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Stratigraphic Variations in the Carboniferous Section Across the Arkansas-Oklahoma State Line Arch

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Geology

By

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ABSTRACT

The State Line Arch is represented by a structural high that trends through the study area in a loose alignment with the Arkansas-Oklahoma state line. Evidence of the arch extending further to the north includes a structural high and stratigraphic variation at an outcrop on Highway 59 near Evansville Mountain in Crawford County, Arkansas. The exact timing of the formation of the arch remains undetermined, but upper Devonian thinning at the top of the arch indicates the structure is pre-Mississippian. The reason for the development of the arch is poorly understood, but evidence linking Mississippian-aged Waulsortian mounds to Precambrian Spavinaw granite structures of northeastern Oklahoma and southwestern Missouri suggests Precambrian basement structures may extend into the study area. The structural nature of the arch provided an environment favorable to carbonate build-up during deposition of the Mississippian interval. A previously unidentified limestone unit measuring 175 feet thick likely represents the transgressive phase of a transgressive-regressive sequence responsible for the deposition of the Mayes Group of northeastern Oklahoma. Growth on the downthrown side of the Muldrow-Mulberry Fault system may indicate earlier movement than previous studies have suggested on the east-west trending normal faults of the Arkoma Basin. A possible roll-over anticline structure may exist to the south of the Muldrow-Mulberry fault system.

This thesis is approved for recommendation
to the Graduate Council.

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For the faculty and students at the University of Arkansas Department of Geosciences, thanks for helping to make my two years in Fayetteville rank among the best of my life. I will never forget the many friends I made at the University of Arkansas, or the countless memorable experiences and endless laughter I was able to share with them.

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INTRODUCTION

The State Line Arch is an ill-defined geologic structure that trends north to south along the Arkansas-Oklahoma boundary. The earliest known mention of the State-Line Arch occurred in a 1963 paper entitled "*Buried Structures of the Boston Mountains*" by James Quinn (Quinn, 1963). In a later University of Arkansas Master's thesis entitled "*Stratigraphy and Structural Geology of the Natural Dam and Evansville Quadrangles, Northwestern Arkansas and Eastern Oklahoma*" Cheston Cooper (Cooper, 2001) constructed a geologic structure map that provides evidence that the State Line Arch exists.

This thesis will utilize well log data from an area near Quinn's proposed State-line Arch (Figure 1) to consider the following:

1) The existence of the arch
2) Geologic timing of the arch formation and related activity
3) Effects of the arch on Devonian through Pennsylvanian stratigraphic intervals
4) Potential gas reservoirs in stratigraphic pinchouts

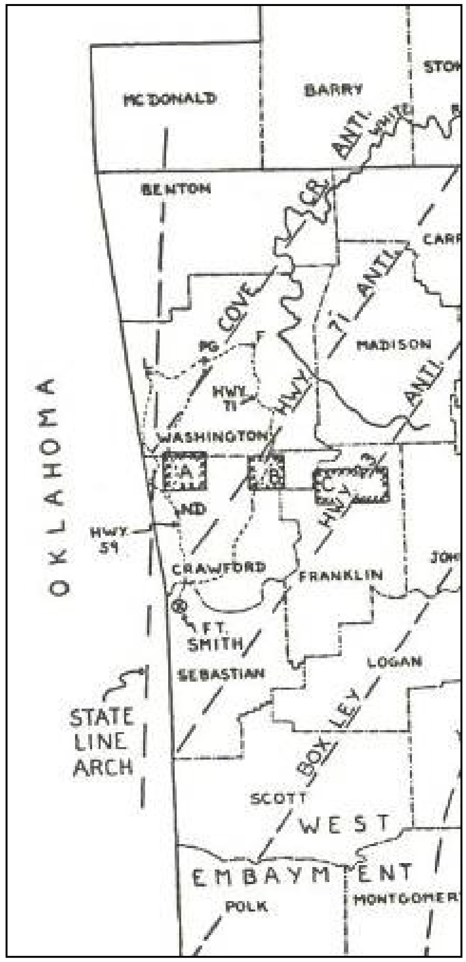

Figure 1. Location of State Line Arch (modified from Quinn, 1963)

BACKGROUND

According to Quinn (1963)**,** two south plunging synclines began to form after the deposition of the Boone Formation with the westernmost lying just east of the Arkansas-Oklahoma state line. A linear stable area designated by Quinn as the State Line Arch is located between the westernmost syncline and the McAlester basin (McAlester Basin will be referred to as the Arkoma basin in this thesis) of Oklahoma (Figure 1). Quinn (1963), without any supporting evidence, suggested that a series of four or more NE trending anticlines lying across the westernmost syncline seem to have formed during Morrowan time and have produced considerable differentiation (shales in troughs, limes on ridges) in the extensively developed Morrowan sediments. Later, additional distortion of the original westernmost syncline occurred due to further east-west trending folding and faulting (Quinn, 1963).

In Section 2, T. 12 N., R. 33 W., near Evansville Mountain, following Highway 59 to the south in Crawford County, Arkansas, the Cane Hill Member of the Hale Formation pinches out and the Prairie Grove Member of the Hale Formation lies atop the Pitkin Formation (Figure 2) at the Mississippian-Pennsylvanian unconformity (Cooper, 2001). Also, the Boone Formation is present at the surface much further south than the typical Boone exposure (Figure 3).

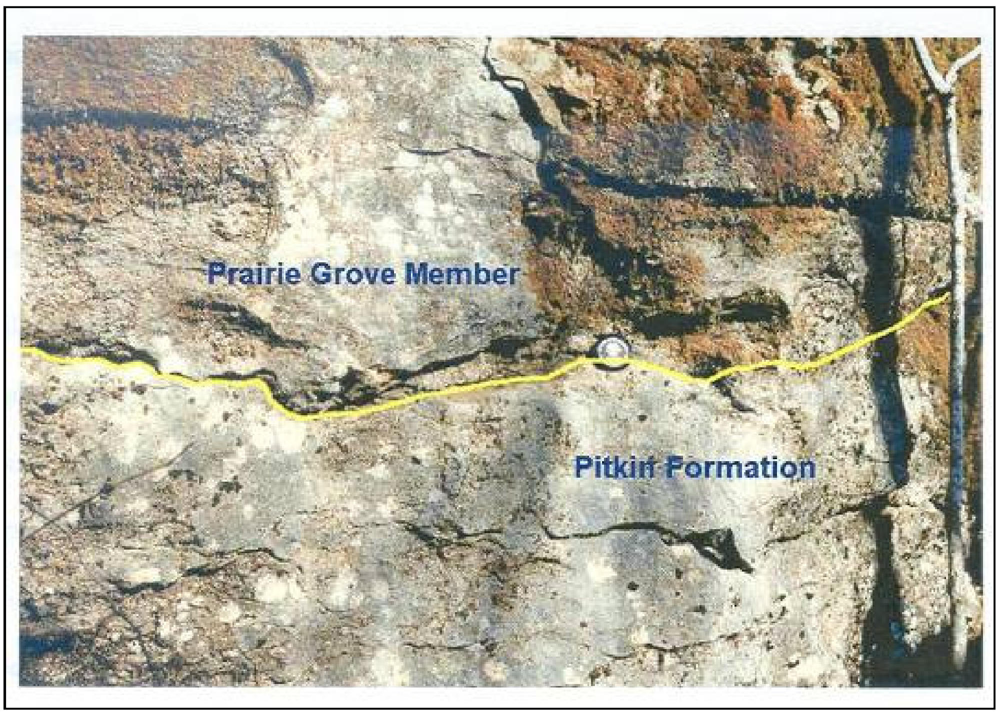

Figure 2. Mississippian-Pennsylvanian Unconformity (Cooper, 2001)

