic nomenclature of the internal subdivision of the Atoka Formation as they are applied in the subsurface by the oil and gas industry. Additionally, many published investigations focus on specific portions of the Atoka, typically one of the three divisions (lower, middle, or upper) rather than the Atoka as a whole and haven't provided an interpretation of the coeval transition to deep-water deposition (Bahram, 2015; Wang, 2016). Therefore, the problem and the objective of this project is to better characterize the shelf to basin transition and tectonostratigraphy of the Atoka Formation by providing updated regional cross sections tied to the original FSGS (1988) section across a major portion of the Arkansas Arkoma Basin. These cross sections include the entirety of the Atoka formation, plus the underlying Kessler limestone as a regional stratigraphic marker.  This allows for the documentation of the transition from marginal marine depositional environments in the north through deepwater depositional environments in the south, in all three divisions of the Atoka Formation.

A problem with the current lack of documentation of the Atoka deepwater transition is the inability to determine the paleogeography and stratigraphic location of the massive stratigraphic expansion, (maximum flood 'hinge line') within the Middle Atoka attributed to the period of elevated subsidence rate during foreland basin evolution.  This project's hypothesis is that if this 'hinge line' can be determined, this would lay the foundation for other observations and conclusions.  An additional problem that this project focused on, is the determination if the cyclic shore zone deltaic packages along the northern margin of the basin can be reasonably correlated to coeval, sand-rich deepwater elements in the deep basin to the south. The regional transect grid and the hinge line migration diagram provide the stratigraphic framework that sets the context for future, more detailed examinations of the internal depositional systems.

### *Study Area*

This project area covers 64 townships in the north-central part of the Arkoma Basin. This covers an area of approximately 2300 square miles within T9N to T2N and R32W to R25W. The study area extends from the northern shallow marine region, down shelf into deeper water settings to the south. This study area doesn't span far enough north to encompass the Atokan strata onlap, so the observation and interpretation of this stratigraphic phenomena isn't included in this thesis.

This is a comprehensive overview of the Atoka Formation - plus the Kessler Limestone. A total of 573 wells were correlated for this project's high resolution and following condensed regional cross sections. Two east-to-west and three north-to-south cross sections were constructed to document regional stratigraphic trends within the interval (Figure 2). The north-to-south cross section A-A' includes 9 wells, B-B' includes 8 wells, and C-C' includes 7 wells. East-to-west cross sections D-D' and E-E' both incorporate 7 wells each. Each cross section, excluding E-E', includes both the structural and stratigraphic illustrations. The southern east-west section (E – E') only includes the stratigraphic cross section due to the complexity of numerous sub-parallel thrust faults across this strike-oriented section. A reasonably accurate structural interpretation of this section is beyond the scope of this study. This study area is shifted farther south than Denham (2018) and Woolsey's (2007) complimentary projects in order to capture the shelf to basin depositional transition (Figure 3).

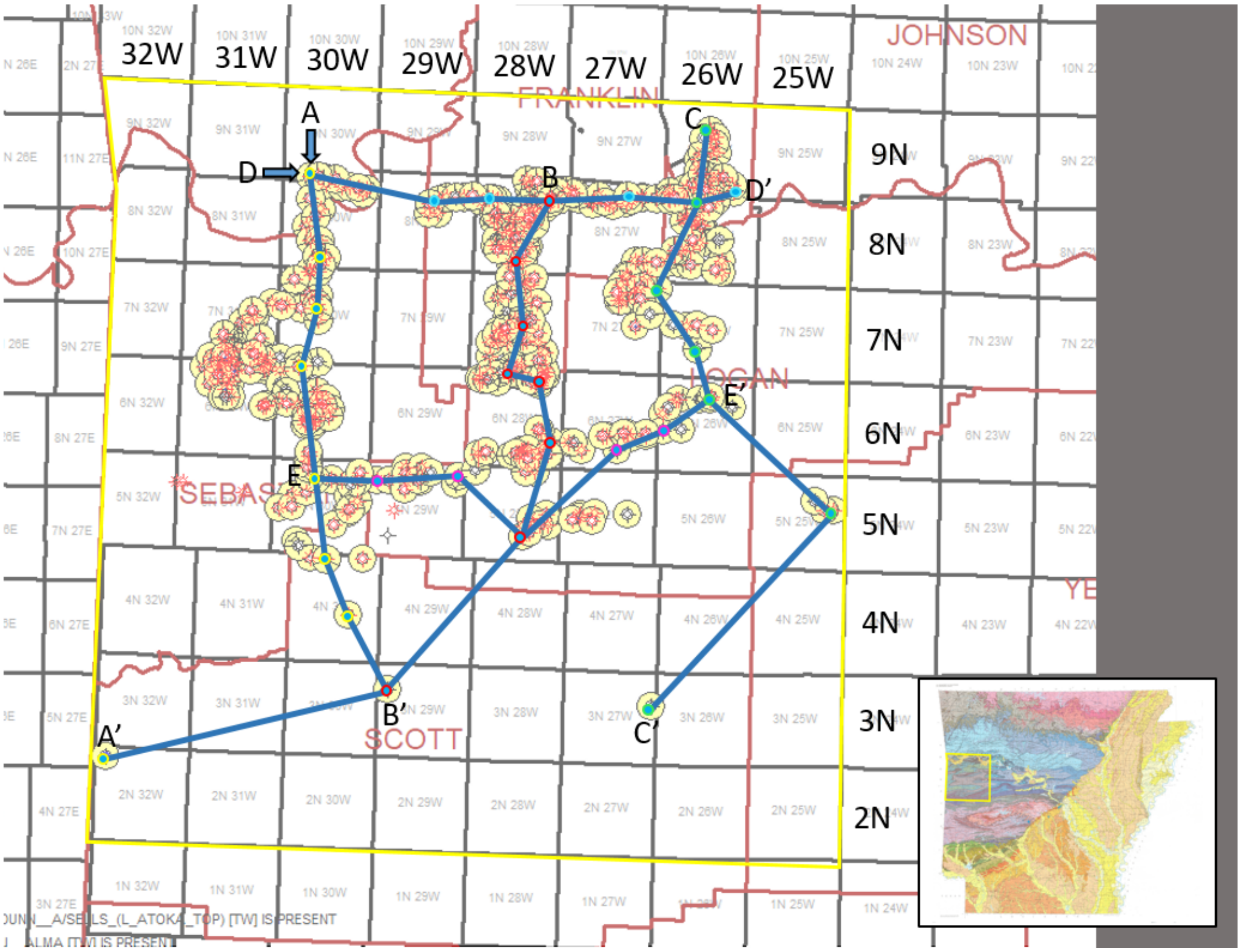


**Figure 2**: The study area is defined by the yellow outline. A-C are stratigraphical oriented dip transects, D-E provide regional strike oriented control. The Petra™ base map includes the United States Public Land Survey System and wells correlated in this project.

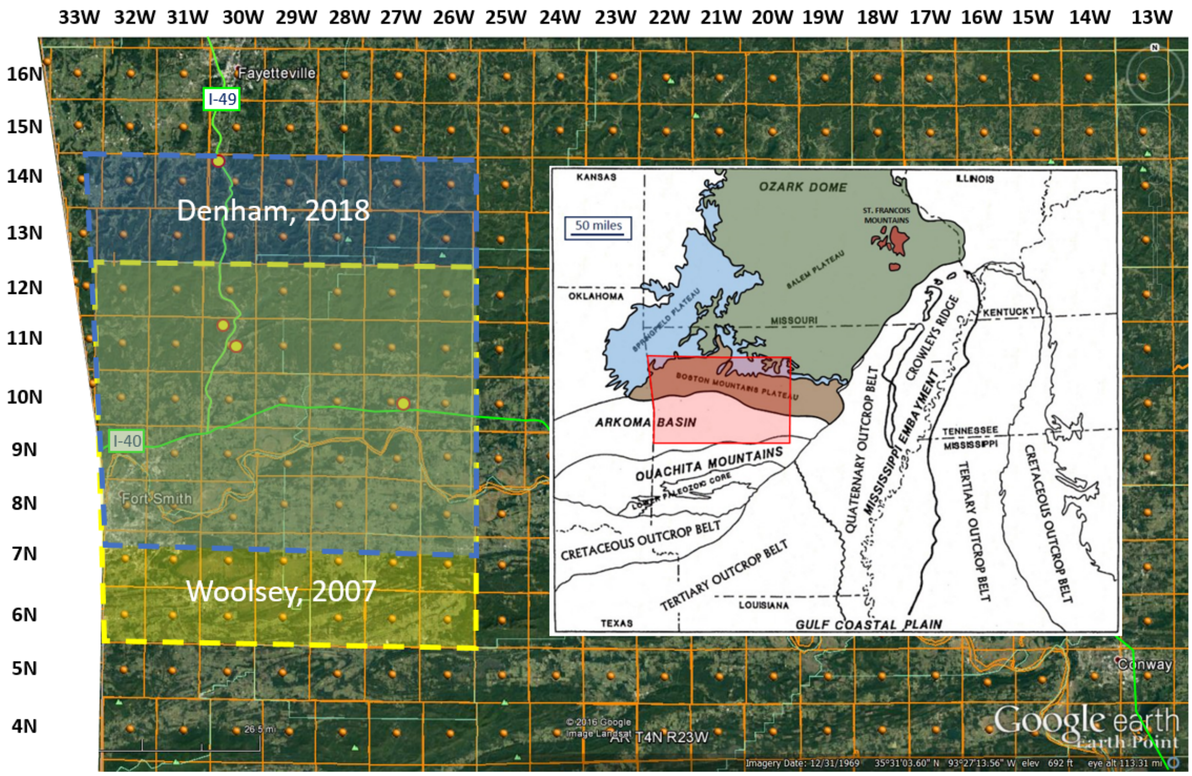


**Figure 3**: Study areas of both overlapping complimentary projects. The blue polygon represents Denham's (2018) study area and the yellow polygon represents Woolsey's (2007) study area.

## *Geologic Setting*

### *Tectonic History*

The tectonic and structural history of this area began with the rifting and separation of the super continent Rodinia into Laurasia and Gondwana during the late Precambrian to earliest Paleozoic (Figure 4.A & 4.B). This breakup led to the development of the Northwest Arkansas Structural Platform as a stable passive margin along southern Laurasia accompanied by southward migration of a mid-ocean ridge, away from that continental margin (Chinn and Konig, 1973). This passive margin (Figure 4.C) persisted to the middle Paleozoic (Houseknecht, 1983; Bahram, 2015). The passive margin was transformed into a northward trending convergent margin with subduction occurring southward under the Gondwanan tectonic plate during the

Mississippian to Early Atokan (Figure 4.D). This convergence resulted in the evolution of the platform into a subsiding foreland basin. By early to middle Atokan time (Figure 4.E), the remnant ocean basin, which had developed during this continental convergence, had been completely consumed by the Laurasian subduction complex (Houseknecht, 1983). The Late Atokan and Desmoinesian (Figure 4.F) encompassed the final stages of foreland basin fill during the continental collision. This continental collision was associated with a rapid increase in sedimentation rate during the Atokan and Desmoinesian time (Figures 5 & 6). The massive change in sedimentation rate marks the initiation of the effects of the Ouachita Orogeny on the Arkoma Basin fill within the Atoka. This increased sedimentation rate was also concurrent with the beginning of Arkoma Basin tectonics. After the tectonic convergence ended at the end of the Pennsylvanian; the development of the Ozark Dome, Arkoma Basin, and the Ouachita Mountains had been completed (Houseknecht, 1983). The Ozark Dome and Arkoma Basin occupy the region that was the Northern Arkansas Structural Platform, and the Ouachita Mountains formed as a result of an accretionary wedge and thrust belt.

Sediment was delivered to the basin from the north-northeast having originated from the Central Appalachians farther to the east. This sediment supply contributed to the lowermost Atoka and pre-Atoka formations (Houseknecht, 1983). The Lower Atoka formation was deposited on a shallow dipping, stable shelf (<1°) defined as the Northern Arkansas Structural Platform (Chinn and Koenig, 1973) that extended well to the south of the present-day Arkoma Basin (Zachry, 1983; Houseknecht, 1983). Due to the shallow dip of this shelf, normal eustatic cyclicity resulted in long distance north-south shifts in the position of the paleoshorelines (Sutherland, 1988; Zachry, 1983; Denham, 2018). During the Early - Middle Atokan, tectonic convergence caused part of the platform to become a subsiding foreland basin, which allowed for extremely high subsidence and sedimentation rates. The stratigraphic thickness of the Middle Atoka can be attributed to lithospheric flexure that caused the propagation of multiple, landward stepping, east-west striking and south dipping normal faults. This created accommodation space for the Middle and Upper Atoka on the downthrown sides of the individual faults (Zachry, 1983; Houseknecht, 1983; Morgan, 2006; Bahram, 2015). These normal faults offset Cambrian through earliest Atokan strata and created a step like substratum during Early and Middle Atoka time, as seen in figure 7 (Zachry, 1983; Houseknecht, 1983; Sutton, 2012). Much of the sediment being deposited by the east to west depositional system was sourced from the Appalachian Mountains and Ouachita Accretionary Prism to the east and south respectively (McGilvery, Manger, and Zachry, 2016). The Upper Atoka and Hartshorne were deposited during the Late Atokan and Desmoinesian. The dominant sediment supply and direction of progradation for this late stage fill continued to be in an axial east to west direction with peripheral southward directed progradation along the northern margin of the basin (McGilvery, Manger, and Zachry, 2016; Zachry, 1983). East to west shore zone depositional systems filled in most of the accommodation space to the east, causing the foredeep to migrate westward. (McGilvery, Manger, and Zachry, 2016; Zachry, 1983). Most of the present structural deformation was complete during this late stage fill (Houseknecht, 1983).

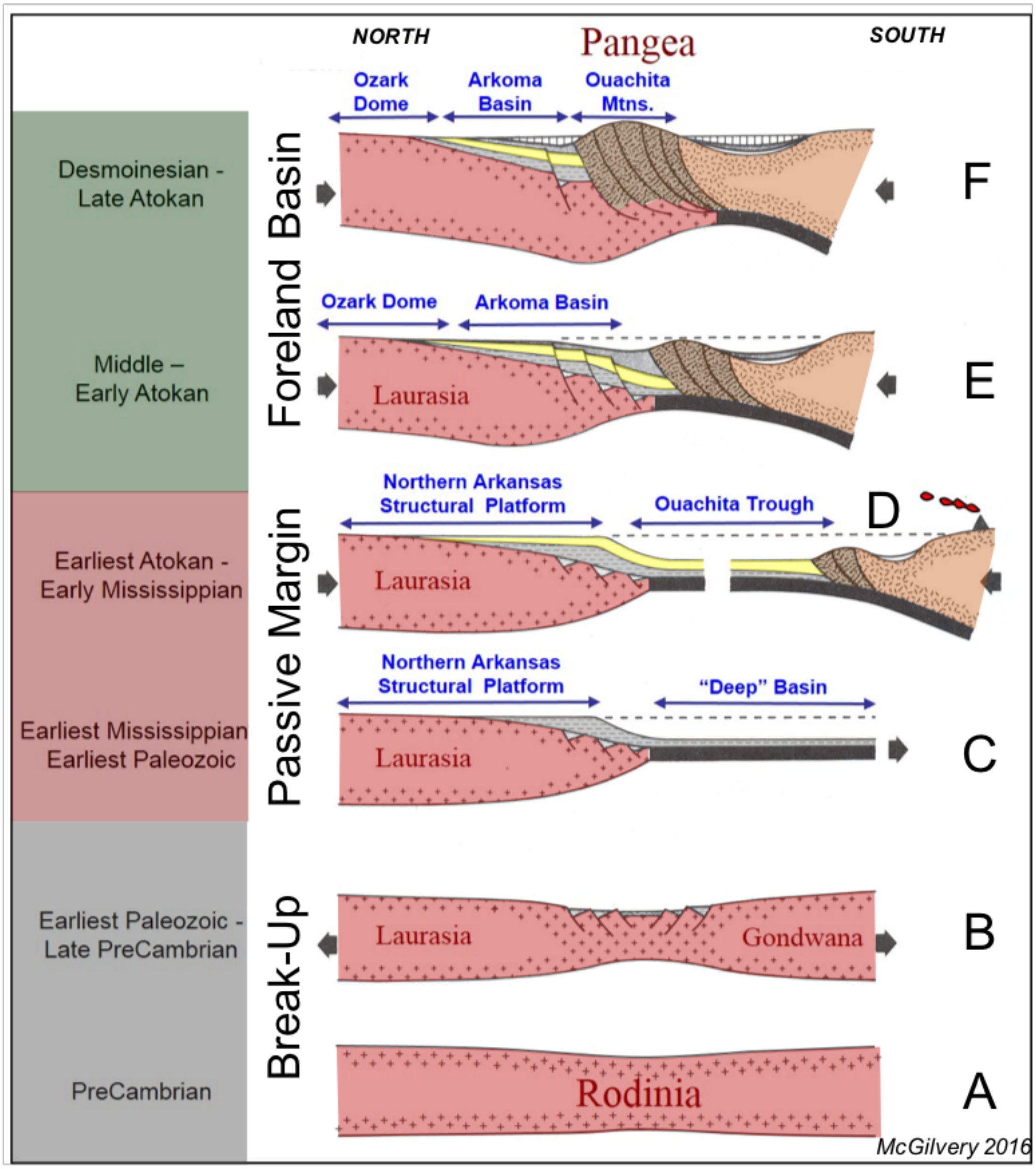


**Figure 4**: The tectonic transformation of the Arkoma Basin. B represents a passive margin and as time progresses, convergence leads to a foreland basin. (Modified from Houseknecht and Kacena, 1983).

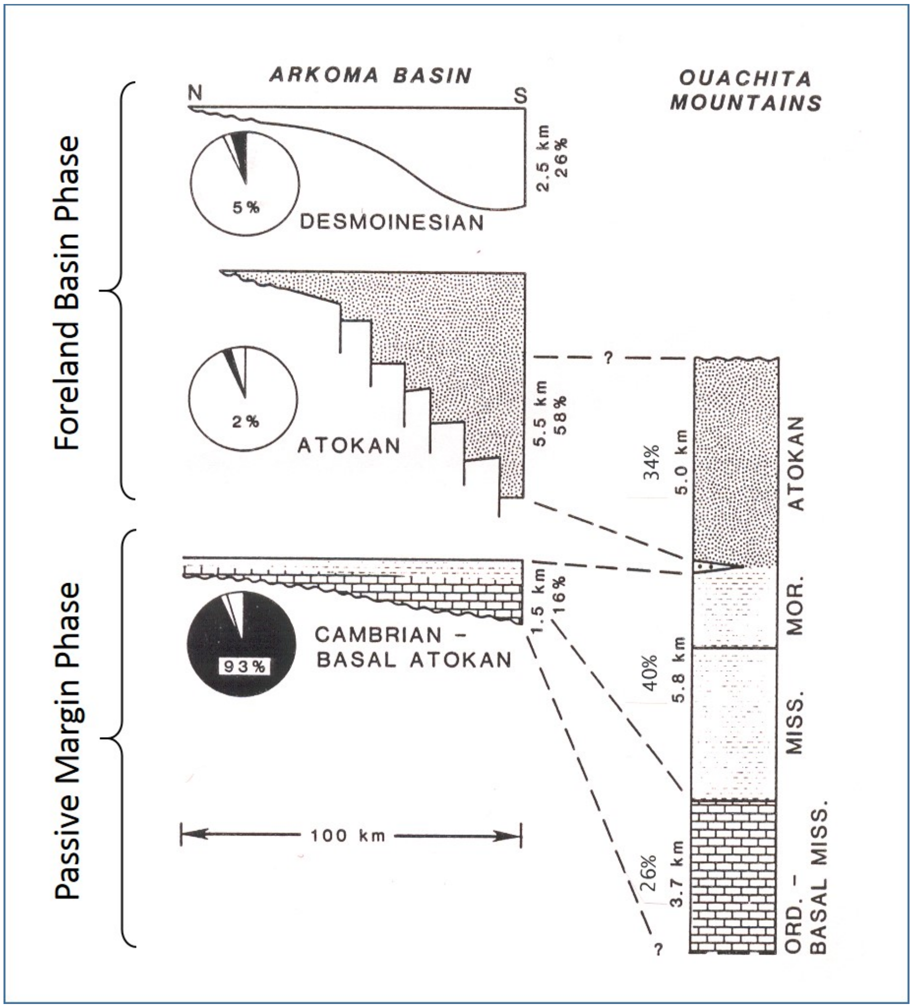


**Figure 5**: Comparison of Rates of Deposition and Percentage Contribution to the Successions in the Arkoma Basin and Ouachita Mountains (modified from Houseknecht, 1987)

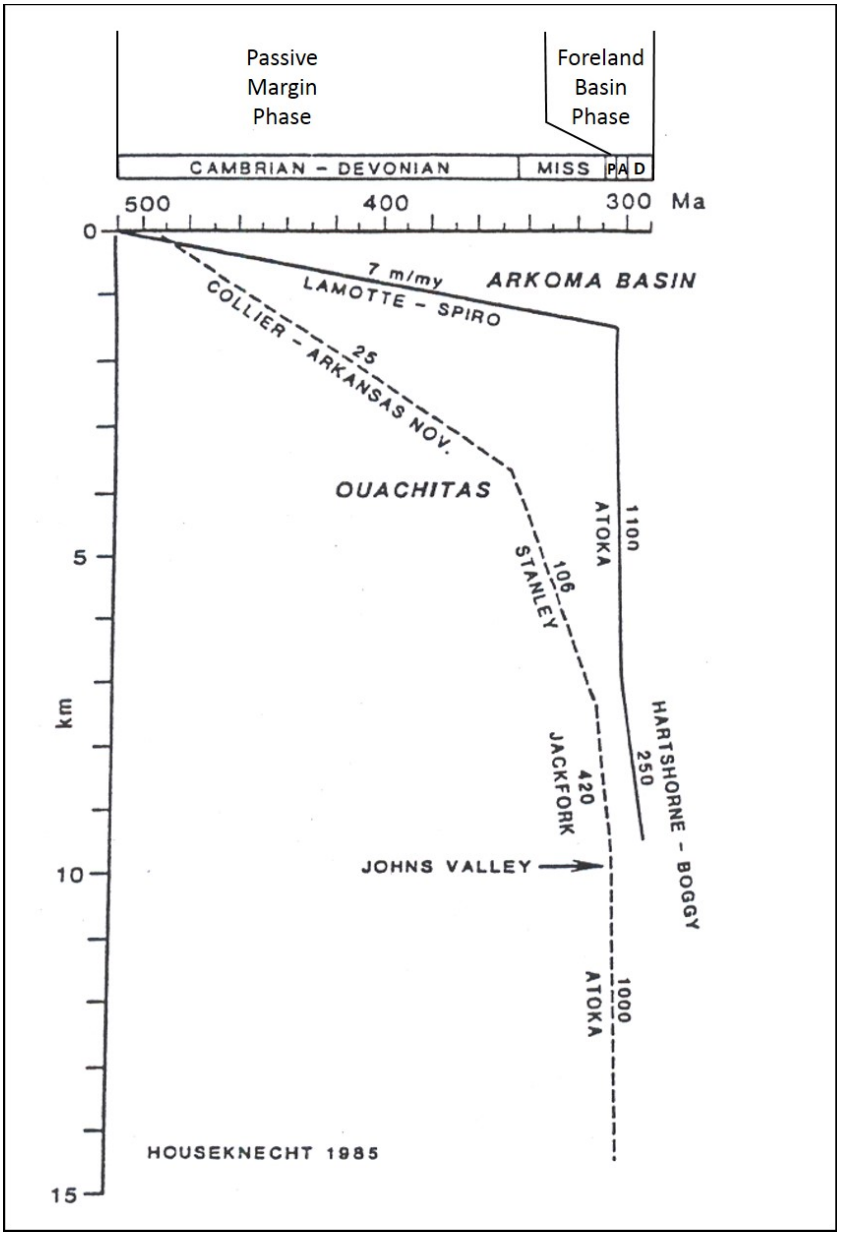


**Figure 6**: Rates of Sedimentation for the Arkoma Basin and Ouachita Mountains (Houseknecht, 1985).

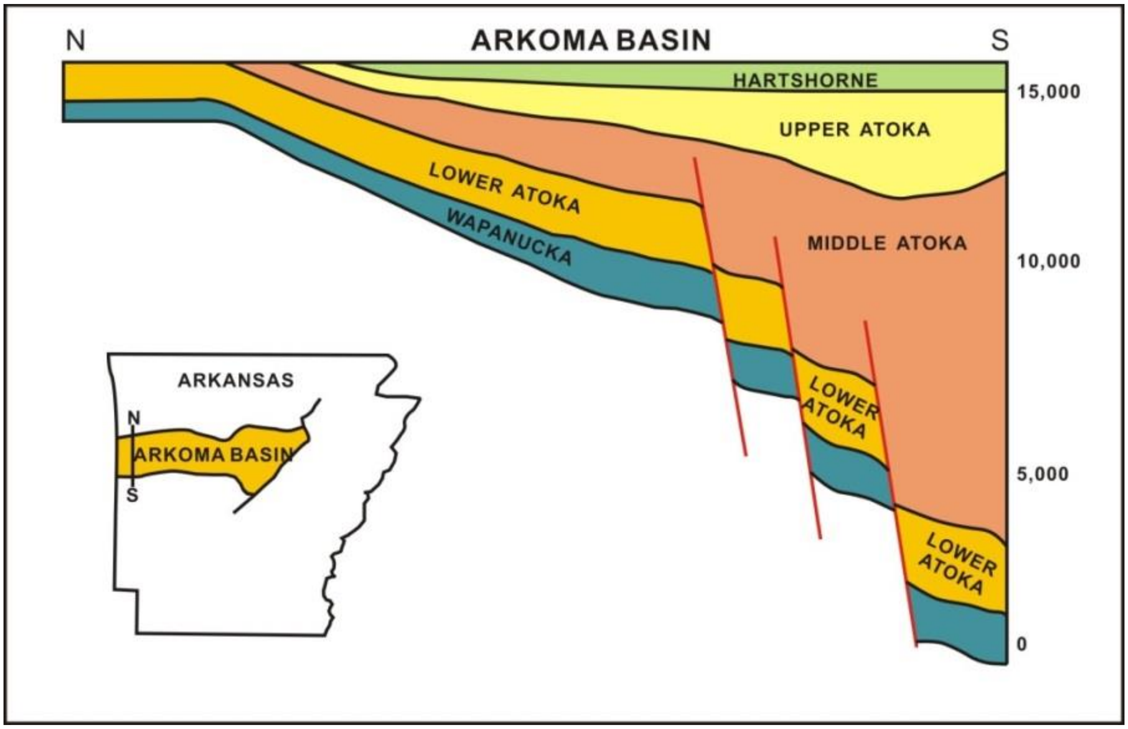


**Figure 7**: Theoretical north-south structural cross section of the Arkoma Basin. (Zachry, 1983).

***Paleogeography and Depositional Environments***

The paleogeographic evolution and stratigraphy of the Atoka Formation reflects the evolution of the Arkoma Basin during the Mississippian to Early Atokan; when the Laurasian passive margin transformed into a convergent margin adjacent to a remnant ocean basin (Figures 8, 9, 10 & 11).

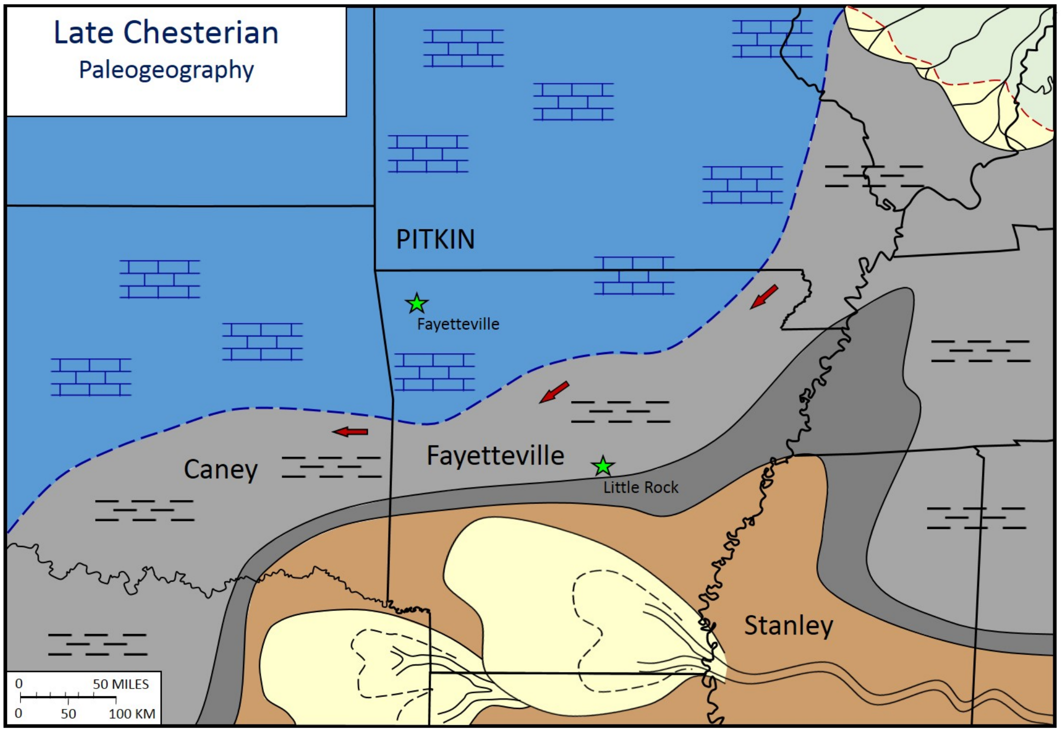


**Figure 8**: Paleogeography of the Southern Midcontinent during the Late Chesterian (Modified from Sutherland, 1988).

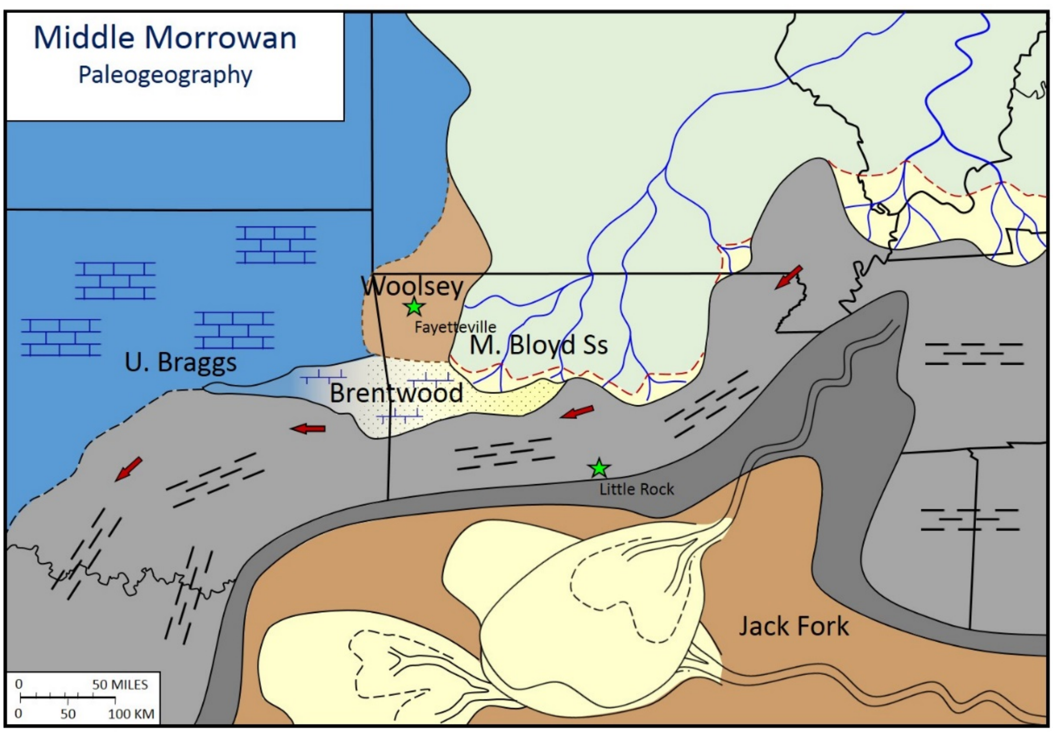


**Figure 9**: Paleogeography of the Southern Midcontinent during the Middle Morrowan (Modified from Sutherland, 1988).

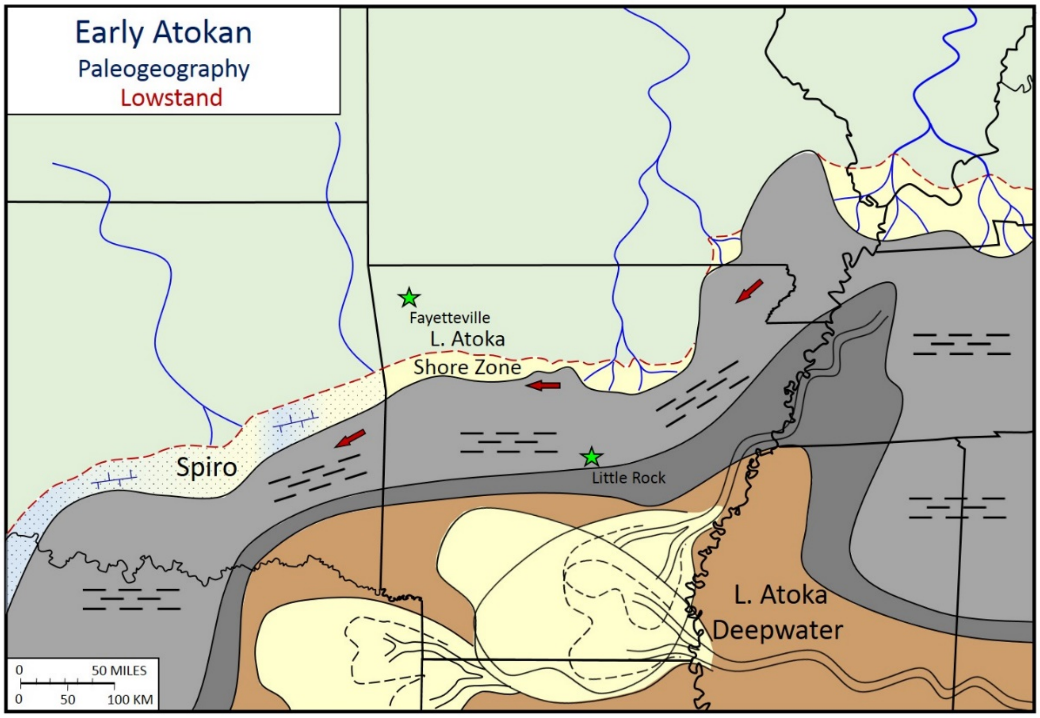


**Figure 10**: Lowstand paleogeography of the Southern Midcontinent during the Early Atokan (Modified from Houseknecht, 1987 in McGilvery, Manger, and Zachry, 2016).

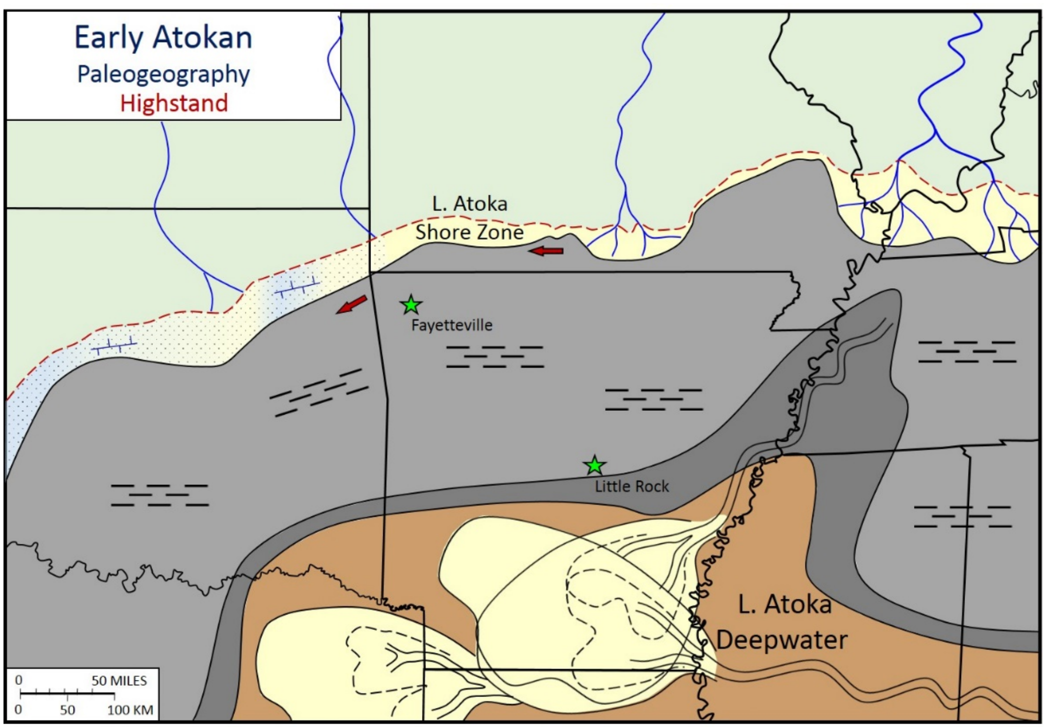


**Figure 11**: Highstand paleogeography of the Southern Midcontinent during the Early Atokan (Modified from Houseknecht, 1987 in McGilvery, Manger, and Zachry, 2016).

The lithology and depositional environments of the Atoka Formation were heavily affected by both the structural history of the basin and eustatic sea level change. The pre-Arkoma Basin Lower Atoka is made up of alternating sandstone and shale sequences reflecting rapid shifts in shoreline position controlled by eustasy (Figures 10 & 11; Woolsey, 2007; Denham, 2018). These sequences were characterized by high destructive delta systems prograding southward, which fed coastal sand complexes (Zachry, 1983). This sequence is between 500 – 1000 ft in thickness (Houseknecht, 1983; McGilvery, Manger, and Zachry, 2016; Denham, 2018).

The Middle Atoka is also comprised of alternating sandstone and shale sequences (Knight, 1985). This alternating lithology is a result of sea-level cyclicity and variable rates of subsidence (Wang, 2016). Middle Atoka sandstone and shale intervals in the eastern portion of the basin, resulted from westward progradation of shore zone and deltaic systems (Figure 12). These prograding depositional systems were the result of a massive increase in sediment supply from the east attributed to the Appalachian – Ouachita Orogeny. These systems fed fault-controlled slope channels and sand-rich aprons which further fed submarine fan complexes (Zachry, 1983; Houseknecht and McGilvery, 1990; McGilvery, Manger, and Zachry, 2016). Sandstone intervals, in the north and central portions of the basin, accumulated from southward prograding constructive deltaic and shore zone systems (Zachry, 1983). The stratigraphic thickness of the Middle Atoka can exceed 25,000 ft and took less than 8 million years to be deposited suggesting a substantial subsidence rate and sediment supply common in evolving foreland basins (McGilvery, Manger, and Zachry, 2016).

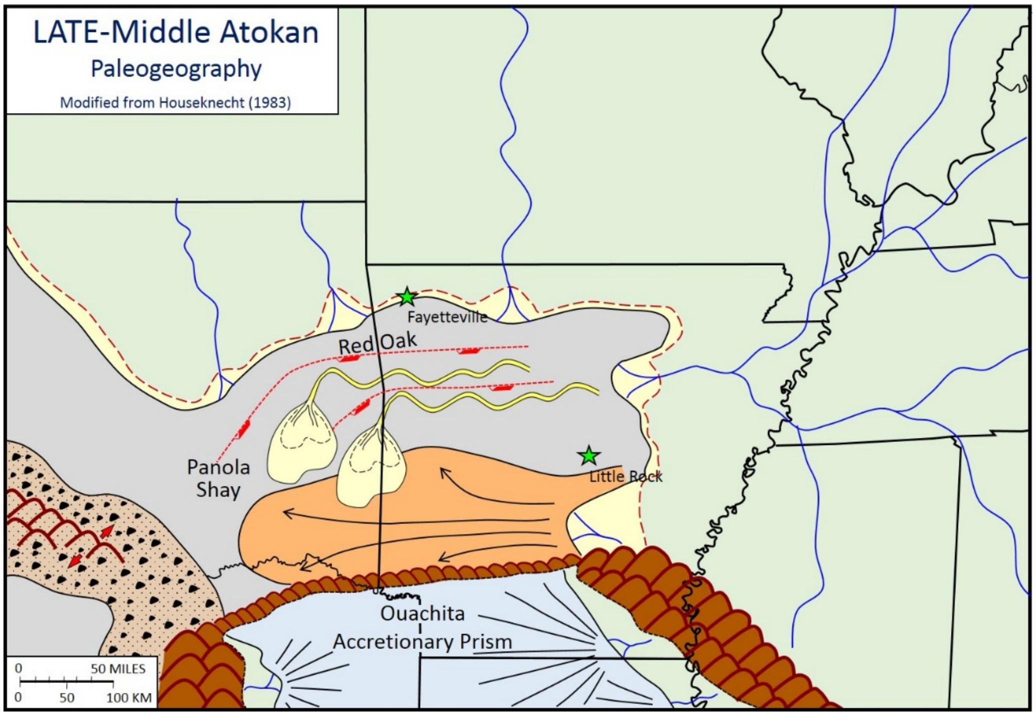


**Figure 12**: Paleogeography of the Southern Midcontinent during the Middle to Late Atokan (Modified from Houseknecht, 1987 in McGilvery, Manger, and Zachry, 2016).

The Upper Atoka and overlying Hartshorne Formation are made up of upward thickening sandstone units deposited by axial prograding fluvial/deltaic depositional systems. This axial dispersal system led to a westward migrating foredeep (Figures 13 & 14). According to Houseknecht (1983), the Upper Atoka interval is between 1500 – 3000 feet in thickness, although this study found that the upper end could be around 3500 feet. The internal progradational cycles are substantially thicker than the "pre-Arkoma Basin" lower Atoka. This is due to the continued high sedimentation rate coupled with a slowing subsidence rate prior to the final closing of the basin.

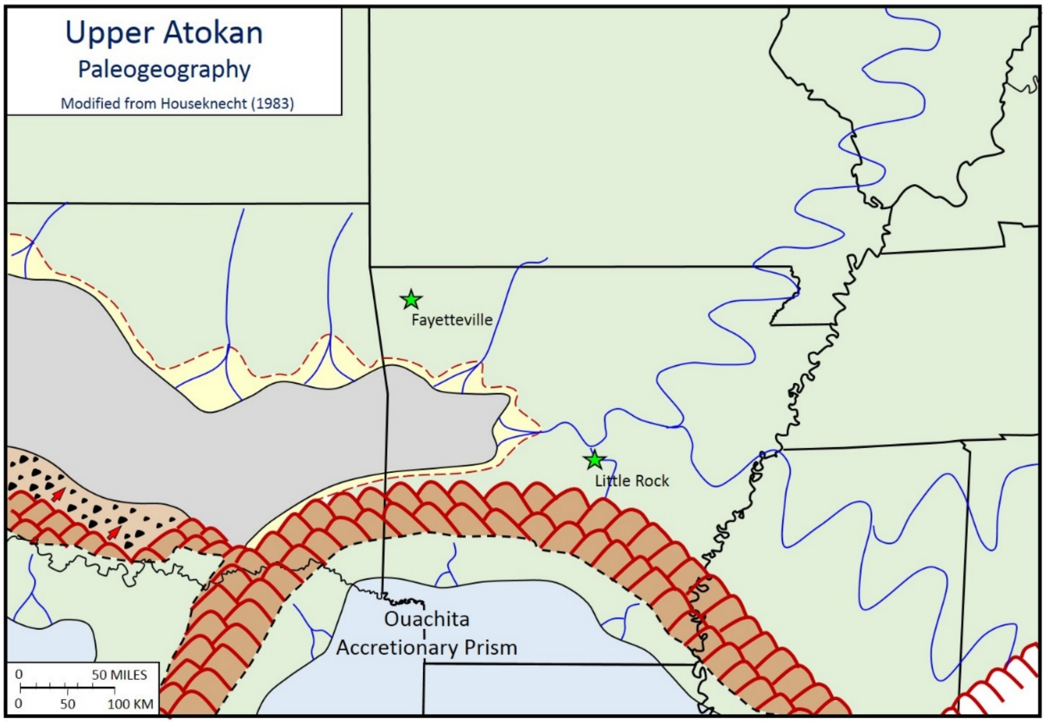


**Figure 13**: Upper Atokan paleogeography of the Southern Midcontinent (Modified from Houseknecht, 1987 in McGilvery, Manger, and Zachry, 2016).