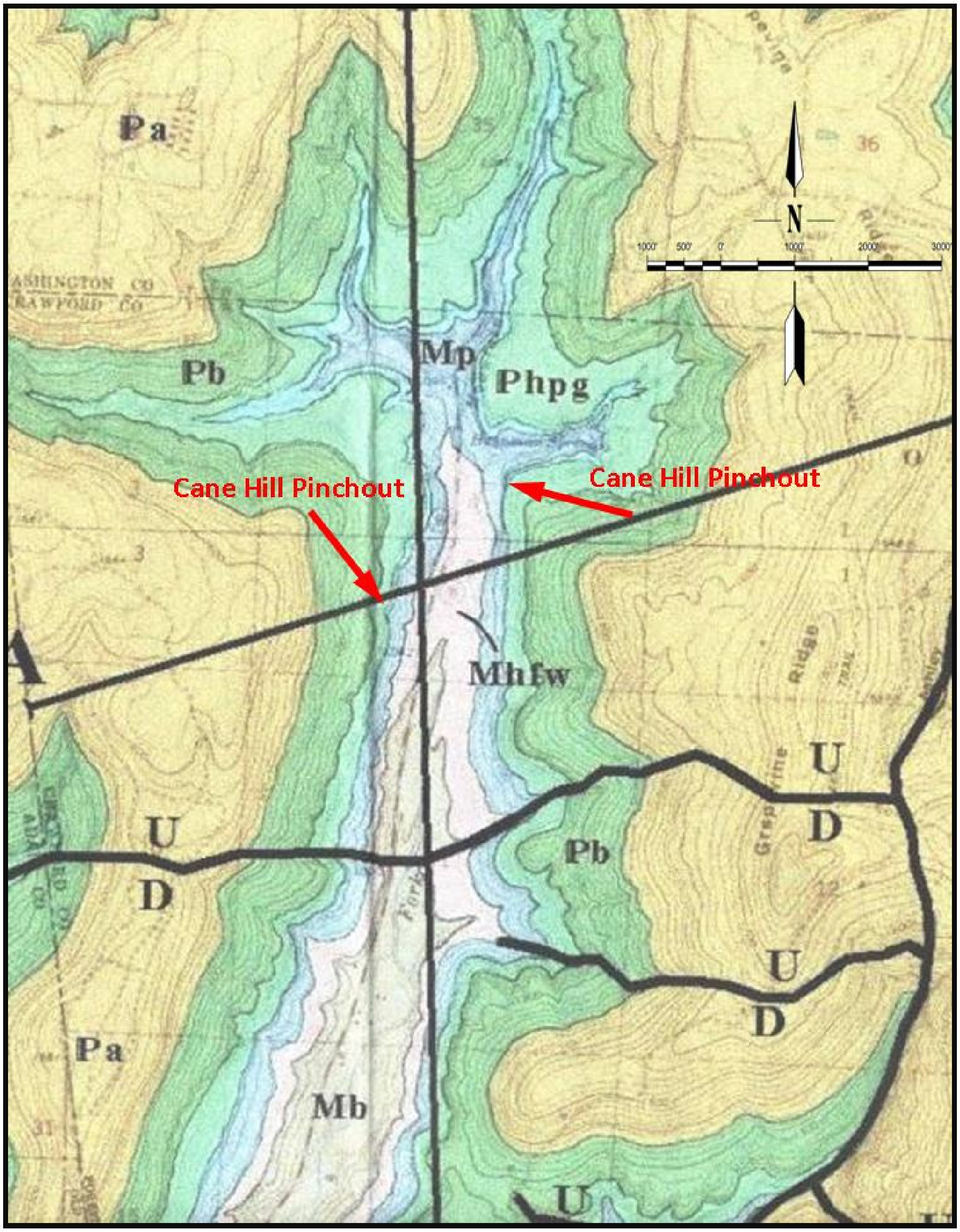

Figure 3. Geologic Map, Highway 59 outcrop with red arrows indicating location of Cane Hill pinchout, black arrow pointing north (modified from Cooper, 2001)

PURPOSE OF STUDY

This study will focus on an area surrounding Quinn's original proposal of the State Line Arch's location and in a southward trend with the Highway 59 outcrop. The area includes Townships 10 N.-13 N. and Ranges 24 E.-27 E. in east central Oklahoma; along with Townships 10 N.-11 N., Ranges 30 W.-33 W., and Townships 8 N.-9 N. Range 32 W. in west central Arkansas (Figure 4).

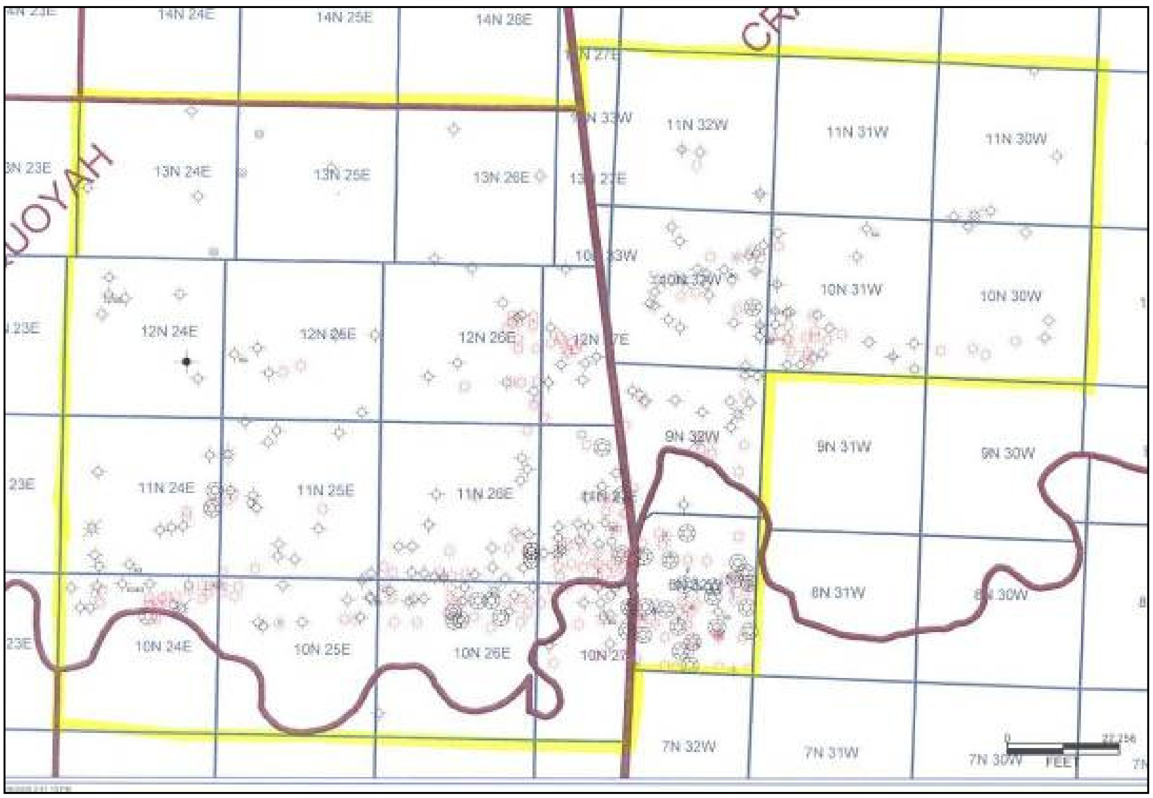

Figure 4. Study Area with well symbols inside yellow project outline

Electric log data is available for 443 wells in the study area. GeoPLUS Petra®, a geologic analysis software program, was utilized to correlate the tops of stratigraphic intervals. From the correlated tops, interval isopach maps were produced to show potential interval thinning on the flanks of the arch. Interval thinning could potentially indicate the timing of the development of the arch along with stratigraphic pinchouts that are of interest due to their gas-trapping capabilities. Structure maps were produced from the correlated tops to identify the location and structural nature of the arch.