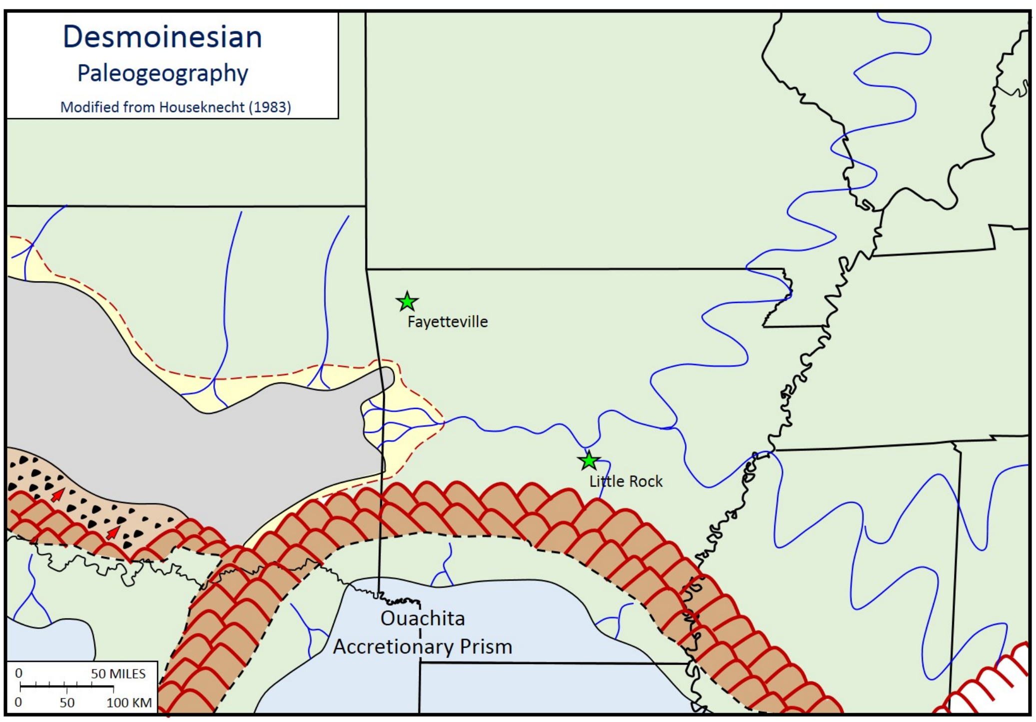


**Figure 14**: Desmoinesian paleogeography of the Southern Midcontinent (Modified from Houseknecht, 1987).

### *Previous Stratigraphic Investigations*

David Dale Owen (1858) was first to document a sandstone and shale sequence overlying what is now known as the Bloyd Formation (Owen, 1858; McGilvery and Berlau, 1980). While studying the Choctaw Coal Fields in Oklahoma, Taff and Adams (1900) described a series of sandstone and shale sequences below the Hartshorne. These sequences were proposed to be designated the Atoka Formation. In 1930, Croneis found that the Winslow Formation, by Adams and Ulrich (1904), and the Atoka Formation were equivalent to one another. This extended the geographic use of the Atoka Formation nomenclature by consolidation. The modern boundaries of the entirety of the Atoka Formation were originally and roughly defined by Spivey and Roberts (1946) while studying Lower Pennsylvanian geology in central Texas. They were attempting to bound a chronostratigraphic series between everything post-Morrowan and pre-Desmoinesian based on foraminifera, despite how finite these available biostratigraphic markers are within the series (Sutherland and Manger, 1984). Therefore, the Atoka Formation is both a lithostratigraphic and chronostratigraphic unit. Gaston (1985) assisted in determining the thickness and extent of the upper, middle and lower Atoka using base maps and cross sections. Houseknecht (1983) helped define the tectonic history of the basin and its formations, including schematic cross sections to visually depict this tectonic evolution as seen in figure 4. Zachry (1983) improved the understanding of the stratigraphic and sedimentological framework of the basin by investigating the complex lithologic successions within the Atoka members.

Although the Arkoma Basin has been studied for over 100 years the current understanding of the subsurface has been greatly advanced during the past 30 years (Woolsey, 2007). This was largely driven by the petroleum industry's significant interest in its hydrocarbon potential (Perry, 1995; Suneson, 2012; Bahram, 2015). As of 2010, the USGS estimated that there were 38 trillion cubic feet of natural gas and 159 million barrels of natural gas liquid reserves within the Arkoma Basin and related areas (Houseknecht, 2010). Exploration for natural gas and coal started in approximately 1910 and 1915 in the Oklahoma portion of the basin (Suneson, 2012). This exploration lead to a drastic increase in the study of the basin by both academia and industry.

The lithostratigraphic subdivision of the of the Atokan sandstones in the subsurface originally arose to denote producing reservoirs during gas exploration within the Arkoma Basin; many established by what is today Southwestern Energy Company as well as many other operators in the basin. This nomenclature was usually derived from the well or field name, when the unit was the main producer. As a result, many of these sandstones were named multiple times with differing nomenclature. In attempt to create consistency amongst actively practiced nomenclature and to designate these sand bodies, the FSGS created a dip-section correlating subsurface Atokan and Morrowan producing formations in northwest Arkansas in 1960 (Woolsey, 2007). In 1988, to further this progress toward uniformity, the FSGS published another regional strike oriented transect along the northern margin of the basin in Arkansas, that ran east-to-west, all the way into Oklahoma (Figure 15). All of this cumulated to the informal naming of 23 sandstone units within the Arkoma basin, recognized by industry and the Arkansas Oil and Gas Commission (Valek, 1999; Woolsey, 2007).

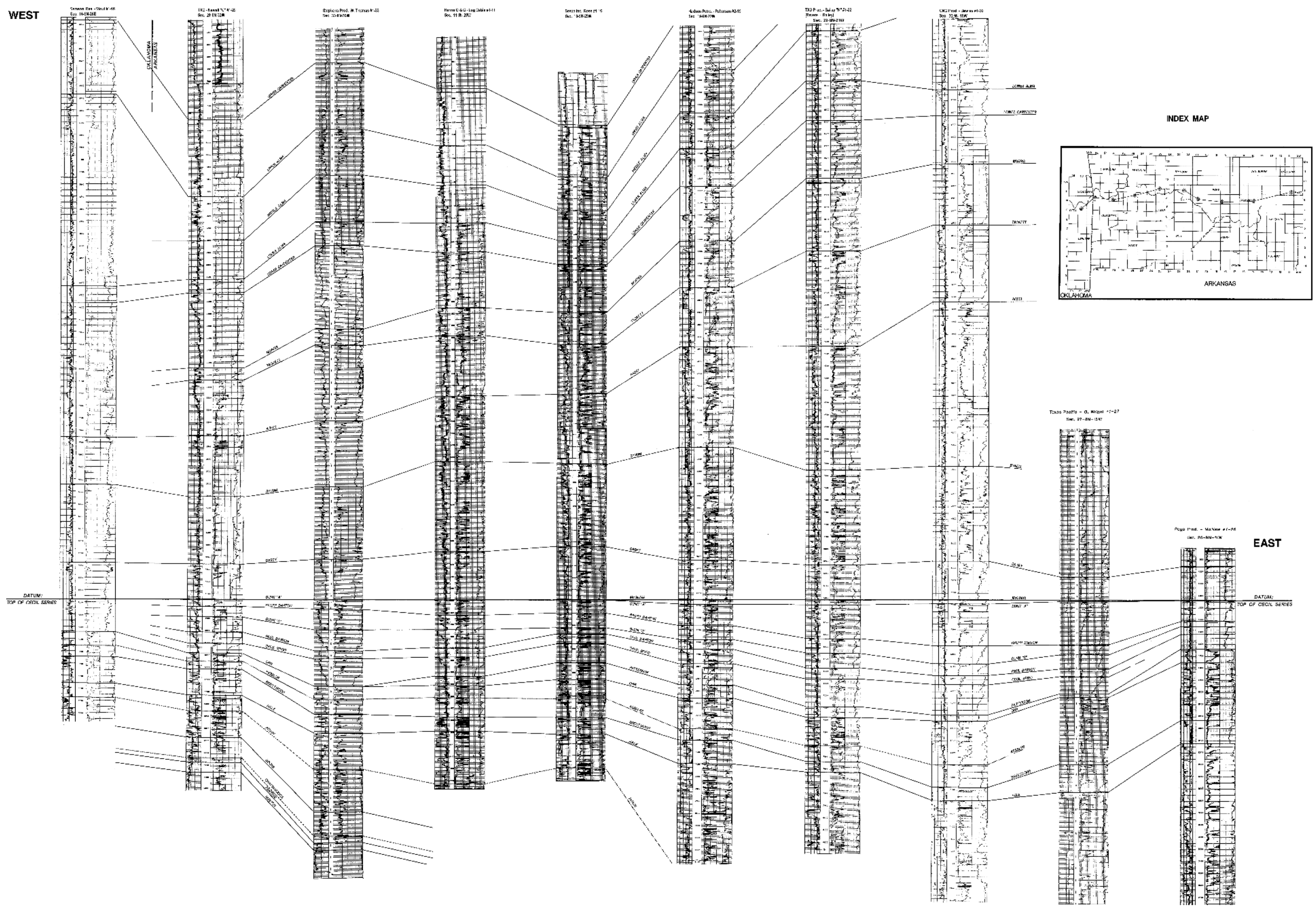


**Figure 15**: Fort Smith Geological Society Stratigraphic Cross-section No. 1 Arkoma Basin, Arkansas (1988).

The stratigraphy, sedimentological framework, depositional environments, and tectonic history of the Arkoma Basin have been heavily studied. This includes many investigations into the Atoka Formation and its members. The broad understanding of the stratigraphic thickness and geometry of the Atoka Formation is known, and even well understood in certain localities, but this study that spans shelf to basin paleoenvironments will build on our understanding of the Atoka within the region. Cross sections that span 2 to 4 townships that include the Atoka are plentiful within the Arkoma Basin. Houseknecht (1986) created a cross section in Oklahoma, spanning approximately 5 townships, that illustrated the stratigraphic expansion across syndepositional normal faults during the foreland basin evolution. Six cross sections, constructed by Nance (2018), cover 3 to 4 townships slightly within this project's study area but are concentrated in what this study has determined as upper slope deposition to the north. Similarly, Johnson (1988) created a regional cross section in Oklahoma related to the shelf-to-basin geology and resource potential of the Pennsylvanian strata. Johnson correlated the Atoka Formation as a whole, without reference to internal subdivisions. Jameson (1998) created a series of cross sections that included the shelf and the deep basin but did not interpret or represent the transition from shallow to deep marine environments. Roberts (2005) constructed two geologic profiles that are within the study area, derived from seismic and surface data. Boyd Haley created a series of regional well log cross sections in 1982 that include the shelf to basin transition across the basin within this project's study area using a progression of numbered units as stratigraphic subdivisions. These cross sections were published without a report and appear to over emphasize pure lithostratigraphic correlation. His key, designed to designate nomenclature, makes it very difficult to determine what member belongs to which correlation within the five cross sections. Mentioned previously, in 1988 the FSGS created an east to west stratigraphic cross section, datumed on the Dunn A/Sells, that extends across a majority of the northern portion of the basin (Figure 15). Due to its strike orientation along the northern basin margin, this cross section didn't include the deep-water depositional environments. Because of the reliability of its correlations, this thesis shares two wells with the 1988 FSGS cross section. Cross section D – D' and B – B' include Log Cabin #1-11 and cross section A – A' includes Wayne Thomas #1-33 (Figures 29, 25, & 23). Nomenclature used in this thesis is also based on nomenclature used in the FSGS cross section (Figure 16). This study's updated cross sections that encapsulate marginal marine to deep marine depositional environments will provide a much need update to these previous investigations.

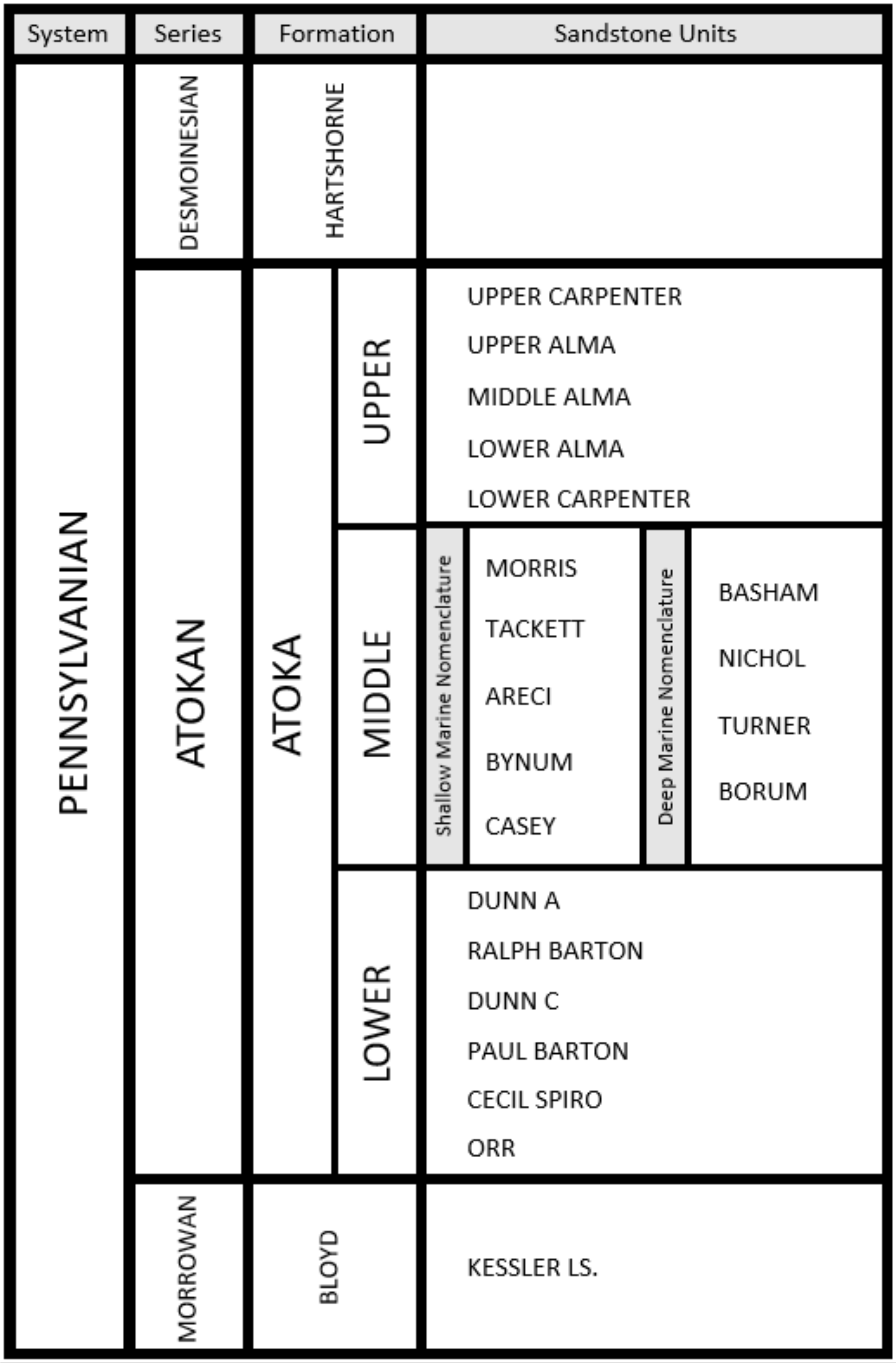


**Figure 16**: Stratigraphic column of nomenclature used within this thesis.

## *Methods*

This study is focused on creating three regional transects that capture the north-to-south shelf to basin transition within the entirety of Atoka Formation, within the western portion of the Arkoma basin in Arkansas. These sections are designated A-A', B-B', and C-C' from west to east. Correlations were based on raster images of gamma ray, resistivity, and conductivity curves. Structural versions of the north-south transects were supported by adjacent 2D seismic profiles. Two east-to-west cross sections were constructed to tie correlations between the regional dip sections to develop a complete correlation grid. One in the northern shallow marine deposits (D-D') and the other in the southern deep marine deposits (E-E'). Previous studies in the area were used as supporting material for this project's interpretations and were utilized in initiating and confirming its correlations. Finally, a tectonostratigraphic fill hinge line migration diagram was constructed as the final product of this thesis.

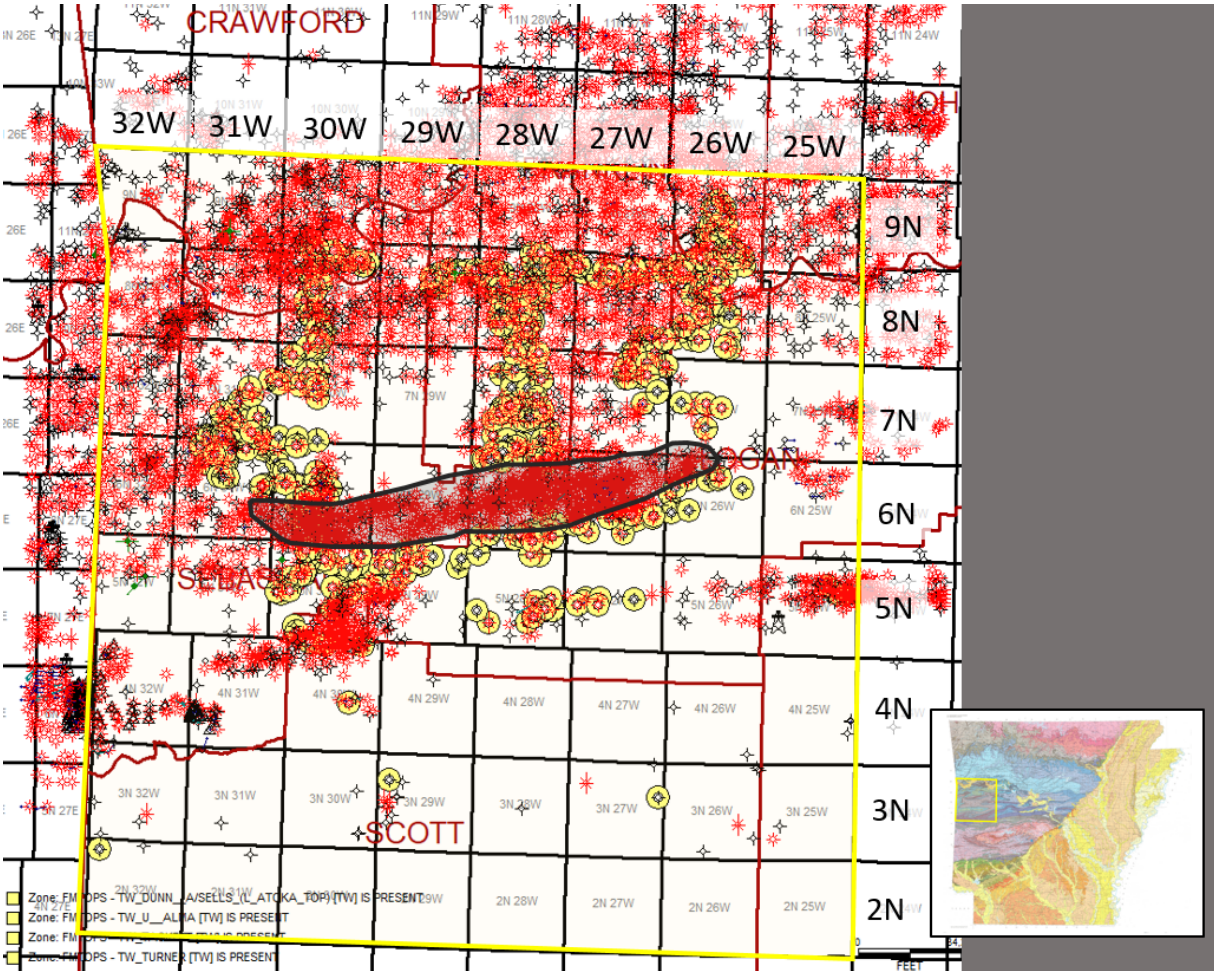


**Figure 17**: Washburn anticline (black) included within all wells within database. Wells correlated (yellow circles) within this projects study area (yellow boundary). The Petra™ base map includes the United States Public Land Survey System.

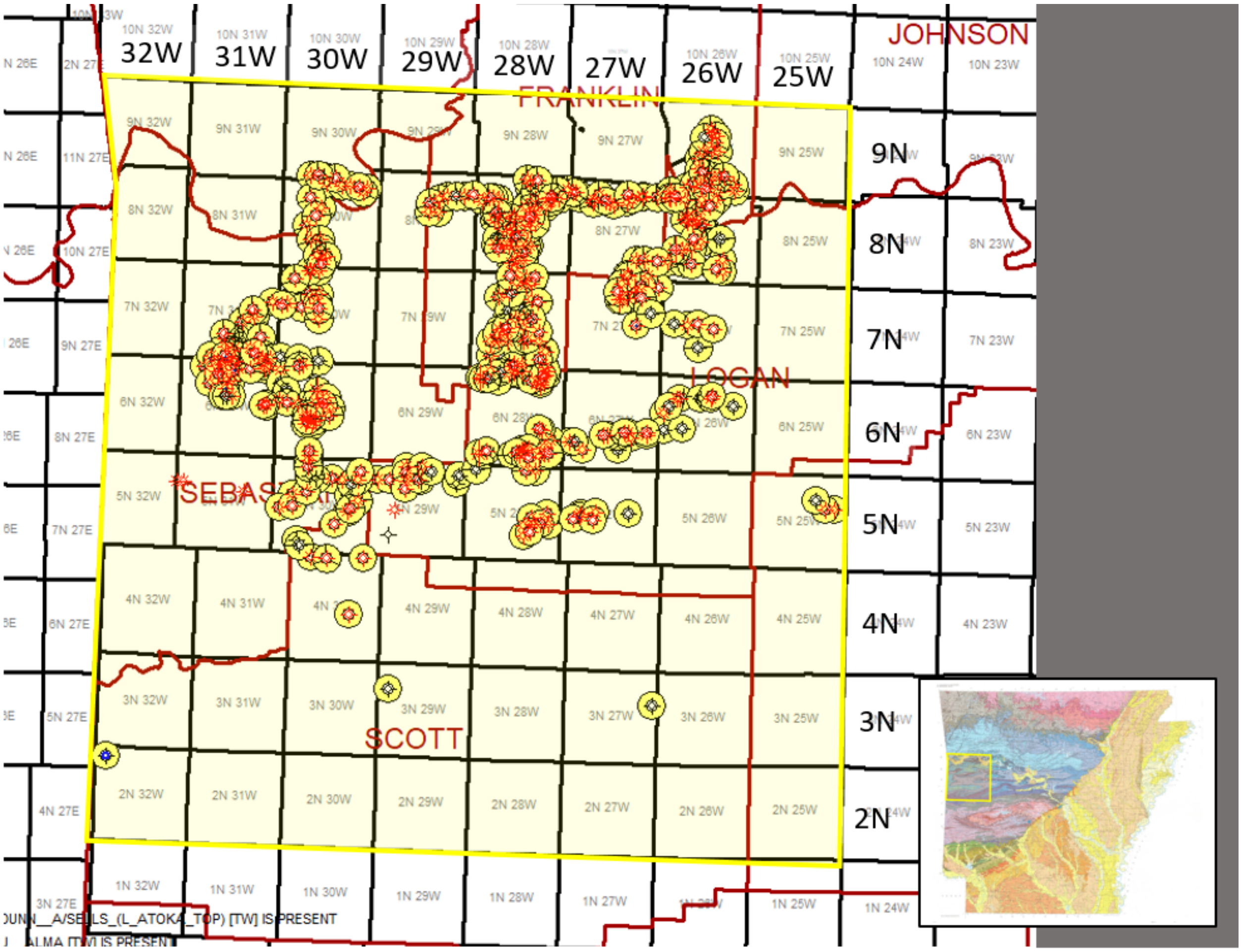


**Figure 18**: All wells correlated, denoted by their well symbols, within this projects study area (yellow boundary). The Petra™ base map includes the United States Public Land Survey System.

This study area includes approximately 2300 square miles. There are 6077 wells, as seen in figure 17, in which 573 wells were picked and correlated (Figure 18). Additionally, the objective of this project was to construct high resolution regional transects and therefore the correlated wells are concentrated along these profiles (Figures 19 & 20). As a result, detailed subsurface mapping was not practical. All horizons within the section were picked concurrently which created more reference points as correlation work progressed across the study area. Correlations were made using manual pattern recognition of log motif. During correlation work, there were gaps between wells that could be between 1 – 5 miles in distance where data was sparse. In the case of this project's farthest southern well, the Edwards No. 1, there is 18.5 miles distance between it and the next correlated well. These gaps of data occurred frequently north, for approximately 5 miles of the Washburn anticline, and continuously south of the Washburn anticline (Figure 17). Correlation work within the Washburn anticline was difficult due to complex compressional faulting resulting in a lower concentration of correlated wells along this trend.

Petra™ was used to gather, organize and manage all of the wells and accompanying data in this project. Correlations of the formation members on raster images and construction of the following cross sections were made using this software. The resulting cross section illustrations (Figures 23-31) were made using Microsoft Powerpoint®.

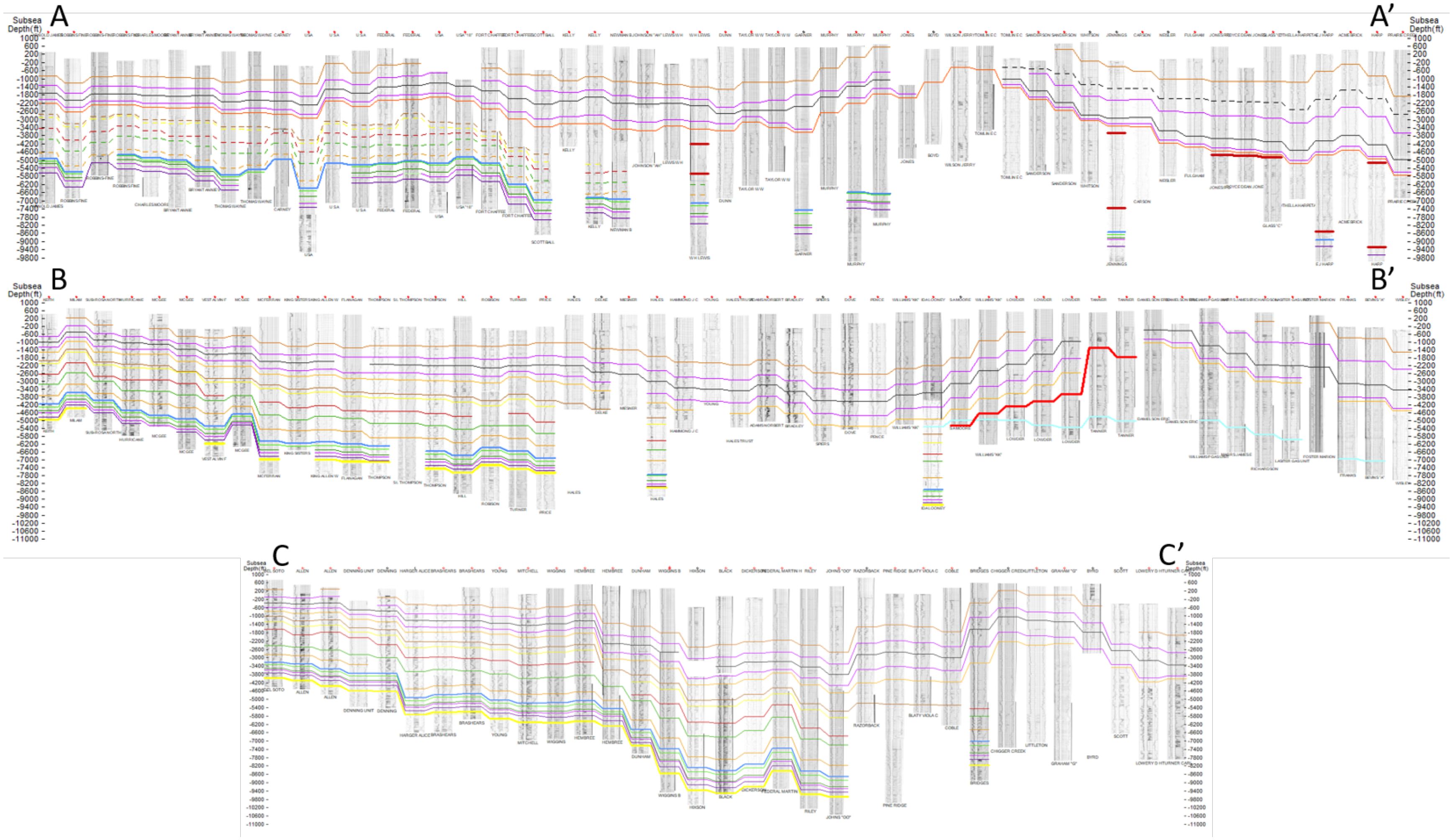


**Figure 19**: High resolution, dip-oriented correlation panels A-A', B-B', and C-C'.

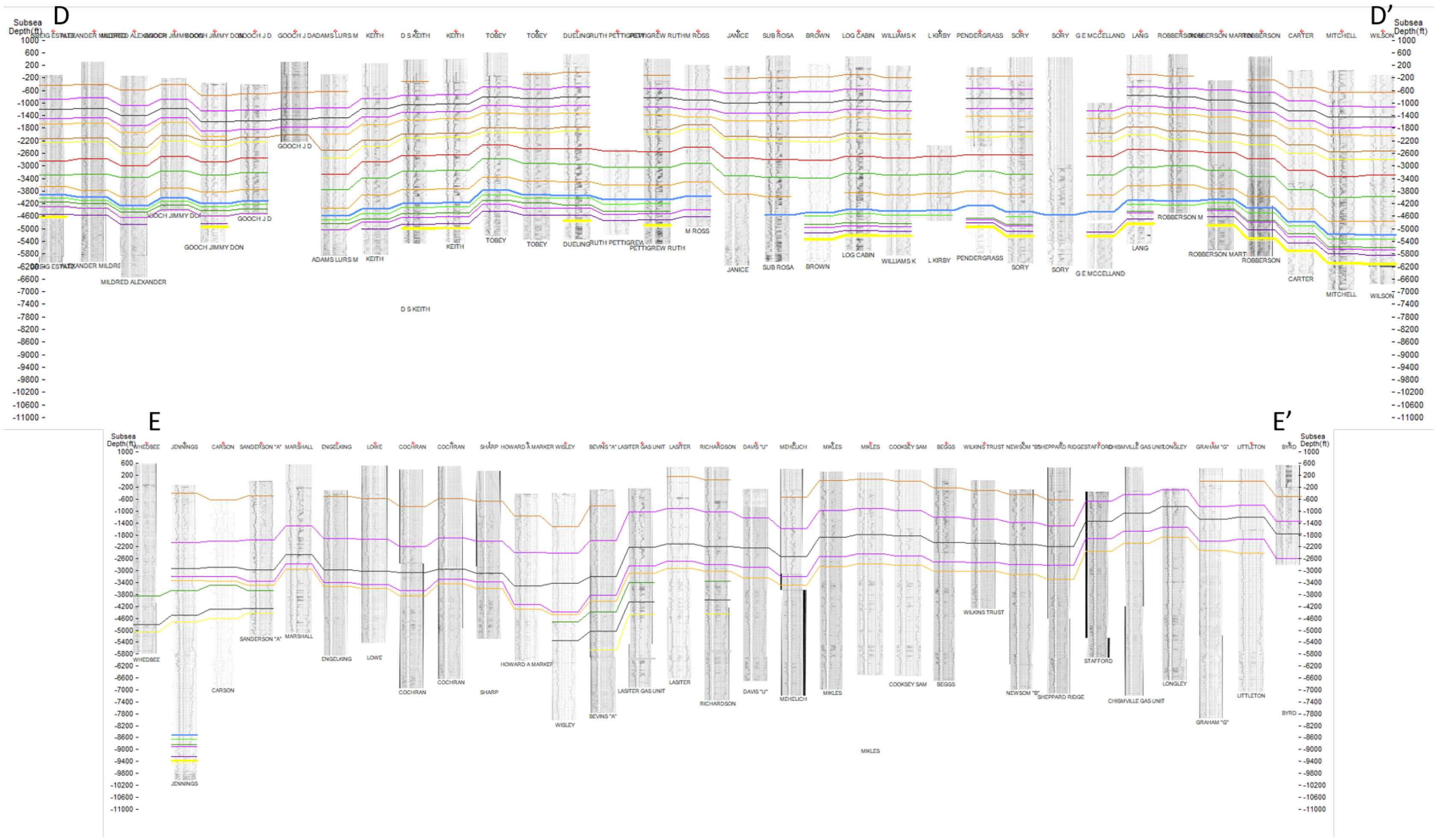


**Figure 20**: High resolution, strike oriented correlation panels D-D’ and E-E’.

### *Log Correlation*

The primary work done in this project was well log correlation. The tops of the members within the Atoka are based on the recognition of sandstone units, which are typically indicated by low gamma ray and conductivity values. These named sand-rich units are traditionally applied as informal member nomenclature. In this project, member cycles include both the sand-rich unit above and, if present, the genetically related mud-rich unit below. By including both the sand and mud-rich facies within a single "upward coarsening" unit bounded by flooding surfaces, the full interval records a depositional cycle as defined by Galloway (1989).

The process of identifying "subsurface members" started with recreating the tops picked in the W. Thomas #1-33 well within the 1988 FSGS regional stratigraphic cross section (Figure 15), and this project's cross sections A-A' and D-D'. This provided the calibration for the consistent use of stratigraphic nomenclature as the correlation work progressed. Both cross sections B – B' and C – C' were created though extrapolation from the A – A' correlations, across the basin. The cyclic, marginal marine deposits to the north on section B-B' were also calibrated to the 1988 FSGS cross section's Log Cabin #1-11 well. The underlying Kessler Member (Morrowan) was correlated as the basal stratigraphic boundary below the Atoka succession. Definition of the Kessler limestone relied on the correlation presented in Woolsey's (2007) thesis. The FSGS cross section was also utilized to further confirm the top of the Kessler. To start the identification of the deep-water Middle Atoka sands, multiple sources from a sparsely studied member group had to be used. Correlation of specific deepwater sandstones can be a challenge due to the nature of isolated sand-rich depositional systems within the Middle Atoka slope deposits. This will be discussed further in the interpretations of this thesis. Bello's (2012) thesis provided the first picks within the Middle Atoka, south of the Washburn anticline.

Bello's correlations were aided by his petrographic study of fifty thin-sections, originating from the deep marine sandstone complexes. In addition to Bello's (2012) work, Robert Liner (Pers. Comm.) helped clarify local industry standards on identification of these deep-water sands. Seismic and surface data were also used to aid in the correlation of horizons in wells without clear log motif or areas sparse of well control.

The approach to correlations of members within this project varied widely within the north-to-south regional cross sections. This was due to the length of sections made and the transition from shallow to deep marine deposits which causes a drastic changes in log motif. This transition generally occurred right along the Washburn anticline, along with its structurally complex imbricate fan. For this reason, many descriptions within this thesis will be divided into north & south of the Washburn anticline (Figure 17).

***North of the Washburn anticline***

Cyclic shallow water deposits characterize the complete Atoka succession in the northern portion of this project resulting in repeated upward coarsening/thickening log motifs that are especially predictable. In addition, there are many publications that include type logs making it relatively easy to maintain consistent stratigraphic nomenclature.

The Kessler, Lower, and Middle Atoka intervals can easily be correlated using all three of the curves – gamma ray, resistivity, and conductivity (Figure 16). Typically, the conductivity curve was the most reliable or consistant correlation tool, although it was often missing at shallow depths. In these cases, the gamma ray curve was used for interpretation.

### *South of the Washburn anticline*

Due to complex faulting, greater formation depths, limited number of published reviews, and transitional shelf to slope depositional environments, correlation work of the Atoka becomes more challenging south of the Washburn Anticline. Log motifs in this southern portion of the study area indicate substantial thicknesses of mud-rich units punctuated by local sand-rich packages. Such variable motifs do not provide the easily recognizable cycle pattern observed to the north. The correlated horizon were based on Bello (2012) with input by local industry professional, Robert Liner (Pers. Comm.).

The Lower Atoka, south of the Washburn anticline, is substantially deeper than the marginal marine to shallow marine equivalents to the north. As a result, many of the wells in that area TD above that stratigraphic interval.

### *Geoseismic Interpretation*

Two north-to-south 2D seismic sections aided in understanding the true structure of the basin. A geoseismic profile was constructed for the western most profile down R30W extending from T4N up to T9N. The profile and interpretation provide structural calibration for cross section A – A' (Figures 21 & 22). This illustration depicts the location of major faults and select formations within the Arkoma basin. The second seismic section, which runs along cross section B – B', was generously donated by CGG and was interpreted using Kingdom®. The interpretation of these seismic sections was aided by the application of surface data and formation tops picked on neighboring wells along the seismic profiles.

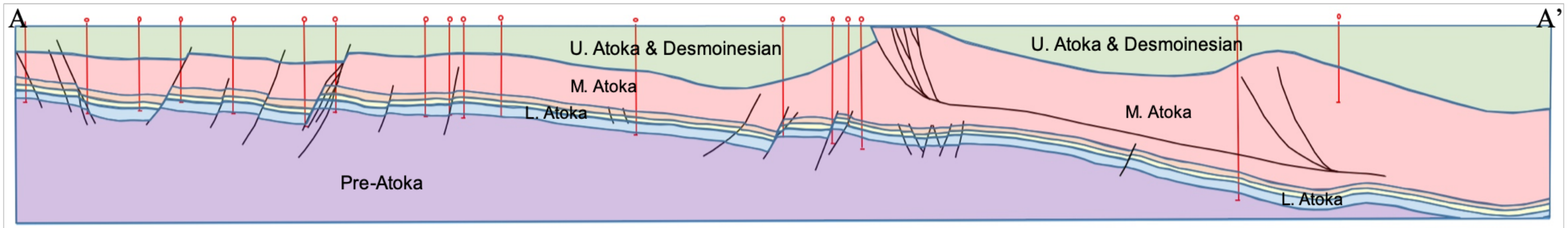


**Figure 21**: Digitized 2D seismic line running though townships T8N R30W through T5N R30W (Vertical red lines indicating wells and their depths; thick black lines indicating fault lines; blue lines indicating formation boundaries).

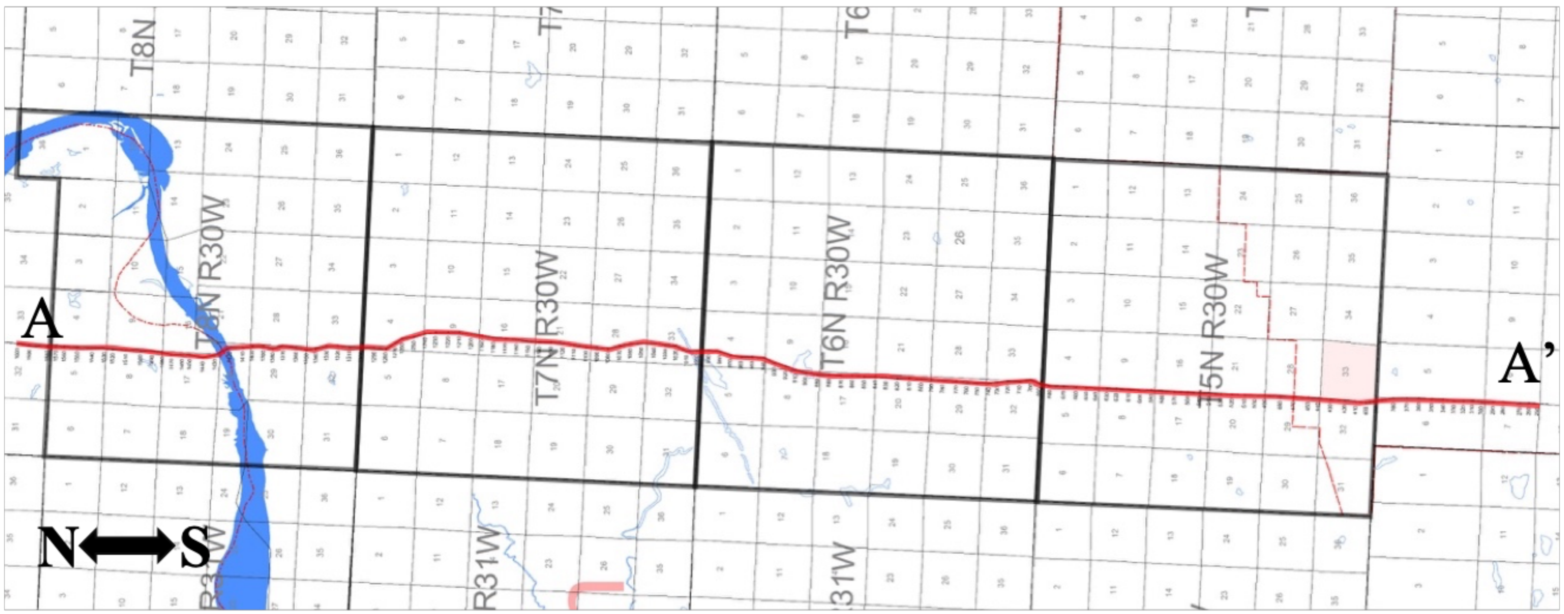


**Figure 22**: Surface location of the 2D seismic line through townships T8N R30W through T5N R30W. The entirety of this seismic line is within this project study area.

### *Deep Marine Hinge Line Migration*

The shelf-slope transition is interpreted on the three regional, dip-oriented sections. Given that, a general geographic trend of this transition is shown in map view. A diagram representing this migration through time has been produced using this shelf to slope transition interpreted for each member of the Atoka Formation. To do this, the high-resolution cross sections were used to better analyze the exact position of these transitions. Ten of the seventeen members correlated within these regional transects were chosen to be included in this diagram. All shallow water members within the Upper and Middle Atoka preserved to the north were selected as the most advantageous members to represent this migration.

## *Observations*

The three dip-oriented sections, A-A', B-B', and C-C', illustrate the regional correlations within the complete Atoka succession with the exception of areas where the upper Atoka is at the surface and not logged. These sections illustrate the marginal marine/shelf transition to coeval slope and basin depositional facies.

### *North-to-south Regional Transect A-A'*

The first regional transect, cross section A-A' seen in figures 23 & 24, is the longest transect at 52.75 miles. The Edwards well at the southern (basinward) end is 18.59 miles southeast of the nearest well, which is reason for the substantial length of this section compared to the other four transects. Accounting for the first 8 wells, the section extends from T9N to T3N and R30W to R29W. The Edwards well is located within T2N R32W.