Intervals that were correlated, isopached and mapped include the Mississippian Kinderhookian, Osagean, Meramecian, and Chesterian Series (Kinderhookian, Osagean, Meramecian grouped together and labeled “lower Mississippian”) in addition to the Pennsylvanian Morrowan and Lower Atokan Series (Figures 5, 6, and 7). The lower Mississippian, Chesterian, Morrowan, and Lower Atokan Intervals were correlated using analysis of electric logs within the study area. The lower Mississippian interval is identified from the top of the Chattanooga Shale to the unconformity located at the base of the Hindsville limestone (Figure 5). The Chesterian interval is identified from the base of the Hindsville limestone to the top of the Pitkin Limestone (Figure 5). The Morrowan interval is identified as the interval from the top of the Pitkin Limestone to the top of the Kessler Limestone (Figure 5). The Lower Atokan interval is identified as the interval from the top of the Kessler Limestone to the top of the Sells Sand (no formal name has been assigned to this interval, but the name “Sells” has been applied by the petroleum industry) (Figure 5).

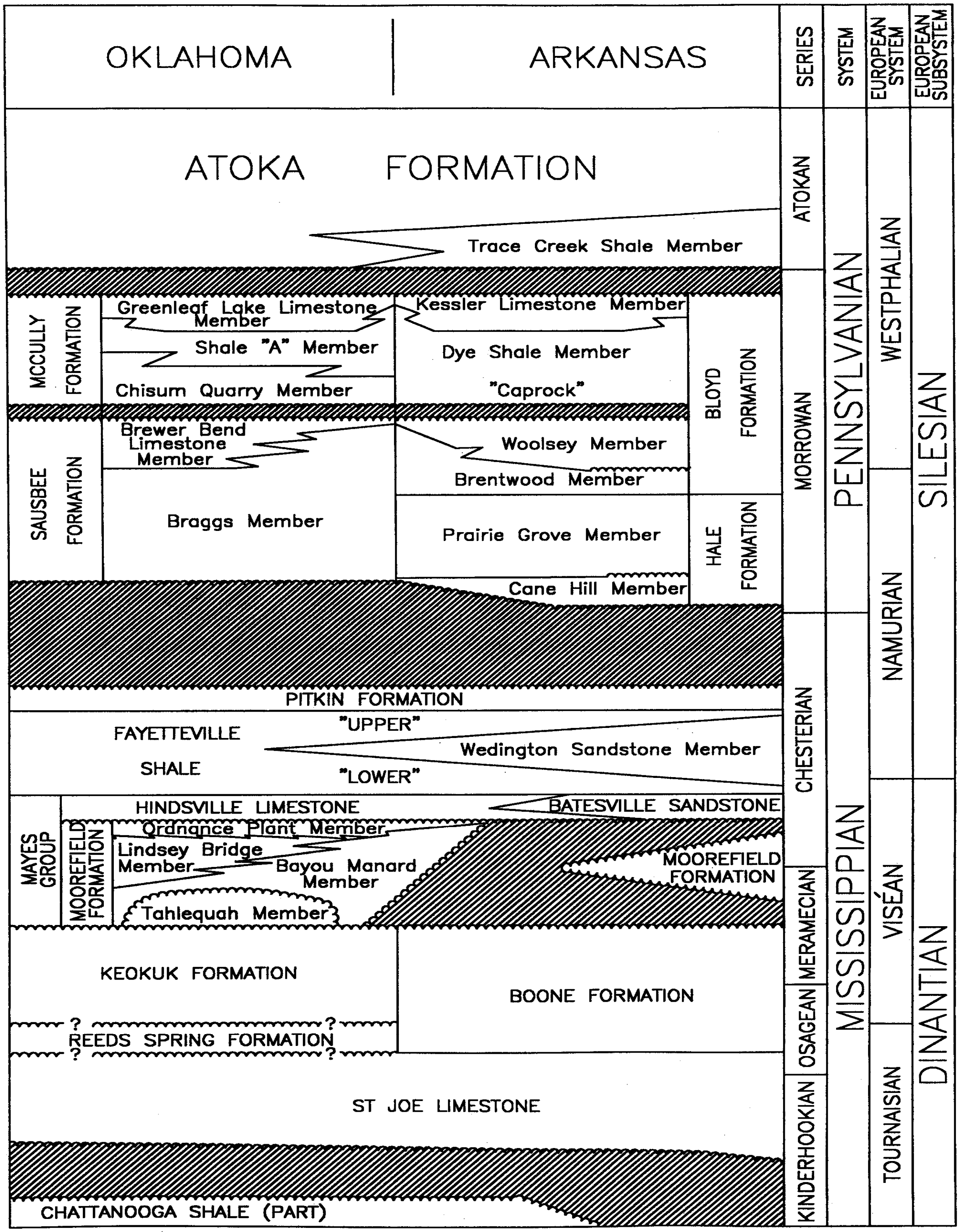

Figure 5. Middle Carboniferous Lithostratigraphy of Northwestern Arkansas and Northeastern Oklahoma (Manger 2008)

LOG ANALYSIS

Log analysis was performed to distinguish lithologies and to identify the markers of the intervals that were correlated. The gamma ray log was used to distinguish shale intervals from limestone or sandstone intervals. Photoelectric (PE) logs and combinations of neutron-porosity and density-porosity logs were used to make the distinction between limestones and sandstones. The conductivity log was used in conjunction with the gamma log primarily for pattern recognition in the lower Atokan sands.

The gamma ray log measures the natural radioactivity of rock formations by recording the number of gamma rays emitted by the formation along with the energy of each, and processes the information into curves representative of the amounts of Thorium (Th), Potassium (K), and Uranium (U) present in the formation (Asquith and Krygkowski, 2009). Shales naturally contain a higher concentration of radioactive materials than limestones or sandstones, therefore correlative shale intervals can be identified by higher values on the gamma ray curve.

The PE log (low energy gamma rays measured in barns/electron) was useful for distinguishing quartz (sandstone) and calcite (limestone) dominated lithologies. A PE curve value of ~2 barns/electron indicates quartz dominated (sandstone) lithology, while a PE value of ~5 barns/electron is consistent with calcite (limestone) lithology. When the PE curve was not available, various combinations neutron-porosity logs and density porosity logs were used to determine lithology.