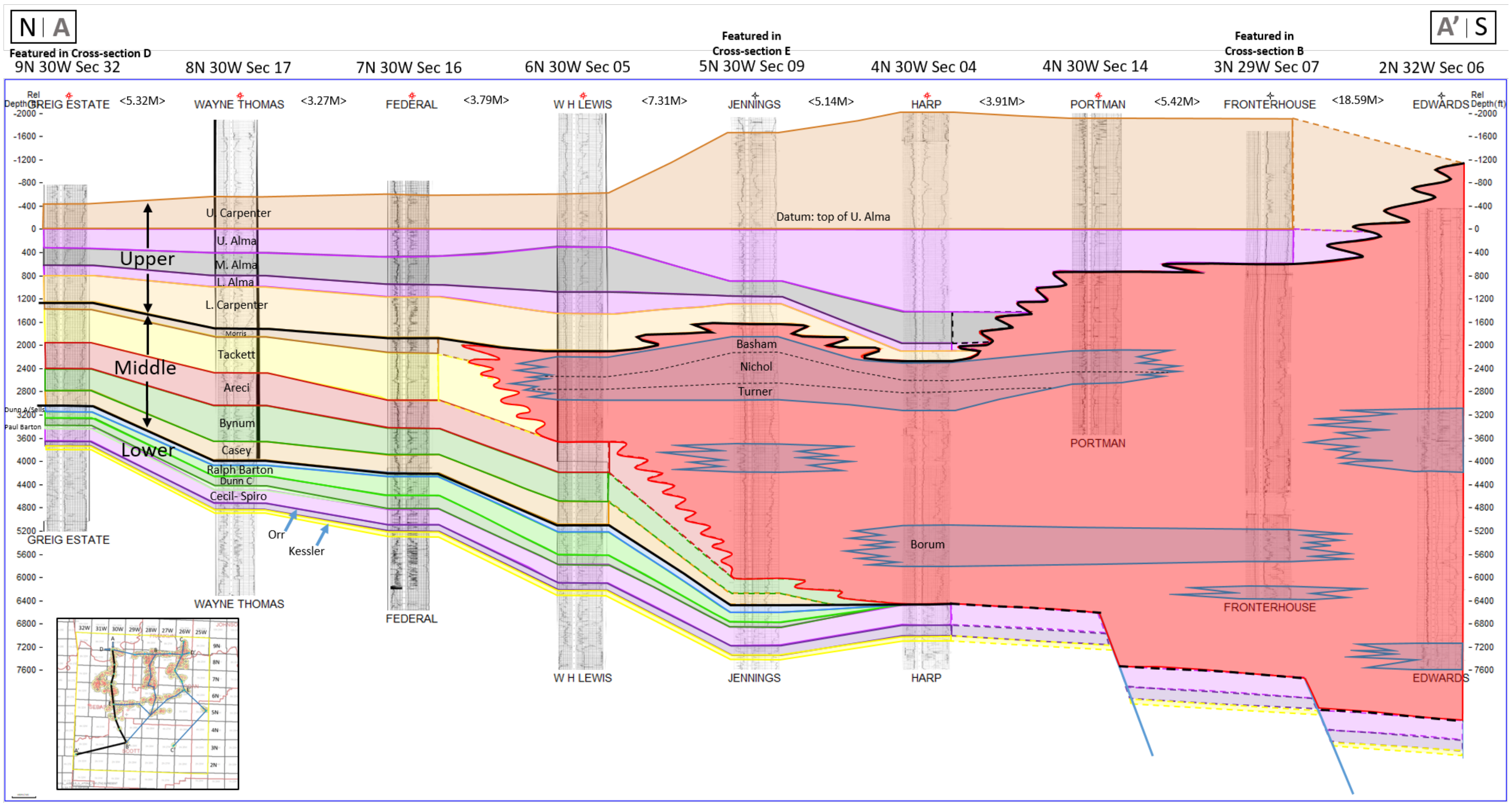


**Figure 23**: Stratigraphic cross section A-A'. Datum referenced to the top of the Upper Alma. Includes shallow marine Atoka members, deep marine Middle Atoka shales (red), and deep marine sandstone packages (blue). Faults are in blue with an apparent offset.

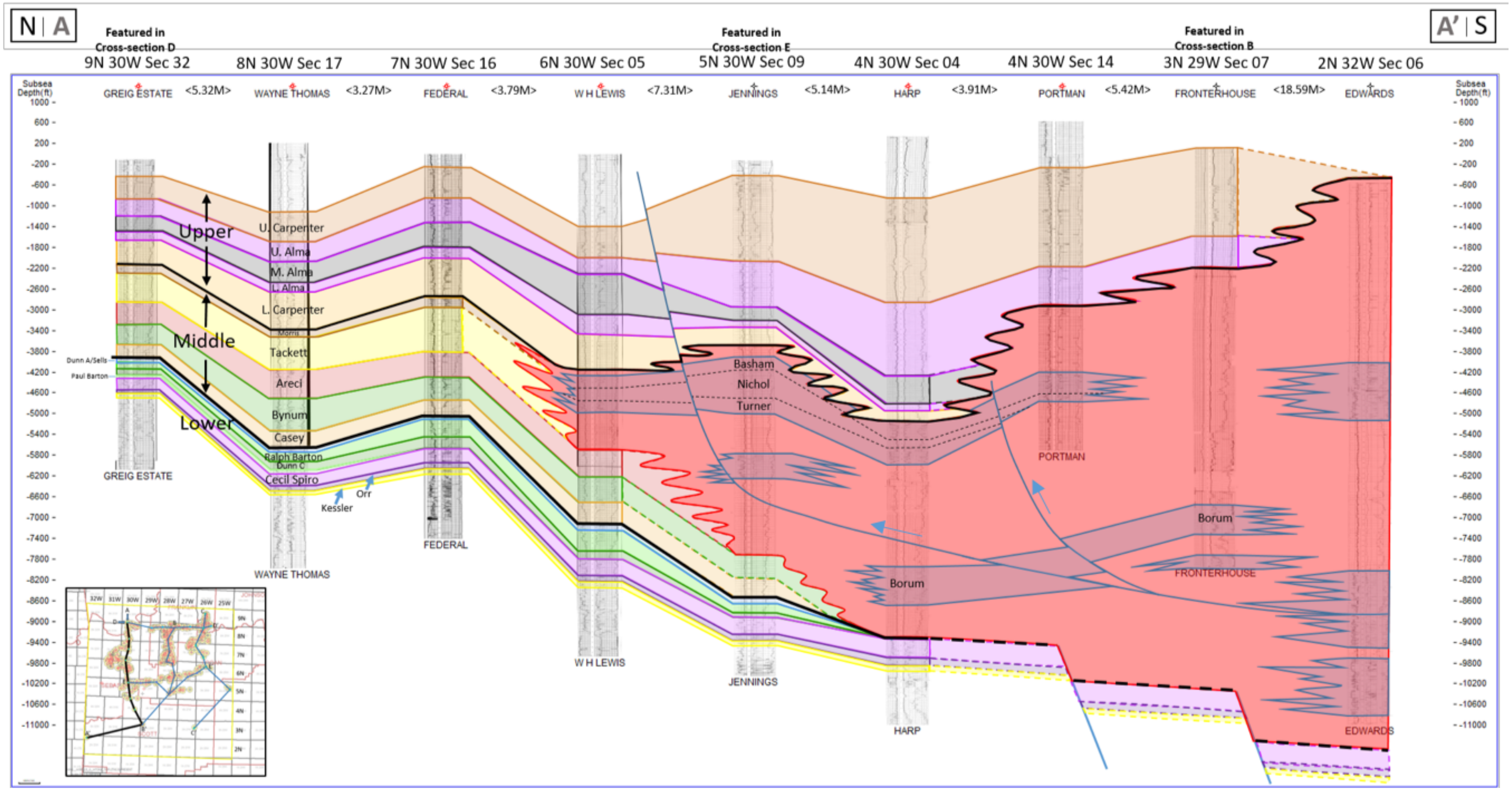


**Figure 24**: Structural cross section A-A'. Includes shallow marine Atoka members, deep marine Middle Atoka shales (red), and deep marine sandstone packages (blue). Faults are in blue with an apparent offset.

The A-A' cross section is the only north-to-south cross section that includes all 6 Lower Atoka members. The Paul Barton pinches out just south of the Wayne Thomas well and does not extend into the B-B' or C-C' cross sections. The Lower Atoka as a whole thickens from approximately 700 feet at the Greg Estate well to the north, to a maximum thickness of 1200 feet at the W H Lewis well. The Lower Atoka thins from that point south until the Dunn A, Ralph Barton, and the Dunn C down lap and pinch out just beyond the Jennings well to the south. This reflects the run out of sediment supply as these depositional cycles prograded across the Northern Arkansas Structural Platform (NASP) prior to its evolution into the Arkoma Foreland Basin (Woolsey, 2007, McGilvery, Manger, and Zachry, 2016, Denham 2018). The two underlying members, the Cecil Spiro and Orr continue farther south across the NASP beyond the limits of well control in this study. Both of these observations are based on the sandstone packages recorded in the Harp well. Down-to-the-basin extensional faults are shown schematically on both version of the A-A' section to reflect the fault-controlled subsidence and thickening within the Middle Atoka succession.

The shallow marine Middle Atoka (Casey through Morris) is a landward stepping, retrogradational set of stacked depositional episodes. In the northernmost well, the Greig Estate, the entire division is approximately 1800 feet thick. Its maximum thickness within this transect, is approximately 2300 feet thick within the Federal well. Therefore, the division is thickening to the south. The two lowermost members of the Middle Atoka, the Casey and Bynum downlap onto the top of the Lower Atoka. The Bynum not only downlaps but is simultaneously shaling out. These occur just south of the Jennings well suggesting continuation of the sediment supply limited distribution of these lower Middle Atoka cycles like the underlying Lower Atoka. The overlying Areci "shales out" between the W H Lewis and Jennings wells and the Morris (uppermost Middle Atoka member) and Tackett "shale-out" between the Federal and W H Lewis wells. This "shale out" reflects the transition to mud dominated outer shelf and upper slope facies that marks the hinge line transition. This is illustrated by the gradational transition to the red shaded area that encompasses the slope and basin deposits (Figure 22). The shelf slope transition occurs at its most landward position within the Morris, between the Federal and W H Lewis wells. This defines the maximum flood of relative sea level reflecting the northern limit of maximum flexure during foreland basin evolution.

The base of the slope/basin shales, shown as the red shaded area, reflects the depositional transition from shallow marine Lower and lower Middle Atoka facies into upward deepening mud-rich slope and basin facies. As discussed, the deep marine shales of the Middle Atoka have a max flood between the Federal and W H Lewis wells equivalent to the Morris, illustrated as the northern limit of the red shaded area on the cross section (Figure 23). The top of these deep marine shales is equivalent to the base of the Upper Atoka, which is defined as the base of the Lower Carpenter unit. Analyzing and describing the desultory deep marine Middle Atoka sandstone packages is more complex due to the sporadic nature of the gravity flows that deposited them and the discontinuity between transects. There are a number of sand-rich packages within the slope/basin facies of the Middle Atoka. These have been interpreted by previous workers as submarine fan complexes (Bello, 2012). The upper three of the four named deep marine sandstone units observed in this project are interpreted as one amalgamated unit with three divisions; the Basham, Nichol, and Turner. In cross section A-A', this package is present within the W H Lewis well in the north all the way to the Portman well in the south. The lowermost designated sandstone package, the Borum, extends from the Harp well in the south to the Fronterhouse well in the north. Unlike the other three sandstone units, the Borum is interpreted as being an isolated sand-rich unit. As seen in the structural cross section A-A', there are multiple imbricate thrust faults that offset many of these deep marine sandstone packages that occur within the deep marine Middle Atoka (Figure 24). The northern thrust surfaces between the W H Lewis and Jennings wells is based on seismic and surface data. The southern thrust dies out before offsetting the Upper Atoka based on seismic data alone. These imbricate faults are believed to "splinter" as they approach the surface and have been simplified.

According to previous investigations, the Upper Atoka (Lower Carpenter through Upper Carpenter) reflects a period of less accommodation space and a high sedimentation rate relative to the Middle Atoka. The overthickened Upper Atoka within this regional transect reflects this. Note the rapid basinward shift of the mud-rich, slope facies toward the southern end of the profile. The Upper Atoka is dominated by a stacked set of complete progradational depositional episodes. In the northernmost well, the Greig Estate, the entire division is approximately 1700 feet thick. Its maximum thickness within this transect is approximately 2700 feet thick observed in the W H Lewis well. In contrast to the other two north-to-south cross sections, the Lower Carpenter, Lower Alma, and Middle Alma all transition to mud-rich slope facies within a 4-mile span between the Harp and Portman wells. This is due to the apparent axis of rotation of the three hinge lines originating west of cross section A-A' that will be discussed in a later section. The shallow marine facies of the two uppermost members of the Upper Atoka, (Upper Alma and Upper Carpenter) either terminate or continue basinward past the Edwards well (the south end of cross section A-A') and are designated by dashed formation lines. These formations are too shallow to appear in well control, but surface data indicates that there should be no Upper Atoka in the area.

### *North-to-south Regional Transect B-B'*

The second north-to-south regional transect, cross section B-B' seen in figures 25 & 26, is approximately 37.18 miles in length. Because this transect only possess five wells south of the deep marine max flood hinge line, compared to cross section A-A's six, this section appears to be shorter. This transect shares the Fronterhouse well with cross section A-A' at its southern end due to limited well control to the south and to insure the integrity of the correlations between these two sections. This cross section spans from T8N to T3N and R29W to R28W.

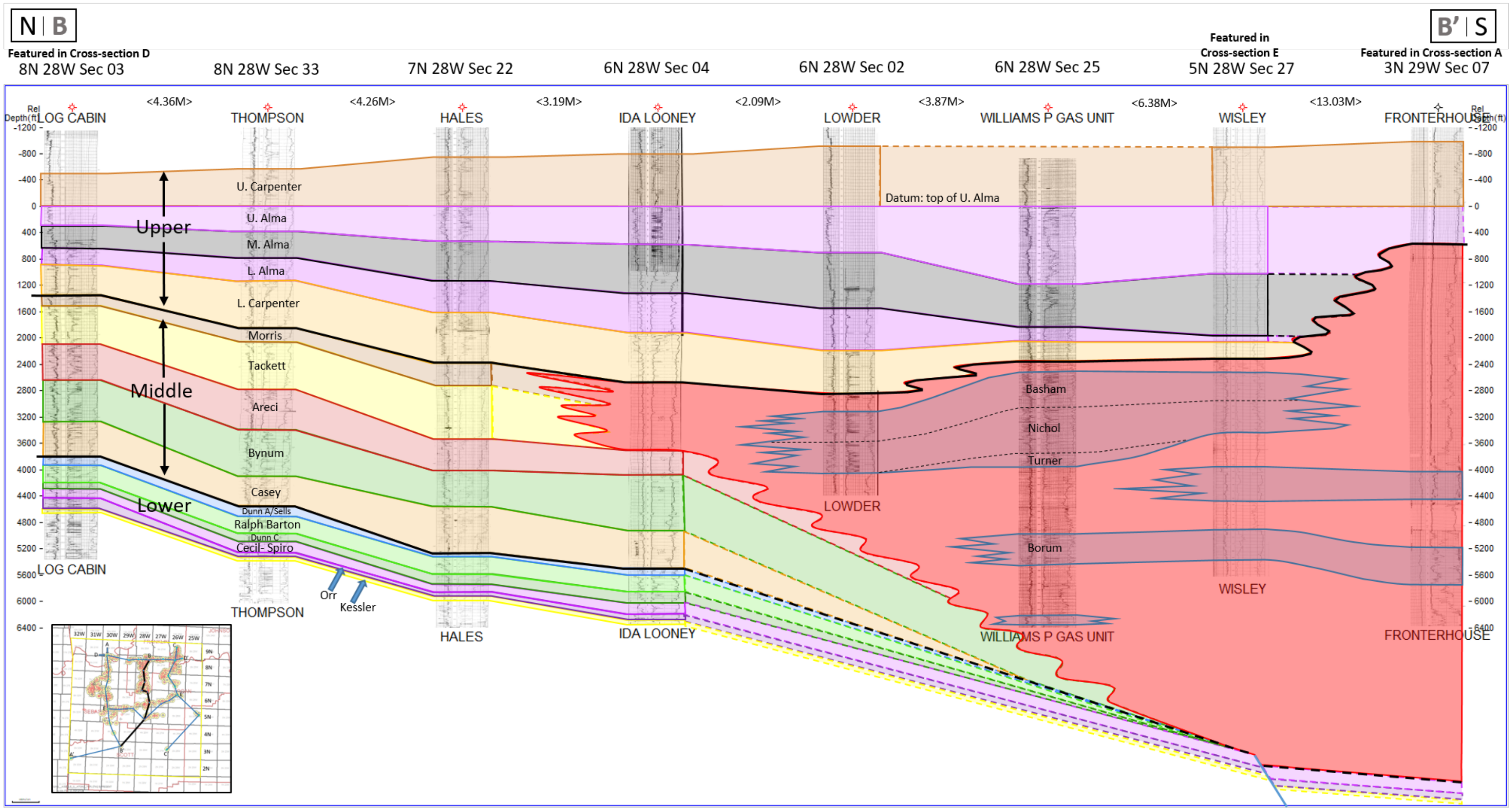


**Figure 25**: Stratigraphic cross section B-B'. Datum referenced to the top of the Upper Alma. Includes shallow marine Atoka members, deep marine Middle Atoka shales (red), and deep marine sandstone packages (blue). Faults are in blue with an apparent offset.

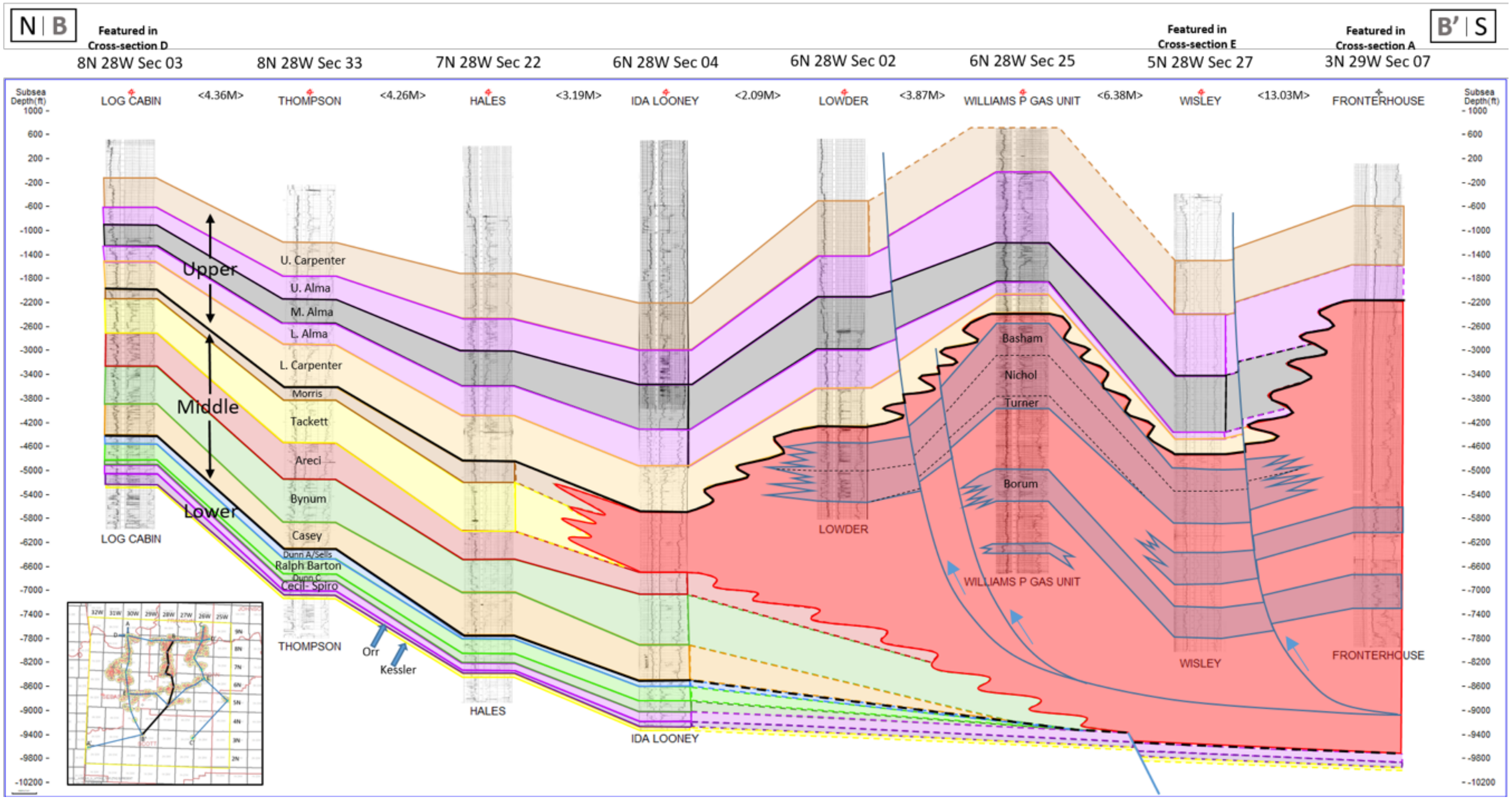


**Figure 26**: Structural cross section B-B'. Includes shallow marine Atoka members, deep marine Middle Atoka shales (red), and deep marine sandstone packages (blue). Faults are in blue with an apparent offset.

This cross section includes all Lower Atoka members, excluding the Paul Barton. In contrast to cross section A-A', the Lower Atoka thickness is consistent across this transect. Each well log includes between 700 and 800 feet of Lower Atoka. All three north-to-south transects illustrate the basinward thinning and downlap of the Dunn A, Ralph Barton, and the Dunn C reflecting distal run out of sediment supply across the Northern Arkansas Structural Platform prior to foreland basin development. This is represented by dashed lines in B-B' and C-C' due to a lack of well control at depth. In this cross section, this termination occurs just south of the Williams P Gas Unit well. The two underlying members, the Cecil Spiro and Orr continue farther south across the platform beyond the limits of this study. The extension of the Lower Atoka members was based on the sandstone packages defined in the Harp well, within cross section A-A'.

Like the other north-to-south transects, the shallow marine Middle Atoka records a landward stepping, retrogradational set of stacked depositional episodes. The shallow marine Middle Atoka is substantially thicker within this transect relative to A-A'. Additionally, there is an apparent thickening trend toward the south. At the northern end of the cross section, the entire division is approximately 2400 feet thick, and is approximately 2900 feet thick at its maximum within the Hales well. The Casey and lower Bynum downlap to the south, just south or near the Williams P Gas Unit well. The upward transition to slope/basin facies, marking the onset of foreland basin subsidence, begins in the upper Bynum (transparent red shading on Figure 25). The Areci shales out at the shelf to basin transition between the Lowder and Williams P Gas Unit well. The northern limit of the mud-rich, slope/basin facies occurs within the Tackett and Morris intervals, between the Hales and Ida Looney wells. This is consistent with that observed on section A-A' and reflects the northern limit of the maximum flood/maximum flexure, establishing the timing within the upper Morris.