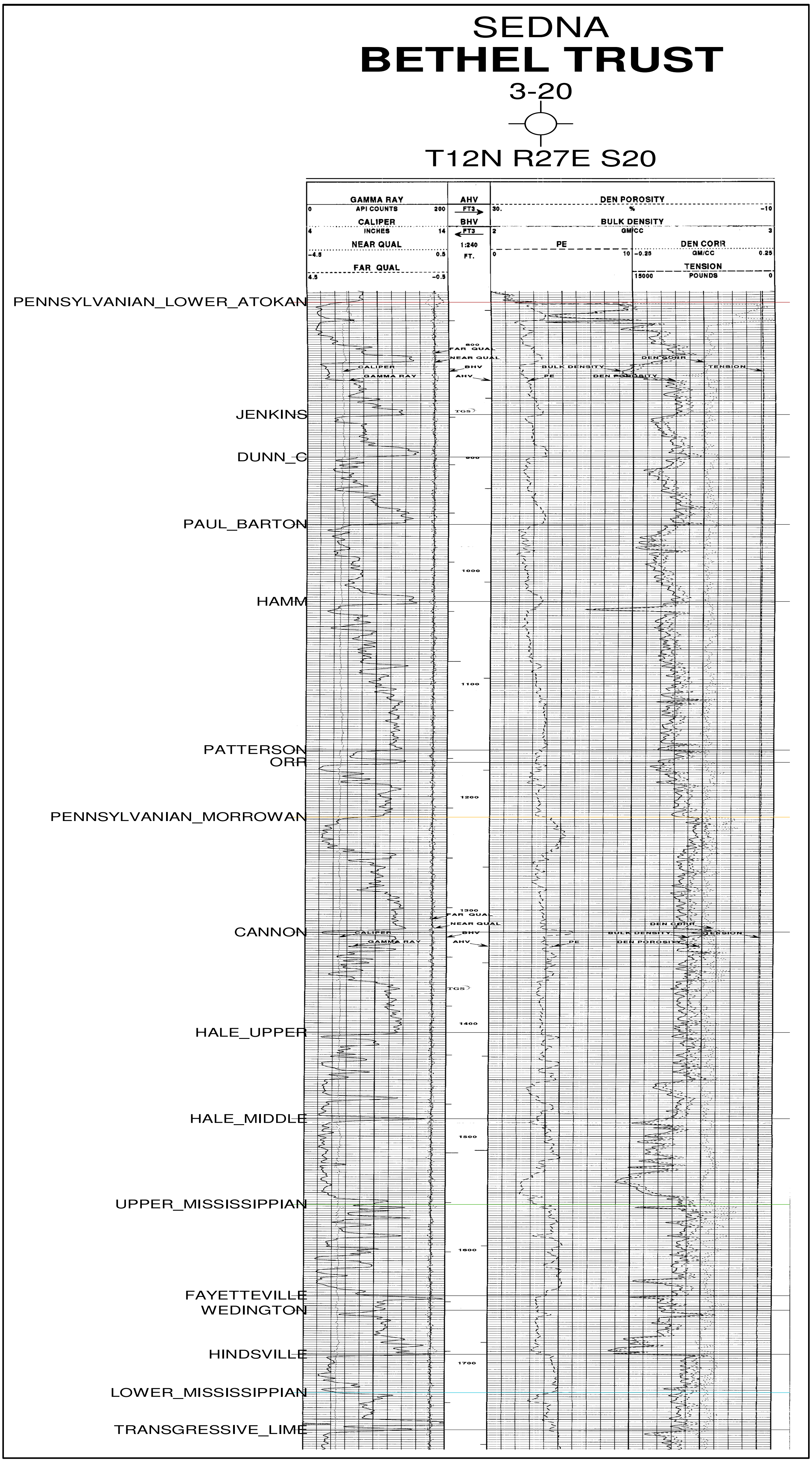

Figure 6. Type Log – Pennsylvanian

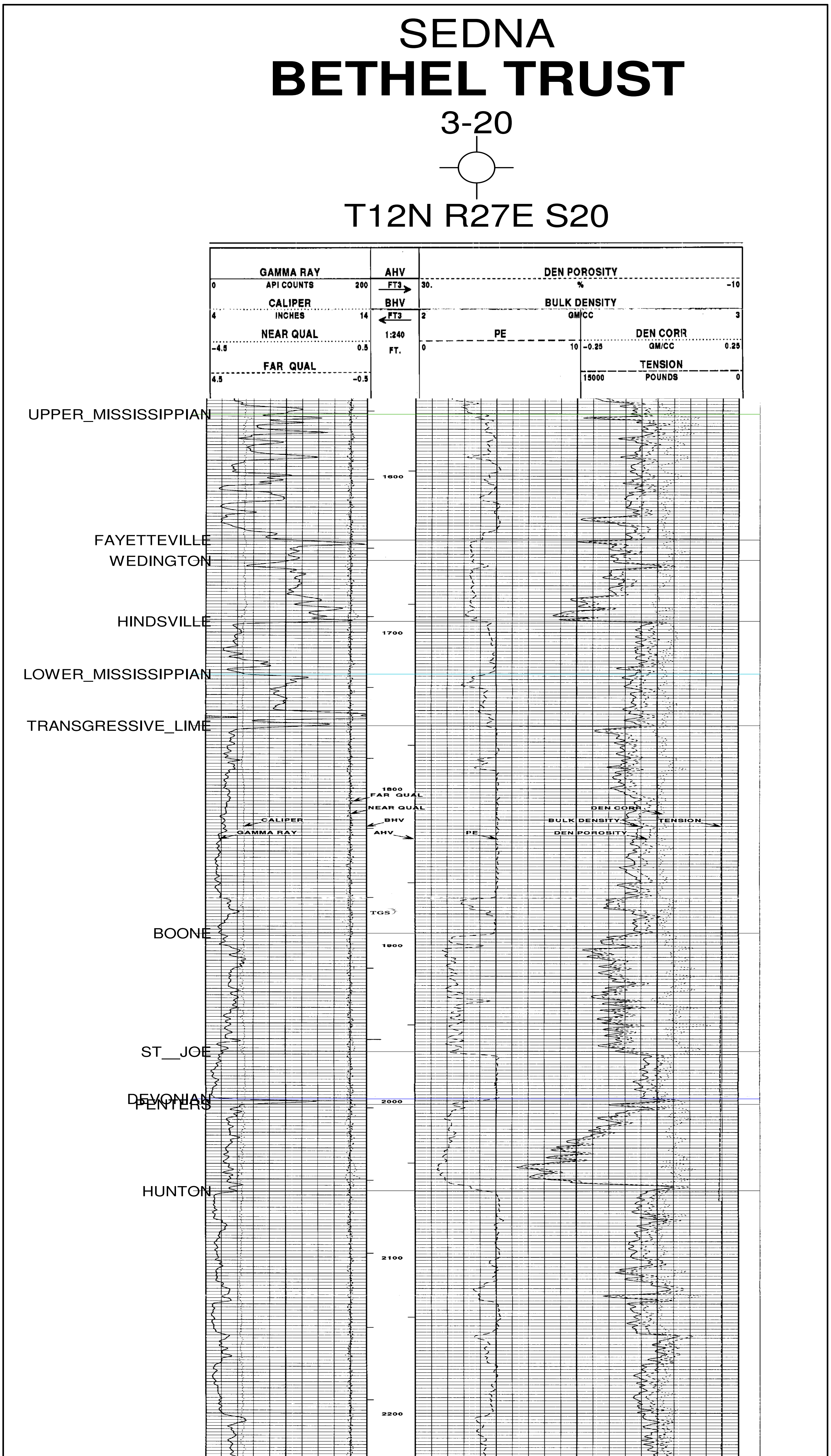

Figure 7. Type Log Mississippian

GEOLOGIC SETTING

The Arkoma Basin is a structurally complex, peripheral foreland basin (Zachry and Sutherland, 1984) located in northern Arkansas and eastern Oklahoma. North to south, the basin ranges from 20 to 50 miles in width. It is bounded by the Ozark Uplift to the north and to the northwest by the Cherokee Platform. The southern boundary of the basin is defined by the Choctaw Fault, which also forms the northern boundary of the Ouachita Mountains (Sutherland and Manger, 1979). East to west, the basin measures 250 miles. The basin is bounded to the west by the Arbuckle Uplift and is buried to the east beneath the Mesozoic cover of the Mississippi River Embayment, where the nature of the basin becomes obscure (Branan, 1968).

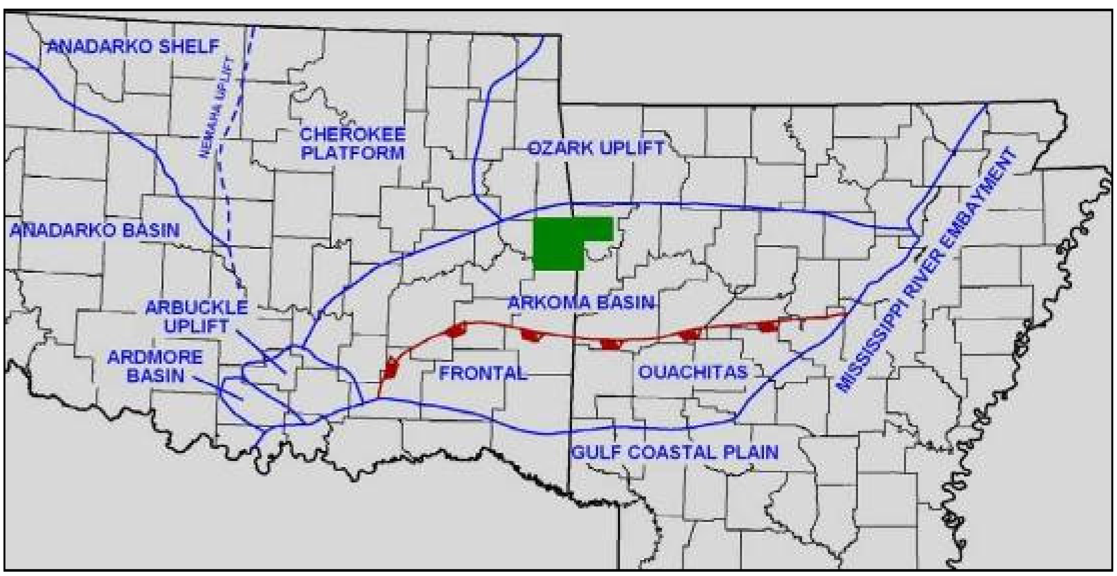

Figure 8. Geological Provinces of Arkansas and Oklahoma with study area shaded green (modified from Zachry and Sutherland 1984).

BASEMENT FEATURES

Northeastern Oklahoma is underlain by one of a number of granite-rhyolite complexes that characterize the buried basement of the southern continental interior of the United States (Denison, 1981). The closest of these exposures is the Precambrian Spavinaw Granite Group which protrudes through the overlying Ordovician Cotter Dolomite in five small hills in Mayes County, Oklahoma and in drill holes along a broad pre-Paleozoic arch extending from southwestern Missouri to Central Oklahoma (Figure 9). Isotopic dating has placed the Spavinaw granite from 1,239-1,315 million years old and the geologic origins of the feature are unknown (Denison 1981).

Two Precambrian rift zones affect the architecture of the southern midcontinent basement; the Central North American Rift System to the west, and the Reelfoot Rift to the east (Figure 10). A series of alternating basement horsts and grabens with subparallel northwesterly strikes connect the two rift systems at right angles (Kisvarsanyi, 2008). These relationships suggest the horst and graben features were formed from transform faults (see Chesapeake and Bolivar Mansfield faults) that were formed during rifting (Figure 10). These northwest-southeast trending faults later became reactivated during the Ouachita Orogen's east-to-west structural tectonic translation (Ingram, 2009).

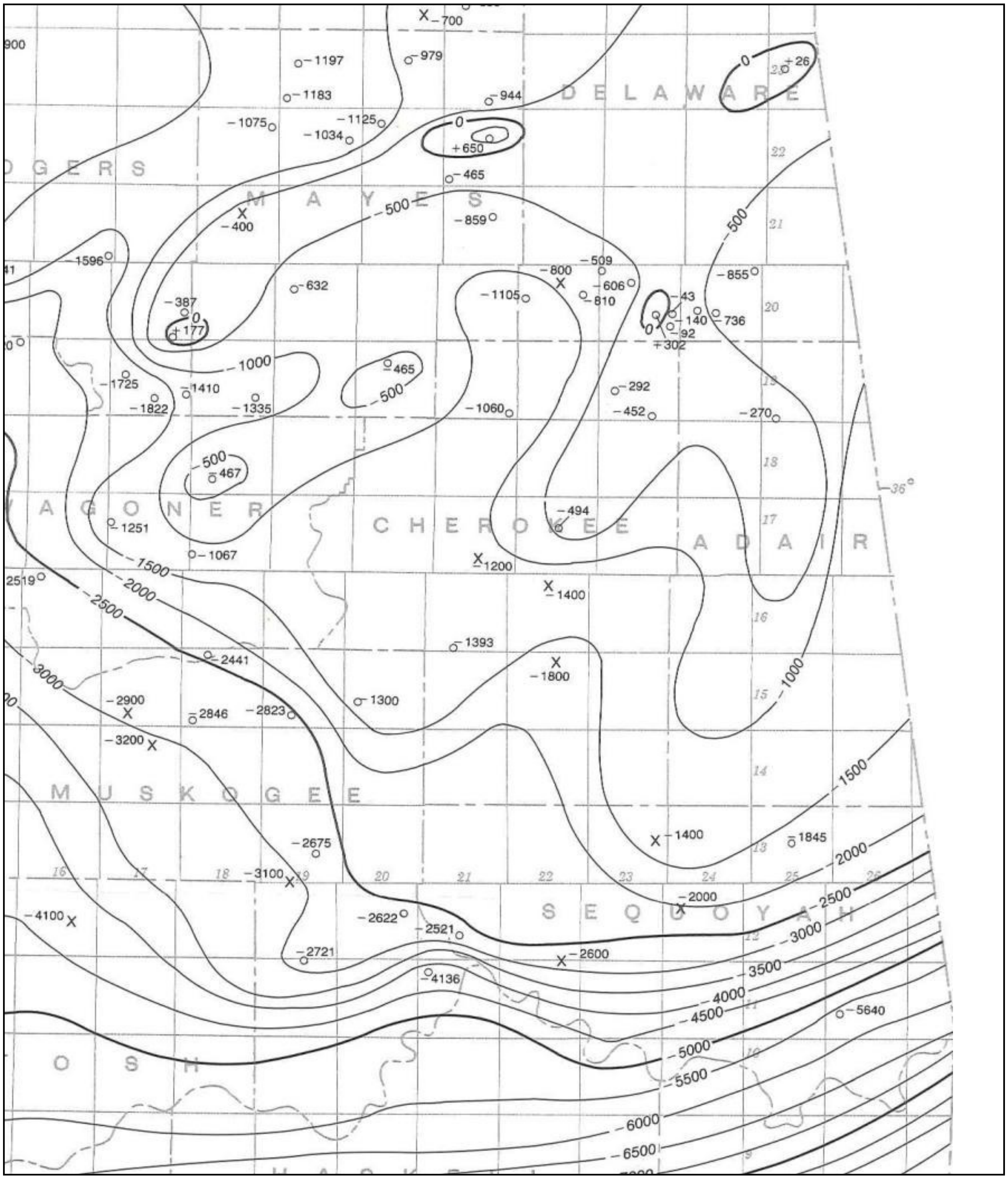

Figure 9. Basement Map of Precambrian Surface in Northeastern Oklahoma, note Spavinaw Granite features as structural highs in Mayes and Delaware Counties (Modified from Denison, 1981)