The three amalgamated Middle Atoka deepwater sands extend from north of the Lowder well to just south of the Wisley well. The Turner, Nichol, and Basham sands are interpreted to be included within this gross, sand-rich interval. The isolated Borum runs all the way north of the Williams P Gas unit past the south end of the cross section. There is a subtle landward stepping progression of the sand-rich deepwater facies. This may reflect the landward stepping progression in hinge lines that will be discussed in a later section. As seen in the structural cross section B-B', there is an imbricate thrust fault that originates within the deep marine Middle Atoka (Figure 26). According to surface and seismic data, two of these fault systems come to the surface within this transect. One between the Lowder and Williams P Gas Unit wells and the other between the Wisley and Fronterhouse wells.

As seen in cross section A-A', the Upper Atoka (Lower Carpenter through Upper Carpenter) records the turn around and basinward, progradational cycles in the marginal and shallow marine units. The Upper Atoka at the northern end of the section is approximately 1850 feet thick and thickens to 3700 feet at the Ida Looney well. All five members expand to contribute to this growth. The lower three members of the Upper Atoka, the Lower Carpenter, Lower Alma, and the Middle Alma all shale-out and transition into deepwater shales between the Wisley and Fronterhouse wells. This defines a substantial basinward shift in shoreline position from the Top Morris to Lower Carpenter, a distance of approximately 15 miles. The two uppermost members of the Upper Atoka (Upper Alma and the Upper Carpenter) terminate past the farthest southern well within the B-B' transect. This reflects the final filling of the Arkoma

Basin in this area by marginal and shallow marine deposits, as suggested by the paleogeographic maps illustrated in figures 13 and 14.

***North-to-south Regional Transect C-C'***

The easternmost north-to-south regional transect, cross section C-C', is illustrated on figures 27 & 28. It is 46.49 miles in length and spans from T9N to T3N and R27W to R25W. This cross section extends the farthest north compared to the other cross sections constructed within this project.

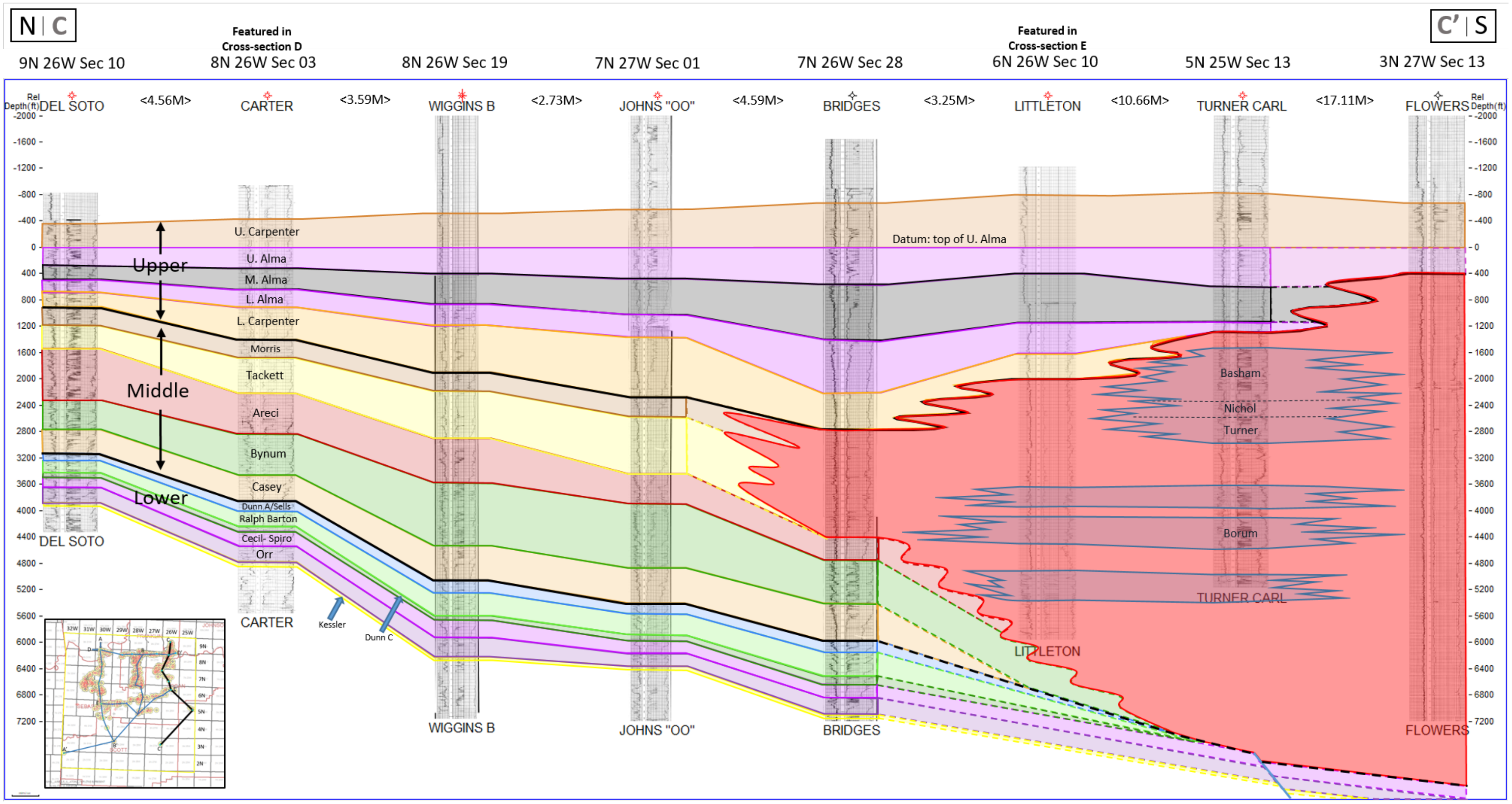


**Figure 27**: Stratigraphic cross section C-C'. Datum referenced to the top of the Upper Alma. Includes shallow marine Atoka members, deep marine Middle Atoka shales (red), and deep marine sandstone packages (blue). Faults are in blue with an apparent offset.

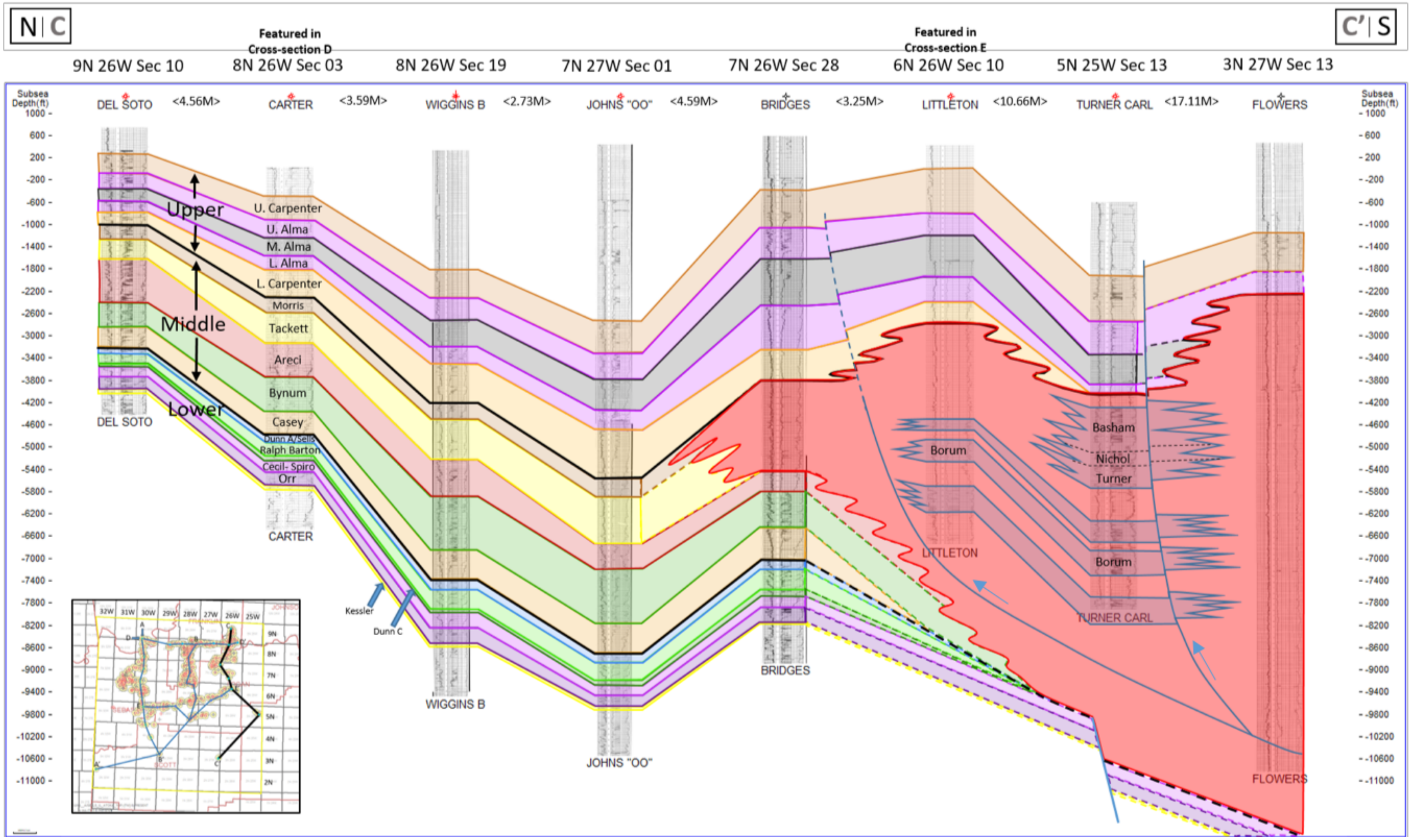


**Figure 28**: Structural cross section C-C'. Includes shallow marine Atoka members, deep marine Middle Atoka shales (red), and deep marine sandstone packages (blue). Faults are in blue with an apparent offset.

Like cross section B-B', this transect includes all Lower Atoka members, excluding the Paul Barton. The Lower Atoka within this cross section thickens towards the south, similar to the division within A-A'. In the northernmost well, the Del Soto, the entire Lower Atoka is approximately 700 feet thick, and thickens to 1100 feet at the Bridges well toward the south. The three uppermost members of the Lower Atoka, the Dunn A, Ralph Barton, and the Dunn C, run out and downlap south of the Littleton well as observed on A-A' and B-B'. The Cecil Spiro and Orr continue farther south down into the basin, as they're offset by syndepositional normal faults. Like section B-B', these extrapolations to the south were based on the sandstone packages found in the Harp well, within cross section A-A'.

The shallow marine to slope/basin transition within the lower Middle Atoka (Casey through Lower Tackett) records a landward stepping, retrogradational pattern. This reflects a northern migration of basinward flexure of the previous Northern Arkansas Structural Platform as it evolved into the Arkoma foreland basin. Another commonality between all three transects is a general thickening of the shallow water Middle Atoka towards the southern end of the cross sections. The northernmost well, the Del Soto, contains approximately 2200 feet of shallow marine Middle Atoka. The Johns "OO" is the southernmost well that records a full section of shallow marine Middle Atoka, which includes approximately 3200 feet of Middle Atoka strata. The Bridges well farther to the south includes the first appearance of deep marine deposition. This deep marine transition begins at the base of the Tackett and extends to the top of the Morris.

The mud-rich slope/basin facies are illustrated by the red shading on figures 27 and 28. The gradational contact is defined by the "Shazam" line as a boundary, which is the red boundary that reflects the transition to deep marine deposition. The lower boundary of this complex is along the depositional environment transition boundary of the shallow marine Middle

Atoka in the north and along the top of the Cecil Spiro in the south. This boundary along the Cecil Spiro includes the southward dipping normal faults that are carried across all three north-to-south regional transects. The lowermost Middle Atoka unit, the Casey, downlaps onto the Lower Atoka south of the Littleton well. The shelf/basin transition within the lower Middle Atoka occurs in a landward stepping progression from the Bynum, Areci, and lower Tackett from just south of the Littleton well northward past the Bridges well. The maximum northern extent of mud-rich, slope/basin facies occurs within the Tackett and Morris units between the Bridges and Johns "OO" wells. Corresponding to the other two north-to-south transects, the Morris hinge line regresses the farthest north making it the location of max flood within the Atoka Formation.

The upper boundary of the deep marine shale complex is along the lower boundary of the Upper Atoka. The Upper Atoka is a progradational set of stacked depositional episodes. This is best observed in the Del Soto and Johns "OO", and Bridges wells. The northernmost well, the Del Soto, includes approximately 1250 feet of Upper Atoka strata. The well with the largest section of Upper Atoka strata, the Bridges well, consists of approximately 3400 feet of the division. Similar to cross section B-B', all five members of the Upper Atoka expanded to contribute to this stratigraphic thickening. The shelf to basin transition occurs in the lowermost member, the Lower Carpenter, just north of the Turner Carl well. This shelf to basin transition continues to step basinward in the Lower Alma and Middle Alma between the Turner Carl and Flowers wells. The overlying Upper Alma and Upper Carpenter continue past the south end of cross section C-C' and their depositional transition had to be inferred on the deep marine hinge line migration diagram.

Sand-rich Middle Atoka deepwater turbidite deposits are defined by the amalgamated Basham, Nichol, and Turner sand complex found within the Turner Carl well. In this C-C' illustration, this complex doesn't appear to be laterally extensive, although it occurs between the Littleton and Flowers wells that are 10.66 and 17.11 miles away respectively. This could leave the possibility that this complex is as broad as it is in the other two north-to-south transects suggesting a submarine fan, lobe complex that is easily 15miles wide (N-S) and 25+miles long (E-W). The Borum as well as other lower Middle Atoka deepwater sands extends from just north of the Littleton well to south of the Turner Carl Well.

Within the structural cross section C-C' (Figure 28), there are two imbricate thrust faults that originate from within the deep marine Middle Atoka that arc towards the surface. According to the surface geologic map, the southernmost fault system is mapped at the surface between the Turner Carl and Flowers wells. The northern thrust is assumed to offset Upper Atoka, Lower Carpenter through the Upper Alma, but never reaches the surface. This occurs between the Bridges and Littleton wells.

***East-to-west Regional Transect D-D'***

The northernmost east-to-west regional transect, cross section D-D' is 27.37 miles in length (Figures 29 and 30). This transect runs along the southern edge of 9N and stretches from R30W to R25W. It is constructed as a regional strike section that ties all three regional dip transects. This northern strike section is restricted to the cyclic marginal to shallow marine and shelf deposits throughout the complete Atoka succession. As a result, of this homogeneous geologic section, the D-D' cross section appears comparatively elementary. Note the cyclic upward coarsening/thickening, funnel shaped log motifs throughout the complete Atoka succession.

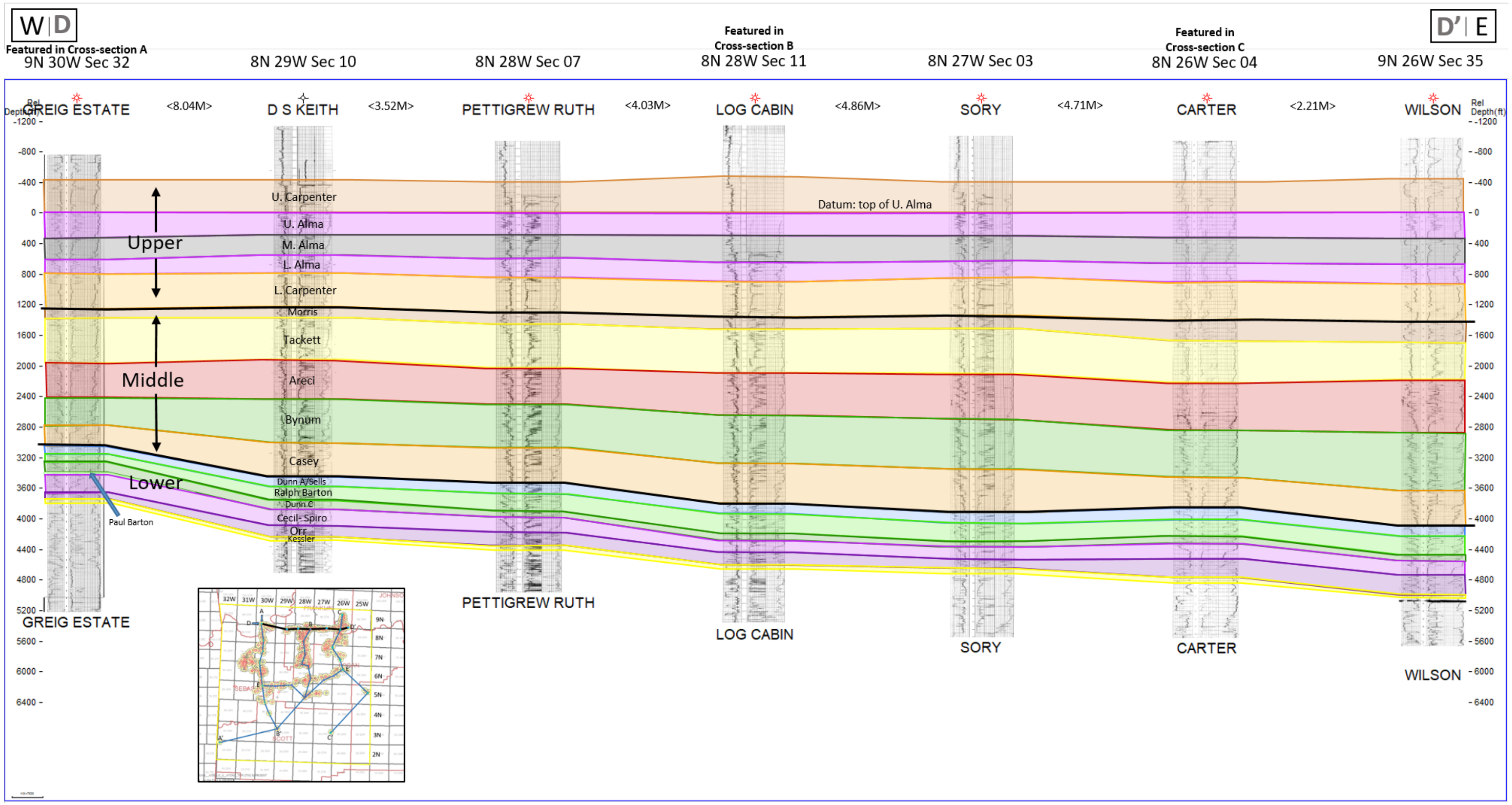


**Figure 29**: Stratigraphic cross section D-D'. Datum referenced to the top of the Upper Alma. Includes shallow marine Atoka members.

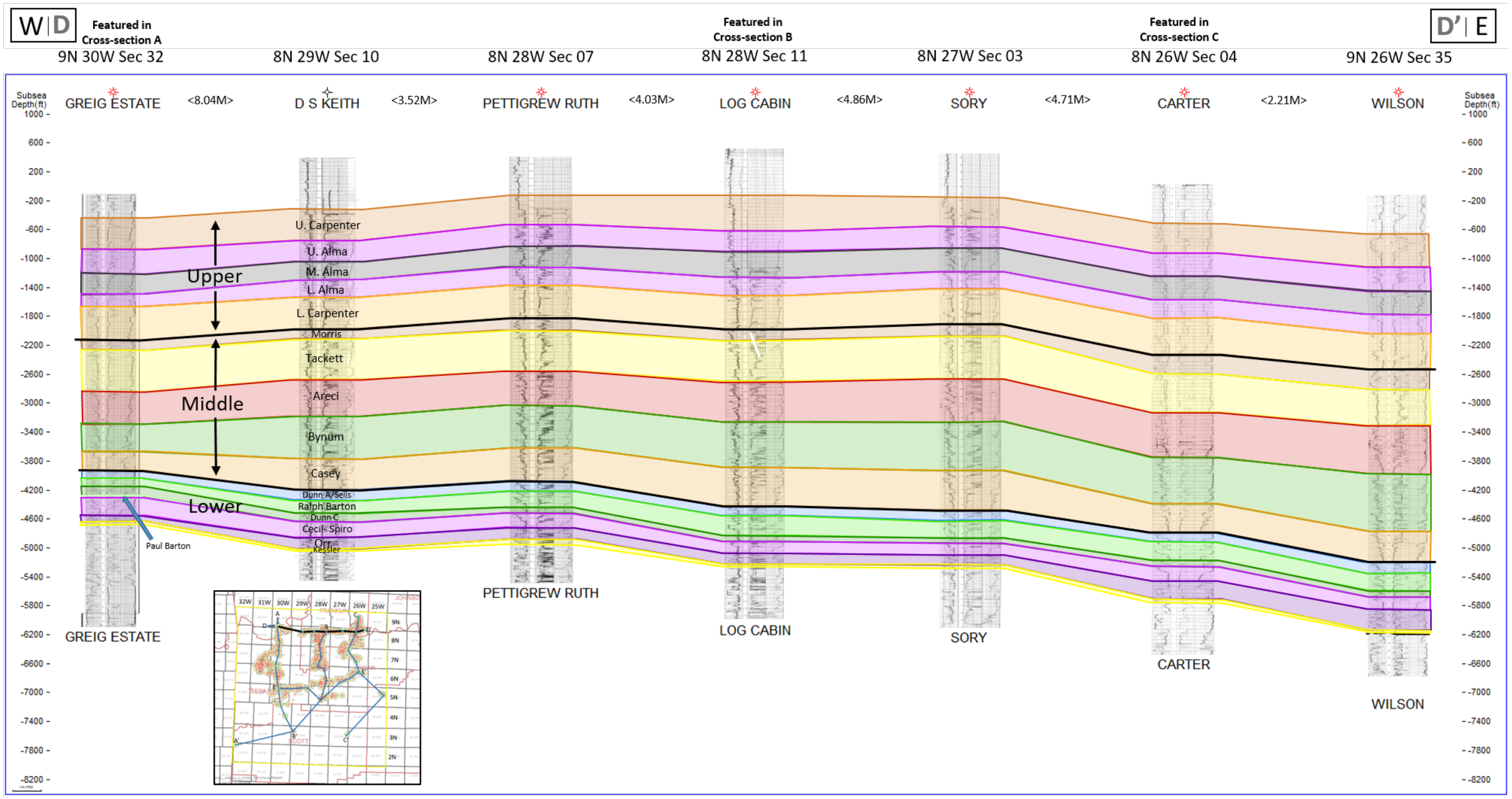


**Figure 30**: Structural cross section D-D'. Includes shallow marine Atoka members.

The Lower Atoka division thickens towards the eastern end of the cross section. Within the Greig Estate well in the west, the division is just 700 feet thick. The thickness expands to 900 feet within the easternmost Wilson well. Much of this thickening occurred within the Orr member, which expands from approximately 100 to 300 feet. Similar to A-A' and unlike the remaining cross sections, this transect includes a small portion of the Paul Barton which pinches out west of the D S Keith well. Interval thickness maps of the complete Lower Atoka and the individual "members" contained therein are presented in Woolsey (2007) and Denham (2018).