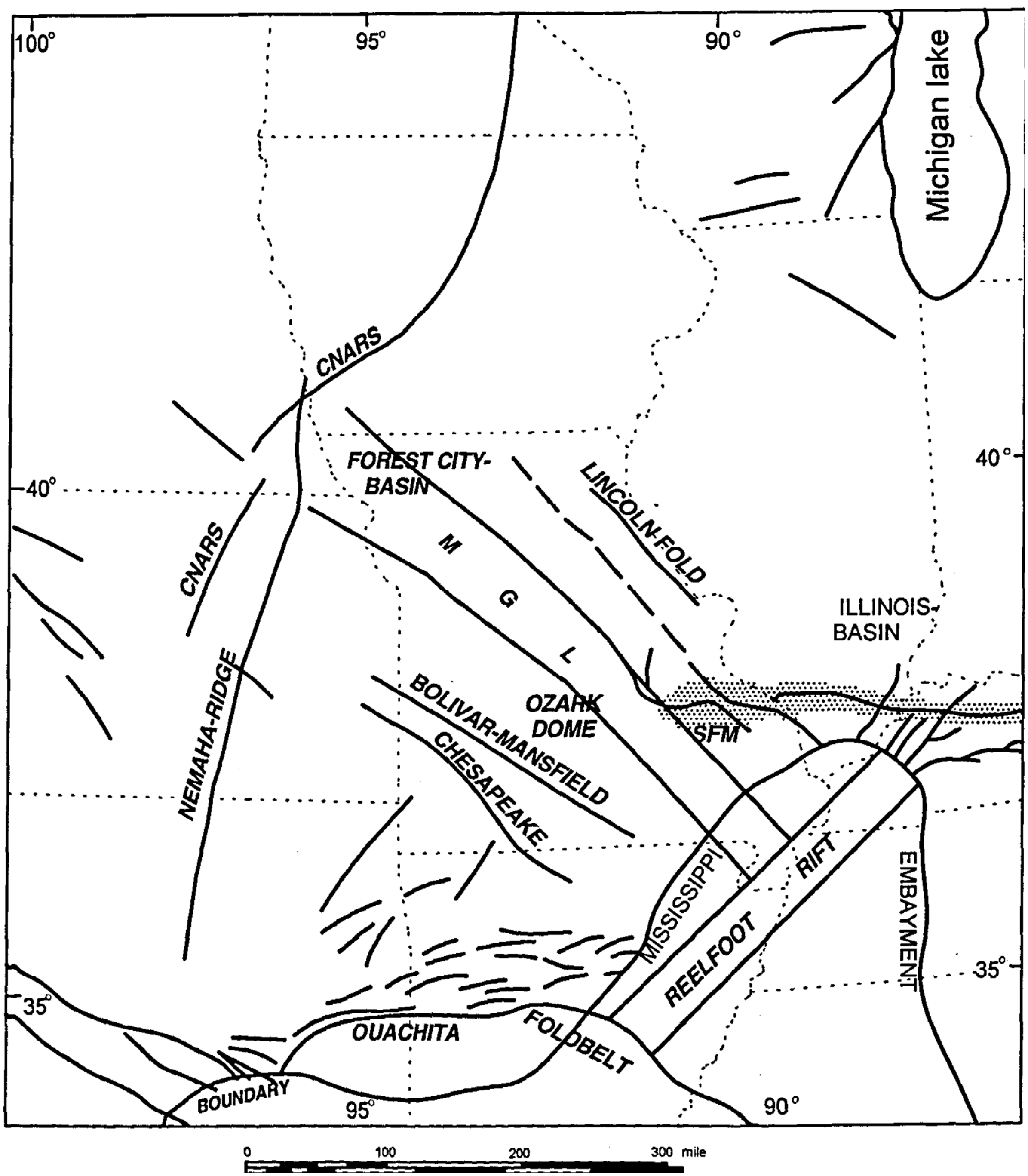

Figure 10. Map showing Central North American (CNARS), Missouri Gravity Low (MGL), Reelfoot Rift Systems and other basement structures of the midcontinent (Kisvarsanyi, 2008).

OZARK DOME

The Ozark Dome dominates the geology of the southern mid-continent as a broad, asymmetrical, cratonic uplift cored by Precambrian granite and rhyolite that is exposed in the St. Francois Mountains region of southeastern Missouri (Manger, 2008). Dips are steeper on the north and east sides of the dome in Missouri, and gentler (less than 1 degree) on the southern flank of the dome in northwestern Arkansas and northeastern Oklahoma (Chinn and Konig, 1973). A series of parallel, northeast-southwest trending normal faults are the only major structural features of the Ozark Dome.

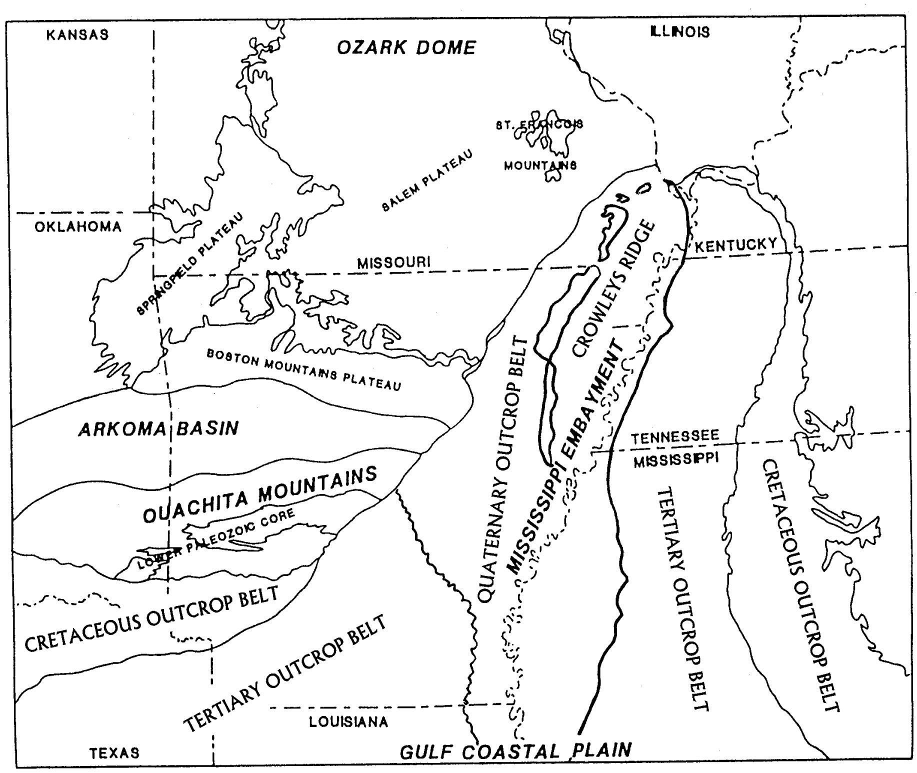

Figure 11. Map showing location of Ozark Dome Plateaus (modified from Manger, Zachry and Garrigan, 1988)

Three broad plateau surfaces are developed away from the center of the dome in the St. Francois Mountains (Figure 11). Of the three, the Salem Plateau is the oldest (capped by lower Ordovician strata), topographically lowest, and the most geographically extensive. The intermediate Springfield Plateau is capped by lower Mississippian strata. The youngest and topographically highest, Boston Mountain Plateau, is capped by lower Atokan strata.

OUACHITA ASSOCIATED TECTONICS

A major episode of rifting resulted in the opening of a proto-Atlantic ocean basin during the latest Precambrian or early Paleozoic (Figure 12A) (Houseknecht, 1986). Following the initial rifting event, the southern margin of North America evolved into a passive margin that persisted throughout the early and middle Paleozoic (Figure 12B). It is along this passive margin, where pre-Devonian shelf carbonates and Devonian-Mississippian marine shales and transported ramp carbonates were deposited.

The ocean basin began to close (Figure 12C) during the Devonian or Mississippian when the oceanic lithosphere was subducted beneath an island arc or continental plate (commonly called Llanoria) (Houseknecht, 1986). Within this convergent tectonic setting, the incipient Ouachita orogenic belt began to form as an accretionary prism along the southern margin of the subduction zone. The exact timing for this event is undetermined. Age dating of Ouachita rocks reveals a widespread metamorphic event during the Devonian (Denison et al., 1977; Denison, 1982) and could be subduction related. By the Mississippian, subduction was clearly underway, as indicated by detritus suggestive of an orogenic provenance (Morris, 1974) and locally abundant volcanic debris (both tuffs and volcaniclastic sandstones) in the Stanley Shale. Throughout the Mississippian and into the earliest Atokan, the shelf along the southern margin of

North America remained a site of slow deposition of shallow marine and non-marine environments, while the deep, remnant ocean basin (Dickinson, 1974) became a site for rapid deposition of eastern-derived (where collision orogenesis had already resulted in uplift along Ouachita trend (Thomas, 1985)) flysch.

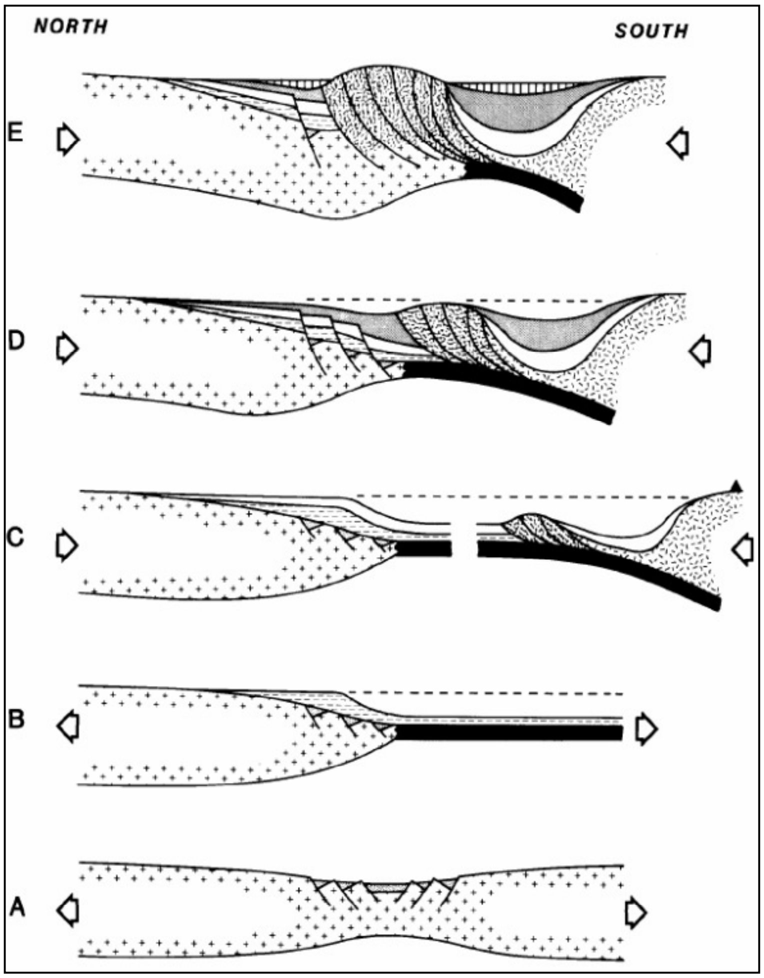

Figure 12. Tectonic History of the Arkoma Basin (Houseknecht, 1986)

A. late Precambrian to earliest Cambrian
B. late Cambrian to earliest Mississippian
C. early Mississippian to earliest Atokan
D. early-middle Atokan
E. late Atokan to Desmoinesian

The remnant ocean basin had become consumed by subduction and the northward advancing subduction complex was being obducted onto the rifted continental margin of North America by early Atokan time (Figure 12D) (Houseknecht, 1986). The southern margin of the North American continental crust was being subjected to flexural bending as a result of attenuated continental crust being drawn into the subduction zone and because of vertical loading by the overriding accretionary prism (Dickinson, 1974). This flexural bending led to widespread normal faulting in the foreland basin. The normal faults generally strike east-west (parallel to the Ouachita fold trend), are mostly downthrown to the south, and offset both the crystalline basement and all overlying sedimentary strata. Normal fault development concurrent with the deposition of lower and middle Atokan strata resulted in thickening on the downthrown sides of the faults (Houseknecht, 1986).

By the late Atokan (Figure 12E), uplift along the frontal thrust belt of the Ouachitas completed the formation of a peripheral foreland basin (Dickinson, 1974) in which shallow marine, deltaic, and fluvial sedimentation prevailed. With the exception of some relatively minor folding and thrusting that continued into the Desmoinesian, the gross structural configuration of the Arkoma-Ouachita system was essentially the same as we see it today (Houseknecht, 1986).

ARKOMA BASIN

The area now occupied by the Arkoma Basin was for 93% of the Paleozoic a tectonically stable shelf, although stable shelf rocks only account for 16% of the basin fill (Houseknecht, 1987). The actual formation of the Arkoma as a foreland basin occurred as a response to compressional tectonics related to the Ouachita Orogeny. Many models have been proposed to explain the origin of the Ouachita orogenic belt. Most of these models have converged on a scenario that involves consumption of oceanic crust and lithosphere via southward dipping subduction and consequent collision between an Atlantic type continental margin (the southern margin of North America) and "Llanoria" (Houseknecht, 1986).

Structurally, the Arkoma basin is asymmetrical with gentle dips on its northern margin and steeper dips on its southern margin. The basin is a topographic low because the Arkansas River has eroded a valley into strata forming the basin along its axis. Within the basin, broad synclines separated by narrow anticlines dominate the surficial structure (Viele, 1973). As noted by Diggs (1961), the area immediately north of the frontal Ouachita thrusts is folded into east-trending and generally east-plunging synclines, such as Poteau Mountain, Mt. Magazine, Mt. Nebo, and subordinate anticlines, such as the Washburn and Ranger anticlines in Sebastian and Yell Counties, respectively. It is accepted that the formation of the basin began with movement on east-west trending normal faults that exhibit growth in the Atokan sections on the downthrown blocks to the south (Figure 13). There seems to be some dispute as to when initial movement on the faults occurred, as some authors suggest the development of the basin began following deposition of the basal Atokan Spiro Sandstone (Houseknecht 1986), where as others suggest the basin did not form until the middle Atokan (Zachry and Sutherland, 1984).