Much like the underlying Lower Atoka, the shallow marine Middle Atoka thickness increases towards the eastern end of the transect. Within the Greig Estate well, this measurement is approximately 1800 feet compared to 2700 feet within the Wilson. A majority of the members comprising this division of the Atoka are contributing to this expanded thickness. One exception is the Bynum which expands from 350 to 700 feet from east to west.

In the case of the Upper Atoka within transect D-D', there is very little variation. The maximum variation in thickness of the Upper Atoka is approximately 150 feet. This variation shows that the Upper Atoka is also thickening towards the east.

***East-to-west Regional Transect E-E'***

The southernmost east-to-west regional transect, cross section E-E' seen in figure 31, is 30 miles in length and runs parallel to and along the southern edge of the Washburn anticline. This transect spans from T6N to T5N and R30W to R26W. Since this strike-oriented transect is positioned along the deep marine hinge line axes, deepwater shales are pervasive across the length of the section. The shelf to basin transition occurs north of this cross section in a majority of the Middle Atoka units due to its southerly position relative to section D-D' and the regional maximum flood/maximum flexure illustrated on A-A', B-B', and C-C'. This is also the only transect that does not include a constructed structural cross section illustration due to the exceedingly complex and pervasive thrust faulting that occurs through and perpendicular to this cross section. Having said this, the wells were selected to minimize the effects of apparent stratigraphic thickening due to thrust repeats.

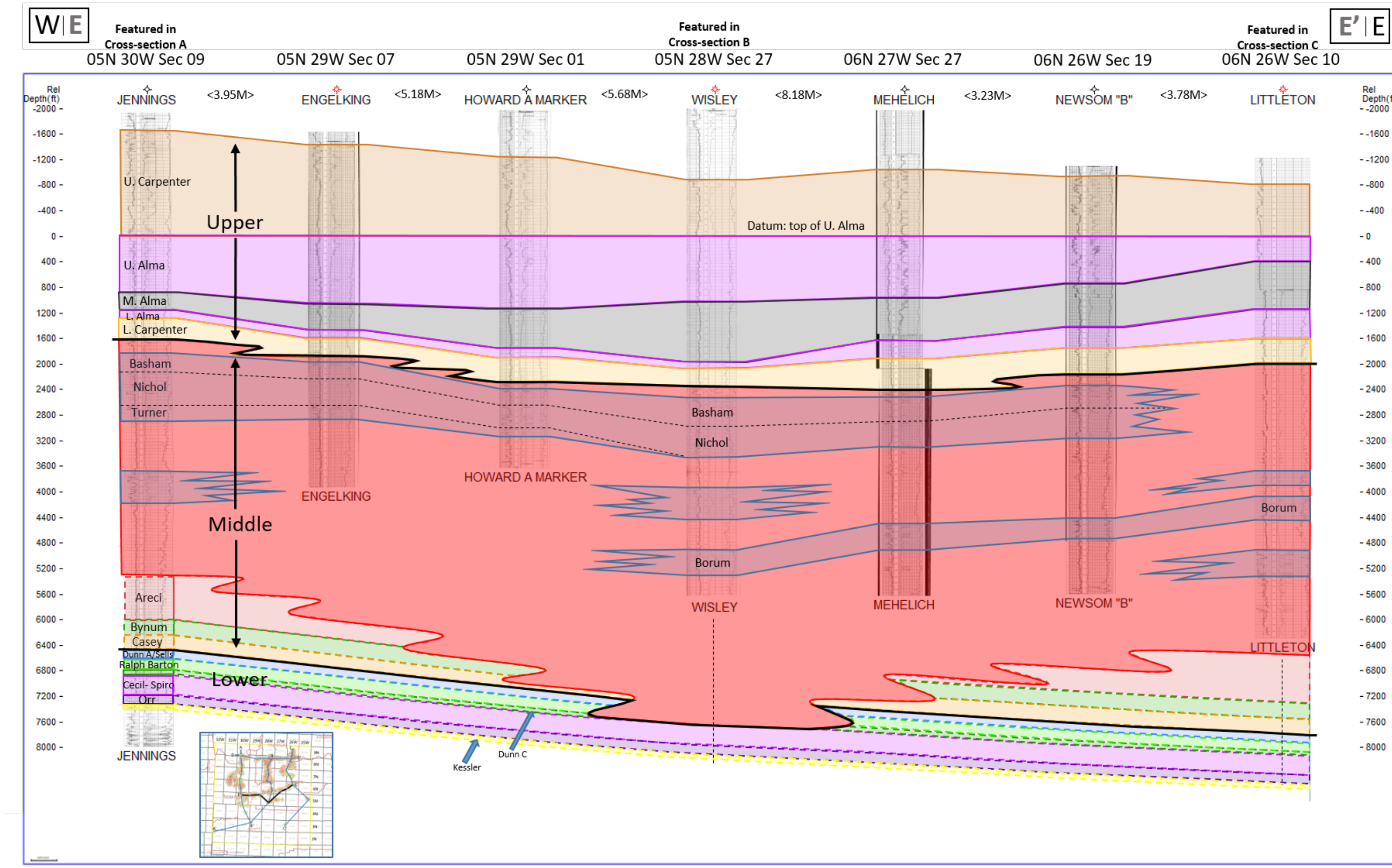


**Figure 31**: Stratigraphic cross section E-E'. Datum referenced to the top of the Upper Alma. Includes shallow marine Atoka members, deep marine Middle Atoka shales (red), and deep marine sandstone packages (blue).

The Lower Atoka is projected to the east of the Jennings well due to the lack of wells along the transect path drilled deep enough to encounter the Lower Atoka succession. The thickness of the Lower Atoka interval in the Jennings well is approximately 850 feet. All members of the Lower Atoka used in this project are present within this well, excluding the Paul Barton. The three uppermost members of the Lower Atoka, the Dunn A, Ralph Barton, and Dunn C, are interpreted to have downlapped by this southern location as shown on A-A' and B-B'.

Much like the Lower Atoka, shallow marine facies are only interpreted in the lower Middle Atoka, Casey, Bynum, and Areci members due to the southern (basinward) position and depth to target of these units. They only occur in the Jennings well at the western end of the section. Within this well, the Casey, Bynum, and Areci combine for a total thickness of approximately 1150 feet. With the Wisley well as the focal point for the depositional environment transition, these three members shale-out as they approach this well from both ends of the transect. Cross section A-A' includes the Jennings well and illustrates this relationship in a dip-oriented, shelf to basin transect.

All five members of the Upper Atoka recognized across this transect. The division thins slightly toward the east, decreasing from 3200 feet in the Jennings well to 2800 feet within the Littleton. The Upper Carpenter and Upper Alma contribute a majority of this thinning. The Lower Carpenter, Lower Alma, and Middle Alma contrarily thicken eastward. The shelf to basin transition occurs within the lowermost part of the Lower Carpenter within this strike section. The Upper Atoka in this section, similar to that observed in the other section, reflects the final phase of basin filling by marginal to shallow marine units.

A majority of transect E-E’ is comprised of a thick succession of slope/basin shales within locally developed deep marine sand complexes such as channel levees, crevasse splays, and submarine fan complexes. The total thickness of this complex of deep marine deposition is approximately 3700 feet thick within the Jennings well. This complex is at its max depth below the aforementioned Wisley well. The upper three amalgamated deep marine sandstone observed in this project, the Basham, Nichol, and Turner, are all present in the Jennings well near the top of the complex. The Turner extends just east of the Howard A Marker well and the other two extend past the Newsom “B” well. The isolated Borum, located close to the base of the deep-water shales, extends west of the Wisley and east of the opposite end of the transect. There are approximately four other unnamed, isolated sand complexes present throughout the deep marine deposition.

### *Interpretations*

The complete Atoka stratigraphic succession can be divided into three tectonostratigraphic units (McGilvery, Manger, and Zachry,2016). These include 1) the pre-Arkoma basin platform succession, 2) early Arkoma foreland basin fill, and 3) late Arkoma foreland basin fill. Lower Atoka (Orr through Dunn “A”/Sells) deposition took place across the stable Northern Arkansas Structural Platform prior to the Arkoma Basin tectonics. The observed stratigraphic cyclicity reflects the dominance of glacioeustatic sea-level change with slight periods of tectonic subsidence (Woolsey, 2007; Denham, 2018). The Middle Atoka (Casey through Morris) record early foreland basin fill characterized by rapid subsidence and sedimentation rates and the Upper Atoka (Lower Carpenter through Upper Carpenter) record late stage foreland basin fill characterized by diminished subsidence rates with sustain high sedimentation rates (McGilvery, Manger, and Zachry, 2016). All three of these divisions are defined by their unique characteristics resulting distinct tectonostratigraphic divisions: the Lower Atoka defined by eustatic sea-level cycles, the Middle Atoka cycles dominated by subsidence, and the Upper Atoka cycles dominated by sediment supply. The following interpretations relate to this geologic context and observations made on the regional transects constructed in this study.

***Lower Atoka Shallow Marine Deposition***

As previously observed, the Lower Atoka slightly thickens towards the south (700 to 1200 feet) in all three north-to-south transects and towards the east (800 to 1400 feet) within cross section D-D'. This indicated the possibility of early onset tilting of the "stable" platform, caused by the north to northwest convergence of Arkoma Basin tectonics.

Within the Lower Atoka, the southern limit of the Dunn A, Ralph Barton, and Dunn C is interpreted as a downlap and pinch-out across the Northern Arkansas Structure Platform prior to reaching the paleo shelf edge (Figures 23, 25, and 27). This is attributed to a limited sediment supply. The depositional cycles observed in the Lower Atoka are the result of rapid and extensive north-to-south eustatic shoreline shifts, atop a shallow pre-Arkoma Basin low relief (<1 degree) platform. Geographic variation of the updip pinchout of these cycles also reflect low relief, limited sediment supply, and/or bypass (Denham, 2018). As previously mentioned, the uppermost three members of this division, observed on cross section A-A' terminate north of the Harp well while the remaining Cecil Spiro and Orr continue farther south (basinward) across the Northern Arkansas Structural Platform and likely downlap on the platform beyond the limit of this project area.

*Middle Atoka Shallow Marine Deposition*

Similar to the Lower Atoka, the shallow marine Middle Atokan deposits thicken to the southern and eastern ends of this project's study area, by approximately 500 to 1000 feet and 600 to 900 feet (respectively). This indicates a higher rate of tectonic subsidence and associated accommodation space as the Northern Arkansas Structural Platform flexed and collapsed from south to north in response to the north to northwest convergence of the Laurasian and Gondwanan continental collision (Houseknecht and Kacena, 1983; McGilvery, Manger, and Zachry, 2016). The tectonics of the early basin fill resulted in basinward (south directed) thickening of both shallow and deepwater facies of the Middle Atoka. In addition to this stratigraphic thickening, the entire division of the Middle Atoka from the Casey through the Morris is interpreted as one retrogradational stack of cyclic depositional episodes (Figures 23, 25, and 27). At the top of the Middle Atoka, within the Morris, this trend reverses at the maximum flood/maximum flexure turnaround. This reflects slowing tectonic subsidence and a proportional increase in the influence of sediment supply at the transition to the upper division of the formation.

*Upper Atoka Shallow Marine Deposition*

In contrast to the Middle Atoka, the entire Upper Atoka is interpreted as one, very rapid, basinward stepping, progradational parasequence set. As mentioned previously, reversal at the point of maximum flood/maximum flexure is essentially at the Middle to Upper Atoka stratigraphic boundary. It can be inferred from this that the base of the Upper Atoka is the point at which the Arkoma Basin flexural regime diminished allowing the high rate of sediment supply to become dominant. Additionally, the Lower Carpenter had an average basinward migration relative to the Morris of approximately 11 miles, which indicates a prompt transition to a progradational parasequence.

The Upper Atoka along the northern basin margin can be characterized as a progradational parasequence comprised of upward thickening sands within full depositional cycles that record inner shelf, tidal flat, and shore zone depositional systems. This is illustrated along the northern ends of cross sections A-A', B-B' and C-C' (Figures 23, 25, and 27) and across section D-D' (Figure 29). The "axial" dispersal systems developed from east-to-west within the basin reflects filling of the foredeep in front of the Ouachita Accretionary prism and transition to shallow marine deposition across the entirety of the basin (Figure 13; McGilvery, Manger, and Zachry, 2016). The maximum thickness of the Upper Atoka reaches to a colossal 3500 feet, in certain areas of this study area. This thickness records similar marginal to shallow marine depositional environments. The greater thickness relative to the Lower Atoka reflects the increased amount of accommodation space during late stage foreland basin fill vs. the pre-basin, platform setting of the Lower Atoka. This also indicates that there was a sustained high sedimentation rate that began during early stage basin fill and continued into the late stage basin fill. The high sedimentation rate led to these overthickened depositional cycles.

The Upper Atoka thickens towards the west by approximately 400 feet within cross section E-E' (Figure 31). This thickening suggests three significant tectonostratigraphic interpretations. First, the southeastern tectonic subsidence bias that was present within Middle Atoka and even Lower Atoka deposition no longer existed. Second, this indicates that the slowing tectonic subsidence was developing earlier in the east than the west; rather than the westward migrating foredeep resulting from an east-to-west sediment supply alone. Third and most significant, similar to how the shallow marine Middle Atoka's compensational thickening increased towards the foredeep, the Upper Atoka's thickening westward indicates a westward migrating deep basin and a rotating depositional hinge line trending north-to-south. The Middle Atoka, Upper Atoka, and Desmoinesian paleogeographic evolution illustrates the transition to axial dominated marginal marine deposition in the Upper Atoka (Figures 12, 13, and 14). The interpretation of decreased tectonic subsidence combined with a high sediment supply, which originated from the Appalachian orogenic trend to the east, also supports the systematic infilling of a westward migrating foredeep in front of the rotating depositional hinge line.

The interpretation of the cross section grid, or deep marine hinge line migration diagram, generally supports this rotation but is largely based on literature and other indicators. This is due to a lack of defined log motif, outcropping members, and a limited southward extent of this projects study area.

***Atoka Formation Deep Marine Shales***

The Lower Atoka was dominated by eustatic processes on an open marine shelf and didn't have any clear deep marine influences within this study area. Deep marine deposition, which plays an essential role in this project, began with the start of Arkoma Basin tectonics during the Middle Atoka. The landward stepping, retrogradational parasequences and shelf to basin transition of the Middle Atoka, defined by the deep marine shale, indicate the dominance of tectonic subsidence within a growing foredeep. The basinward stepping, progradational parasequences and shelf to basin transition of the Upper Atoka indicate a slowing tectonic subsidence and a continuous high sediment supply. This division records the rapid basinward expansion of the shallow marine systems as the deep marine basin was filled as the Arkoma Foreland Basin began to close.

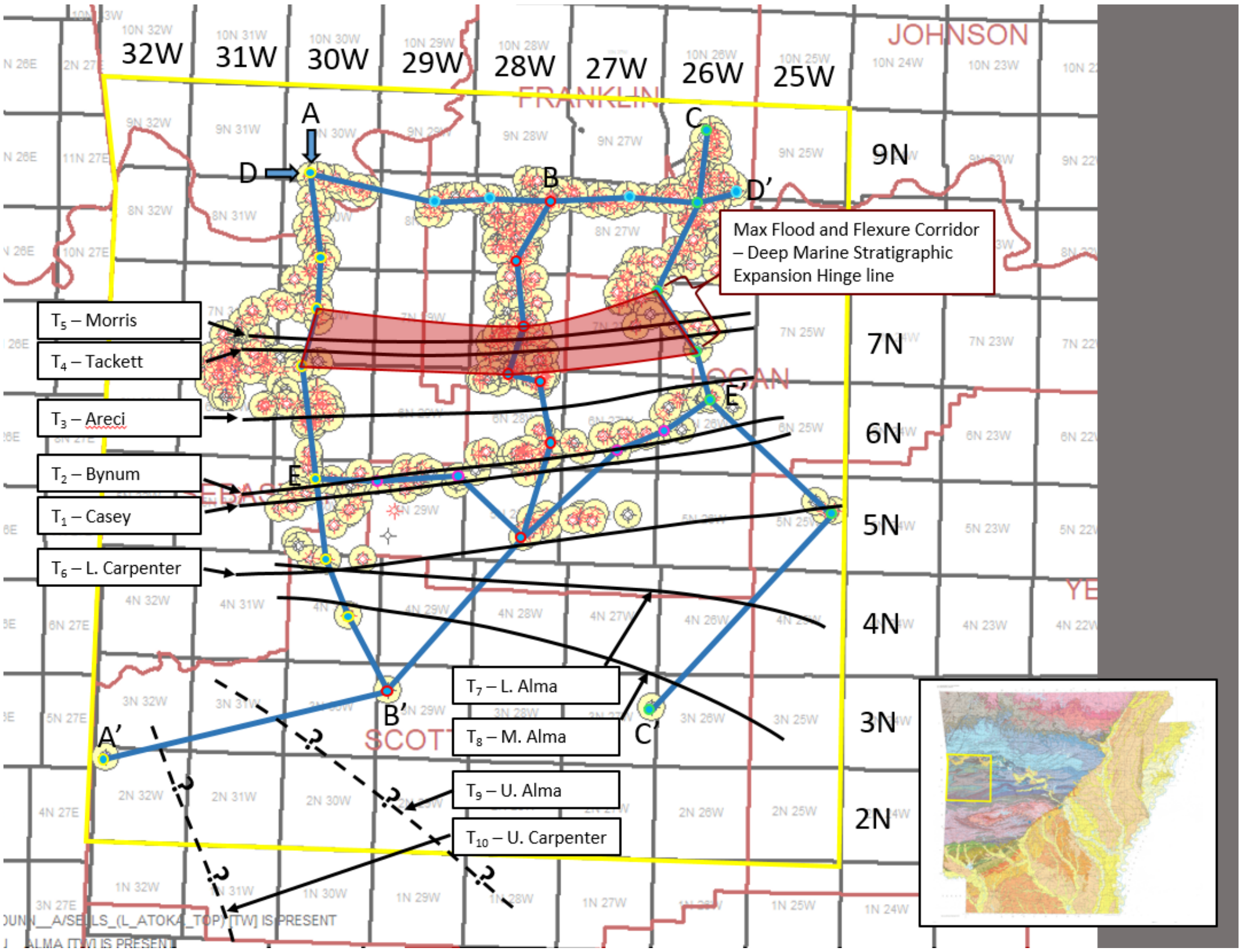


**Figure 32**: Study area in yellow. Black lines indicate hinge line of shallow to deep marine depositional transition for members of the Atoka Formation. The red polygon confines the paleogeographic location of the deep marine maximum flood.

The objective of the deep marine hinge line migration diagram is to represent the hinge line location, orientation, and migration magnitude over multiple stratigraphic timelines (Figure 32). Starting with the oldest members included in this diagram; the Middle Atoka shallow marine deposits retrograde northward starting from the lowermost member, the Casey (T1), all the way up to the uppermost Middle Atoka member, the Morris (T5). The hinge lines and marginal marine environments of these members trend approximately east-to-west along the northern margin of the basin, with a slight bias toward the northeast (Figures 12 and 32). The

Casey hinge line (T1) extends from R31W to R25W and shows a slight SW-NE inclination. The remaining Middle Atoka units, the Casey, Bynum, Areci, Tackett, and Morris, (T2 – T5) all continue this general orientation as their hinge lines shift to the north. The Morris hinge line (T5) spans from R31W to R26W and entirely within T7N. The hinge line migration magnitude of the Middle Atoka division, from the Casey to the Morris, is approximately 8.7 miles of landward stepping, retrograding shallow marine deposits. The average migration magnitude between members of the Middle Atoka is approximately 2.2 miles. The maximum flood and flexure corridor is located almost entirely within the lower half of T7N and spans from R30W to R26W. This area includes four significant geologic occurrences that develop or arise in this corridor; 1) maximum flooding of the deep marine deposits, 2) the start of the massive stratigraphic expansion of the deep basin Middle Atoka, 3) a change in the dominant driving force of deposition (from tectonic subsidence to sediment supply driven), and 4) maximum flexure of the syndepositional Middle Atoka and pre-Arkoma Basin Lower Atoka.

The transition to the Upper Atoka reflects the turn around and shift to basinward migration of the hinge lines. The lowermost member of the Upper Atoka, the Lower Carpenter (T6) exhibits a rapid shift in the hinge line that occurs basinward of the original T1, Casey hinge line (Figure 32). This is interpreted to reflect a slowdown of tectonic subsidence and basin filling driven by a continued high rate of sediment supply. The Lower Carpenter hinge line migrated basinward approximately 11 miles within this single cycle from the Morris maximum flood hinge line. This is in comparison to the average 2.2 miles of landward migration, retrogradation, between the individual members within the Middle Atoka (T1-T5). The Lower Carpenter hinge line spans from T5N to T4N and R31W to R25W. This rapid progradation continued throughout the Upper Atoka (T7 and T8). Beginning with the Lower Alma, the deep marine hinge lines begin to rotate and trend toward a more north-to-south orientation (T9 and T10). The Middle Alma, the hinge line spans from T4N to T3N and R31W to R25W with a nearly northwest-to-southeast orientation. The hinge line in the uppermost member of the Upper Atoka, (the Upper Carpenter, T10), trends nearly north-to-south which reflects the filling foredeep and a dominant east-to-west axial sediment dispersal system (Figures 13 & 14). Although the interpreted hinge lines intersect cross section A-A', the hinge line orientation for the Upper Alma and Upper Carpenter had to be inferred using what is known from literature and extending the trend established by the underlying members. This is due to the fact that the upper two members of the Upper Atoka are exposed at the surface and are not present in well logs in the area just east of cross section A-A'. These two hinge lines are designated by dashed lines with question marks within.

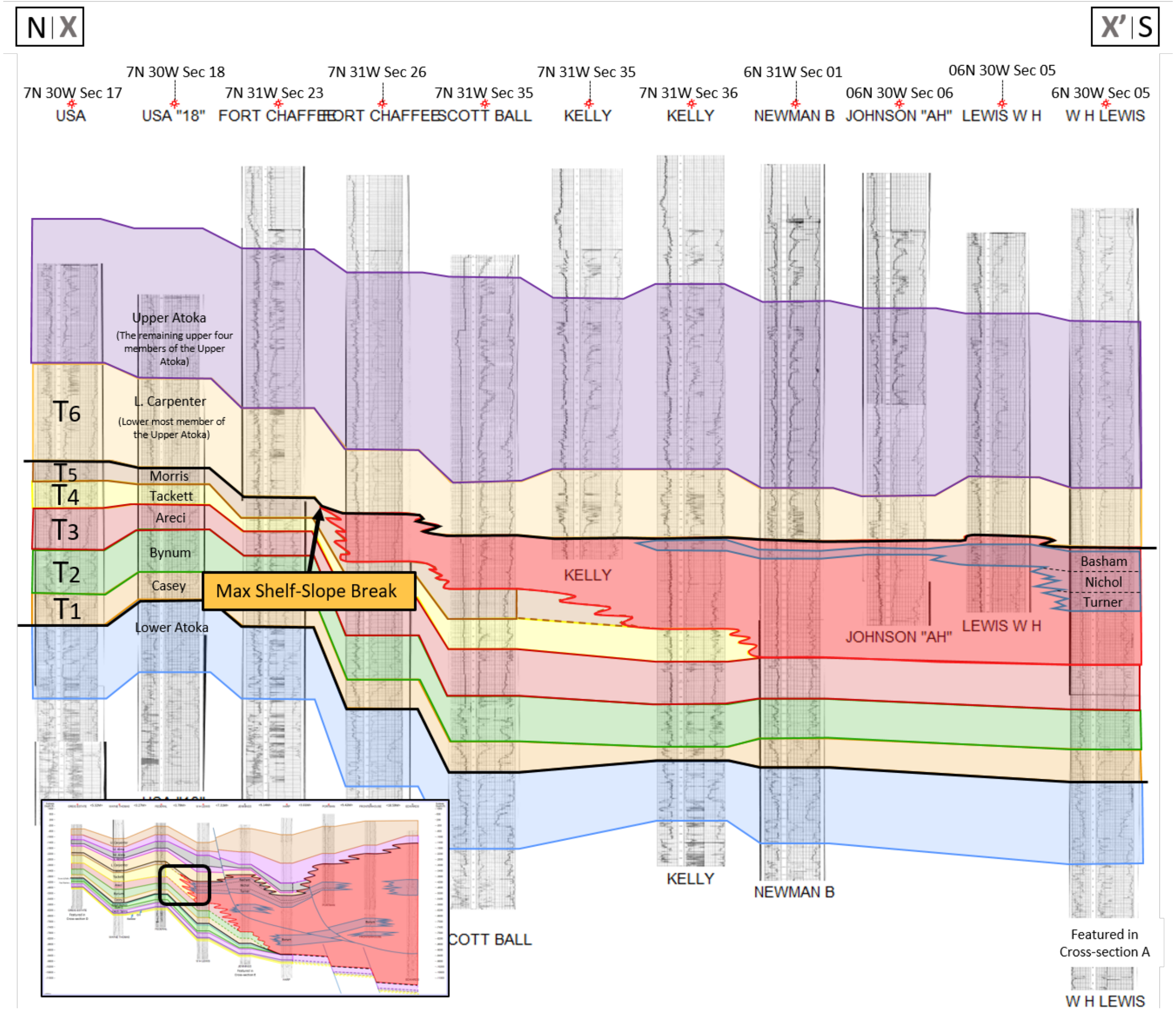


**Figure 33**: Continental shelf to slope transition profile. Max shelf-slope break label in gold.

Within the hinge line migration diagram, a maximum flood and flexure corridor was added. Despite the Morris hinge line indicating the exact location of maximum flood, this band was necessary to provide a reasonable margin of error (shaded band on Figure 32). This corridor is significant as it represents the approximate area of maximum northward flexure and massive stratigraphic expansion within the Middle Atoka. This is commonly referred to as the point of "maximum flood" which is not necessarily wrong, but it must be considered within the context of relative sea level driven by tectonic subsidence rather than global glacial eustasy. This northern boundary marks the slowing of tectonic subsidence and transition to sediment supply dominated deposition within the Upper Atoka. Due to its significance, a detailed cross section was made from the high-resolution A-A' cross section that represents the continental shelf - slope transition within this corridor (Figure 33).

The continental shelf-to-slope diagram, as seen in figure 33, depicts all five members of the Middle Atoka plus the Lower Carpenter, the Lower Atoka, and the rest of the Upper Atoka. It is roughly 4 miles in length, direct line end-to-end. Only three of the four deep marine Middle Atokan sandstone members appear this far north. This diagram characterizes the paleo-continental margin, with the max shelf-slope break represented in gold. The shelf-slope break occurs between the Fort Chaffee (section 23) and Fort Chaffee (section 26) wells as determined by the maximum northward migration of deepwater shale. The deep marine max flooding terminates just before the point of maximum flexure or the shelf-slope break. This indicates the extent of deep basin shales were impaired by the considerable relief that resulted from the bending of substrata along the continental slope. South of the Fort Chaffee (section 26) well, along the base of the deep marine deposition, is the shelf-slope break boundary of the underlying members determined by the location of their depositional extent. The largest increase in the degree of slope, or maximum flexure, is approximately where the shelf-slope break is depicted. Both the Morris, which transitions first, and the Tackett, shale-out within this small cross section.

The max flood corridor indicates the farthest transgressional extent to the north that the deep marine basin had migrated, based on the interpreted deep marine shale-out (Figures 23-28). This isle is perhaps the most significant interpretation produced from this study because the Arkansas geologic public domain has a very limited number of studies that theorize the location of this hinge line. The behavior of the deep marine deposits, before and after the point of max flood, also aid in determining the point of transition for the dominant depositional drivers within the Arkoma Basin fill.

### *Atoka Formation Deep Marine Sand Complexes*

There are series of sand-rich, deepwater depositional elements within the Middle Atoka succession. These are the down dip equivalents of the cyclic marginal marine units within the Casey through Morris units that have been defined north of the shelf/slope transition. The isolated and sporadic nature of these sandstones indicate that a majority of the sediment bypassed through slope channels and fed directly into lower slope/basin floor deepwater fan complexes. This mud-rich bypass zone, likely consisting of outer shelf to upper slope deposits, results in the detached distribution of deepwater and shallow water sandstones. As a result, a direct correlation between specific shallow marine cycles and "coeval" deepwater sands is a significant challenge. Within certain deposits in this study area, these deepwater sand complexes are interpreted as multiple amalgamated sheets that can reach 1400 feet in thickness. An example of this is the interpretation that the Basham, Nichol, and Turner deepwater sands as occurring within a single amalgamated complex, divided into three divisions (Figures 23 - 28, and 31). The thin sheets within these complexes are interpreted to be the result of multiple gravity driven event beds. This study interprets most thick deep marine sand-rich units, greater than 50 feet in thickness, as stacks of amalgamated sheets within fan lobe complexes.

As a result of continental convergence during early stage basin fill, a series of southward dipping syndepositional growth faults developed through Lower Atoka strata (Figure 12). Some of these deep marine sand packages, such as channel levees, crevasse splays, and submarine fans that were deposited concurrently with the developing normal faults, could have been deposited and originated off the hanging wall side of these normal faults (Houseknecht, 1986; Houseknecht and McGilvery, 1990). This interpretation implies that the submarine bypass channels, that fed the deep marine depositional systems, originated against these faults down the step-like substratum.

## *Conclusions*

The Atoka Formation is separated into three tectonostratigraphic subdivisions. Two of which, the middle and upper, were deposited during developing Arkoma Basin tectonics. The following conclusions relate to the context of this project's study area. The Lower Atoka deposition was dominated by eustatic forces, on a stable passive margin, with a north-to-south migrating shallow marine hinge line. The Middle Atoka deposition was dominated by a high tectonic subsidence rate which overprinted the effects of eustasy. It possessed a retrogradational stacking pattern, with a deep marine hinge line that ran east-to-west. The max flooding hinge line of the entire formation is located within the Middle Atoka member, the Morris, spanning from R31W to R26W and entirely within T7N. Due to a slowing tectonic subsidence and sediment supply originating from the east, the Upper Atoka's foredeep began to migrate westward. This caused the deep marine hinge line of this sediment supply dominated division to rotate nearly north-to-south. The overthickened members of this division, compared to the Lower Atoka, begin to prograde at a rate much quicker than the rate of retrogradation within the shallow marine Middle Atoka. The deep marine deposition, which is considered entirely within the middle division of the formation, is characterized by tumultuously distributed and isolated sandstone complexes, incapsulated by deepwater shales.

### *Future Works*

- Continue the work done in this project, by creating regional transects farther to the east to better capture the westward migrating foredeep and thicker Upper Atoka.
- Extend the transects created within this project farther north to display the Atoka strata onlap and analyze its tectonostratigraphic features.
- Expand the stratigraphic analysis of the Lower Atoka that Denham (2018) had completed, within the shallow marine depositional cycles of the Middle Atoka and Upper Atoka.
- Analyze the effects of eustacy on the Upper and specifically Middle Atoka, despite both divisions being overprinted by sediment supply and tectonic subsidence. Mapping the sand and shale sequences within each member.
- A more in-depth mapping project of the deep marine Middle Atoka sandstone complexes, building upon Bello's (2012) project.
- A comprehensive mapping analysis of the Upper Atoka, south of the Washburn anticline due to the complexity of its log motif.
- Regional transects through the Washburn anticline to aid in correlating the Atokan informal members across the region. Due to complex faulting, the log motif drastically changes from the north to the south sides of this structure.
- Correlate production data to the sands within the lower two divisions of the Atoka Formation.

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***Appendix***

## *Table 1 - High Resolution Cross Section A-A' Well List*

| UWI/API | WELLNAME | WELLNO |
|---|---|---|
| 3033102490000 | ARNOLD JAMES | 6-C |
| 3033002120000 | ROBBINS FINE | 1 |
| 3033105530000 | ROBBINS-FINE | 5 |
| 3033100180000 | ROBBINS FINE | 2T |
| 3131300390000 | CHARLES MOORE | 29-Jan |
| 3131101770000 | BRYANT ANNIE | 2 |
| 3131105070000 | BRYANT ANNIE V | 3 |
| 3131106300000 | THOMAS WAYNE | 2 |
| 3131107680000 | THOMAS WAYNE | 4 |
| 3131101580000 | CARNEY | 1-T |
| 3131104730000 | USA | 2 |
| 3131101010000 | U S A | 1-8C |
| 3131100770000 | U S A | 9-Jan |
| 3131103120000 | FEDERAL | 1-T |
| 3131105370000 | FEDERAL | 2-16T |
| 3131102620000 | USA | 17-1 |
| 3131105490000 | USA "18" | 18-Mar |
| 3131104790000 | FORT CHAFFEE | 1-23T |
| 3131106850000 | FORT CHAFFEE | 26-Jan |
| 3131101410000 | SCOTT BALL | Jan-35 |
| 3131114080000 | KELLY | Apr-35 |
| 3131113060000 | KELLY | 3-36T |
| 3131103080000 | NEWMAN B | 1 |
| 3131103160000 | JOHNSON "AH" | 1-T |
| 3131103970000 | LEWIS W H | 2 |
| 3131100050000 | W H LEWIS | 1 |
| 3131112590000 | DUNN | 15-Jan |
| 3131111310000 | TAYLOR W W | 16-Jul |
| 3131107300000 | TAYLOR W W | 3 |
| 3131102770000 | GARNER | 17-Jan |
| 3131108910000 | MURPHY | 7-21T |
| 3131111960000 | MURPHY | 9-21T |
| 3131109340000 | MURPHY | 8-21T |
| 3131108130000 | JONES | 20-Feb |
| 3131106570000 | BOYD | 2 |
| 3131114690000 | WILSON JERRY | 29-Apr |
| 3131111350000 | TOMLIN E C | Dec-33 |

*Table 1 - High Resolution Cross Section A-A' Well List*

| UWI/API | WELLNAME | WELLNO |
|---|---|---|
| 3131111450000 | TOMLIN E C | 13 |
| 3131110970000 | SANDERSON | 3-T |
| 3131112250000 | SANDERSON | 7 |
| 3131110570000 | WHITSON | 2 |
| 3131101660000 | JENNINGS | 1 |
| 3131101590000 | CARSON | 1 |
| 3131103670000 | NEISLER | 1 |
| 3131300460000 | FULGHAM | 1 |
| 3131114130000 | JONES R D | 15-23 |
| 3131101720000 | ROYCE DEAN JONES | 1-LT |
| 3127101540000 | GLASS "C" | 27-Mar |
| 3127300060000 | OTHELLA HARPETAL | 1 |
| 3127100020000 | E J HARP | 1 |
| 3127000020000 | ACME BRICK | 1 |
| 3127000010000 | HARP | 1 |
| 3127101150000 | PRAIRIE CREEK | 2-Jan |

## *Table 2 - High Resolution Cross Section B-B' Well List*

| UWI/API | WELLNAME | WELLNO |
|---|---|---|
| 3047100850000 | KEITH | 1-10C |
| 3047100960000 | MILAM | 1 |
| 3047105560000 | SUB-ROSA NORTH | 1-T |
| 3047103340000 | HURRICANE | 1 |
| 3047105410000 | MCGEE | 2-T |
| 3047112640000 | MCGEE | 4-15C |
| 3047105290000 | VEST ALVIN F | 1 |
| 3047110710000 | MCGEE | 3 |
| 3047112270000 | MCFERRAN | 21-Jun |
| 3047111900000 | KING SISTERS | 28-Mar |
| 3047105250000 | KING ALLEN W | 2 |
| 3047111030000 | FLANAGAN | 3 |
| 3047104730000 | THOMPSON | 2-T |
| 3047300340000 | S L THOMPSON | 1-LT |
| 3047104990000 | THOMPSON | 3 |
| 3047113450000 | HILL | 1-4T |
| 3047101830000 | ROBISON | 1T |
| 3047101760000 | TURNER | 1-T |
| 3047000010000 | PRICE | N-1 |
| 3047111400000 | HALES | 15-Jan |
| 3047102570000 | DELKE | 1 |
| 3047102630000 | MIESNER | 1-C |
| 3047102560000 | HALES | 1-T |
| 3047113600000 | HAMMOND J C | 3 |
| 3047102980000 | YOUNG | 1 |
| 3047111760000 | HALES TRUST | 2 |
| 3047107350000 | ADAMS NORBERT | 21-Feb |
| 3047102580000 | BRADLEY | 1 |
| 3047109540000 | SPIERS | 1 |
| 3047102660000 | DOVE | 1 |
| 3047102070000 | PENCE | 1 |
| 3083103140000 | WILLIAMS "KK" | 2 |
| 3083000060000 | IDA LOONEY | 1 |
| 3083100690000 | S A MOORE | 1 |
| 3083112600000 | WILLIAMS "KK" | 3-Jul |
| 3083109810000 | LOWDER | 2-Jul |
| 3083110150000 | LOWDER | 2-Sep |
| 3083109910000 | LOWDER | 2-Aug |

*Table 2 - High Resolution Cross Section B-B' Well List*

| UWI/API | WELLNAME | WELLNO |
|---|---|---|
| 3083110230000 | TANNER | 21-15 |
| 3083106180000 | TANNER | 15-Jun |
| 3083107700000 | DANIELSON ERIC | 23-May |
| 3083106560000 | DANIELSON ERIC | 23-Mar |
| 3083101500000 | WILLIAMS P GAS UNIT | 1 |
| 3083108130000 | MARRS JAMES E | 2 |
| 3083109670000 | RICHARDSON | 1 |
| 3083101980000 | LASITER GAS UNIT | 1 |
| 3083112660000 | FOSTER MARION | Apr-34 |
| 3083102820000 | FRANKS | 1 |
| 3083102760000 | BEVINS "A" | 1 |
| 3083102020000 | WISLEY | 1-T |

*Table 3 - High Resolution Cross Section C-C' Well List*

| UWI/API | WELLNAME | WELLNO |
|---|---|---|
| 3047107270000 | DEL SOTO | 1-10T |
| 3047110610000 | ALLEN | 15-Jun |
| 3047110130000 | ALLEN | 15-May |
| 3047100290000 | DENNING UNIT | 1 |
| 3047107830000 | DENNING | 22-Feb |
| 3047108660000 | HARGER ALICE | 27-Feb |
| 3047102520000 | BRASHEARS | Jan-34 |
| 3047108280000 | BRASHEARS | 2T |
| 3047101980000 | YOUNG | 1 |
| 3047102140000 | MITCHELL | 1-T |
| 3083105730000 | WIGGINS | 2-9T |
| 3083103280000 | HEMBREE | 1-T |
| 3083101220000 | HEMBREE | 1-T |
| 3083101540000 | DUNHAM | 21-Jan |
| 3083105960000 | WIGGINS B | 19-Feb |
| 3083102100000 | HIXSON | 29-Jan |
| 3083100700000 | BLACK | 1 |
| 3047102330000 | DICKERSON | 2 |
| 3083104050000 | FEDERAL MARTIN H | 2 |
| 3083104510000 | RILEY | 2 |
| 3083102130000 | JOHNS "OO" | 00-1 |
| 3083103160000 | RAZORBACK | 18-Jan |
| 3083103010000 | PINE RIDGE | 17-Jan |
| 3083103510000 | BLATY VIOLA C | 16-Jan |
| 3083103730000 | COBLE | 15-Jan |
| 3083102720000 | BRIDGES | 28-Jan |
| 3083102230000 | CHIGGER CREEK | 9-Jan |
| 3083113150000 | LITTLETON | 10-Jan |
| 3083102530000 | GRAHAM "G" | 1-T |
| 3083102320000 | BYRD | 1 |
| 3149101070000 | SCOTT | 11-Mar |
| 3149100420000 | LOWERY D H | 3-14T |
| 3149100210000 | TURNER CARL | 13-Jan |

## *Table 4 - High Resolution Cross Section D-D' Well List*

| UWI/API | WELLNAME | WELLNO |
|---|---|---|
| 3033100340000 | GREIG ESTATE | 1&2 |
| 3033104020000 | ALEXANDER MILDRED | 2UT |
| 3033100220000 | MILDRED ALEXANDER | 1C |
| 3033103640000 | GOOCH JIMMY DON | 5 |
| 3033101640000 | GOOCH JIMMY DON | 3 |
| 3033101890000 | GOOCH J D | 4 |
| 3033104900000 | GOOCH J D | 7 |
| 3033100130000 | ADAMS LURS M | 1 |
| 3047111860000 | KEITH | 2-10T |
| 3047300510000 | D S KEITH | 1 |
| 3047100850000 | KEITH | 1-10C |
| 3047102260000 | TOBEY | 1 |
| 3047110820000 | TOBEY | 3 |
| 3047111750000 | DUELING | 1 |
| 3047300450000 | RUTH PETTIGREW | 1 |
| 3047107240000 | PETTIGREW RUTH | 4 |
| 3047000070000 | M ROSS | 1 |
| 3047600220000 | JANICE | 1 |
| 3047105130000 | SUB ROSA | 1-T |
| 3047100580000 | BROWN | 2 |
| 3047111920000 | LOG CABIN | 3 |
| 3047101250000 | WILLIAMS K | 1 |
| 3047001770000 | L KIRBY | 1 |
| 3047101840000 | PENDERGRASS | B-1T |
| 3047111870000 | SORY | 3-Feb |
| 3047112120000 | SORY | 3-Mar |
| 3047300500000 | G E MCCELLAND | 1 |
| 3047105480000 | LANG | 1-Apr |
| 3083103190000 | ROBBERSON M | 6-Mar |
| 3083110330000 | ROBBERSON MARTIN | 6-May |
| 3083100570000 | ROBBERSON | 1-T |
| 3047101470000 | CARTER | 4-Jan |
| 3047102140000 | MITCHELL | 1-T |
| 3047600260000 | WILSON | 1 |

## *Table 5 - High Resolution Cross Section E-E' Well List*

| UWI/API | WELLNAME | WELLNO |
|---|---|---|
| 3131111830000 | WHEDBEE | 9-Jan |
| 3131101660000 | JENNINGS | 1 |
| 3131101590000 | CARSON | 1 |
| 3131103240000 | SANDERSON "A" | 1 |
| 3131108700000 | MARSHALL | 2 |
| 3083102350000 | ENGELKING | 1 |
| 3083102520000 | LOWE | 1 |
| 3083112410000 | COCHRAN | 10-Jan |
| 3083101700000 | COCHRAN | 3-Jan |
| 3083112840000 | SHARP | 3-Feb |
| 3083101100000 | HOWARD A MARKER | 1 |
| 3083102020000 | WISLEY | 1-T |
| 3083102760000 | BEVINS "A" | 1 |
| 3083101980000 | LASITER GAS UNIT | 1 |
| 3083108140000 | LASITER | 2 |
| 3083109670000 | RICHARDSON | 1 |
| 3083101990000 | DAVIS "U" | 1 |
| 3083102490000 | MEHELICH | 1 |
| 3083108210000 | MIKLES | 22-Mar |
| 3083112150000 | MIKLES | 22-Apr |
| 3083110910000 | COOKSEY SAM | 1 |
| 3083101940000 | BEGGS | 1 |
| 3083111150000 | WILKINS TRUST | 1 |
| 3083102060000 | NEWSOM "B" | 1 |
| 3083102580000 | SHEPPARD RIDGE | 1 |
| 3083102290000 | STAFFORD | 1-C |
| 3083106770000 | CHISMVILLE GAS UNIT | 7-Apr |
| 3083102080000 | LONGLEY | 8-Jan |
| 3083102530000 | GRAHAM "G" | 1-T |
| 3083113150000 | LITTLETON | 10-Jan |
| 3083102320000 | BYRD | 1 |