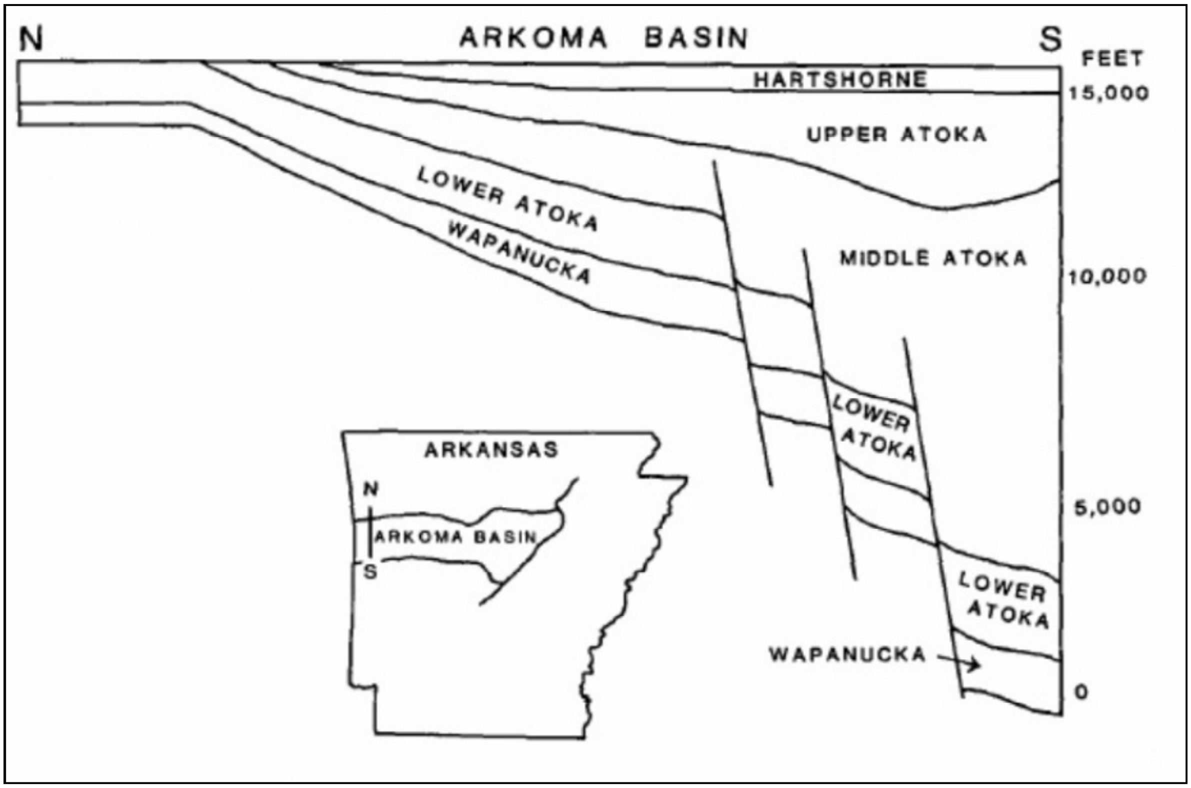

Figure 13. Cross-section showing normal faulting across the Arkoma Basin (Zachry and Sutherland, 1984)

OUACHITA MOUNTAINS

The Ouachita Mountains are fold belt mountains formed from strata that were deformed by the Late Paleozoic compressional events associated with continental collision between the southern margin of North America and “Llanoria”. The entire Ouachita fold belt extends from the Marathon Basin region of west Texas, all the way to the southern edge of the Appalachian Mountains in west Alabama. Except for the Ouachita Mountains (western Oklahoma and central Arkansas) and the Marathon Uplift (west Texas), most of the fold belt is confined to the subsurface (Figure 14).

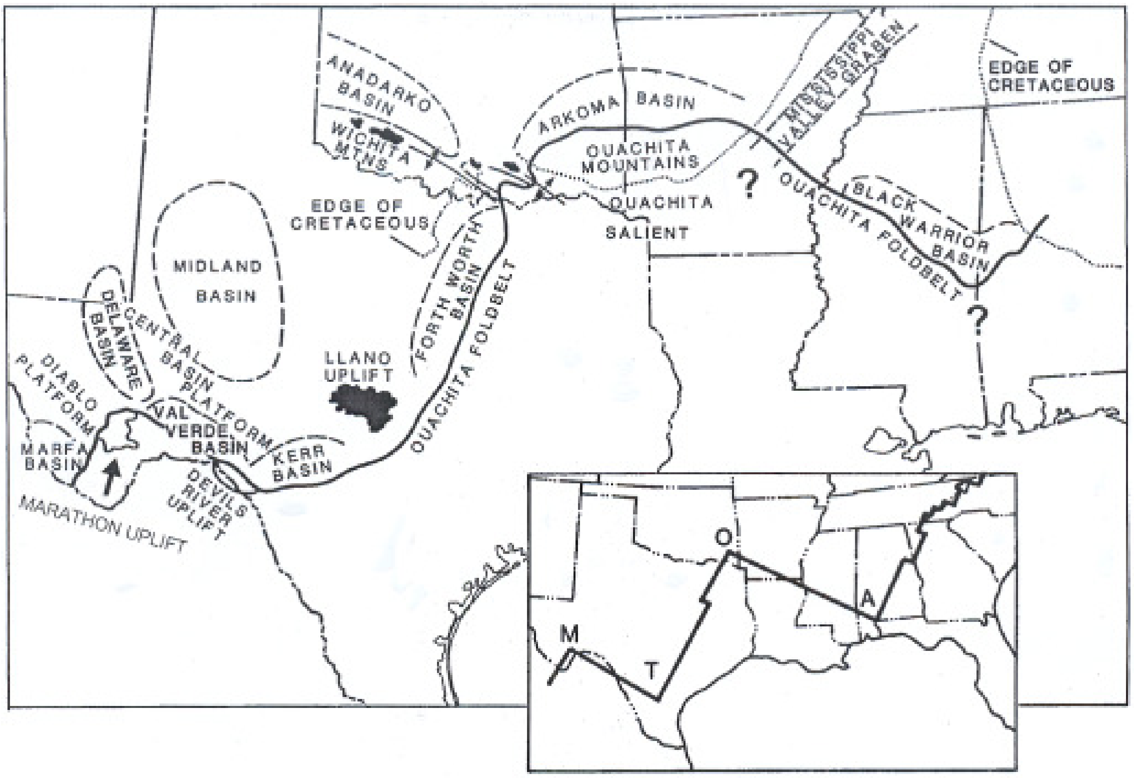

Figure 1. Major foreland structural features adjacent to the Ouachita foldbelt. Inset map shows the interpreted outline of the late Proterozoic–early Paleozoic continental margins from Thomas (1977). A = Alabama recess, O = Ouachita salient, T = Texas recess, M = Marathon salient.

Figure 14. Major Structural Features Associated with the Ouachita Foldbelt, Southern Continental Margin, North America (modified from Denison, 1989, Figure 1)

LITHOSTRATIGRAPHY

LOWER MISSISSIPPIAN

The Kinderhookian St. Joe Limestone composes the oldest strata of Mississippian age in the study area. Named after the town of St. Joe near its type locality in Searcy County, Arkansas, the St. Joe rests unconformably on the Chattanooga Shale as indicated by a weathered zone of green-black shale at its base and the localized absence of the Chattanooga Shale (Huffman, 1958). The St. Joe is divided into four members; in ascending order, they are the Bachelor, Compton, Northview and Pierson. The Bachelor and Northview are terrigenous clastic units that pinch-out eastward and into the subsurface (Manger, 2008). Where the Northview pinches out, the Compton and Pierson are indistinguishable and therefore, the St. Joe Limestone is undifferentiated. Over 40 Waulsortian mounds (named after "reef" limestones and dolomites cropping out near Waulsort, Belgium) have been reported from the Compton Member in Oklahoma and Missouri, but not Arkansas (Troell, 1962; Manger and Thompson, 1982) (Figure 15). They are modeled as homogeneous carbonate mud-cored bodies that contain crinozoan fragments, fenestellid bryozoans, *Stromatactis*, and various other subordinate amounts of allochemical constituents; they developed along a northeast southwest trending axis, below effective wave base, on the upper portion of the ramp separating the Burlington Shelf and Marathon-Ouachita Trough (Manger, 2008). The core is mostly carbonate mud, lacks a framework organism, and may have steep sides, dipping up to 50 degrees (Lees, 1961).

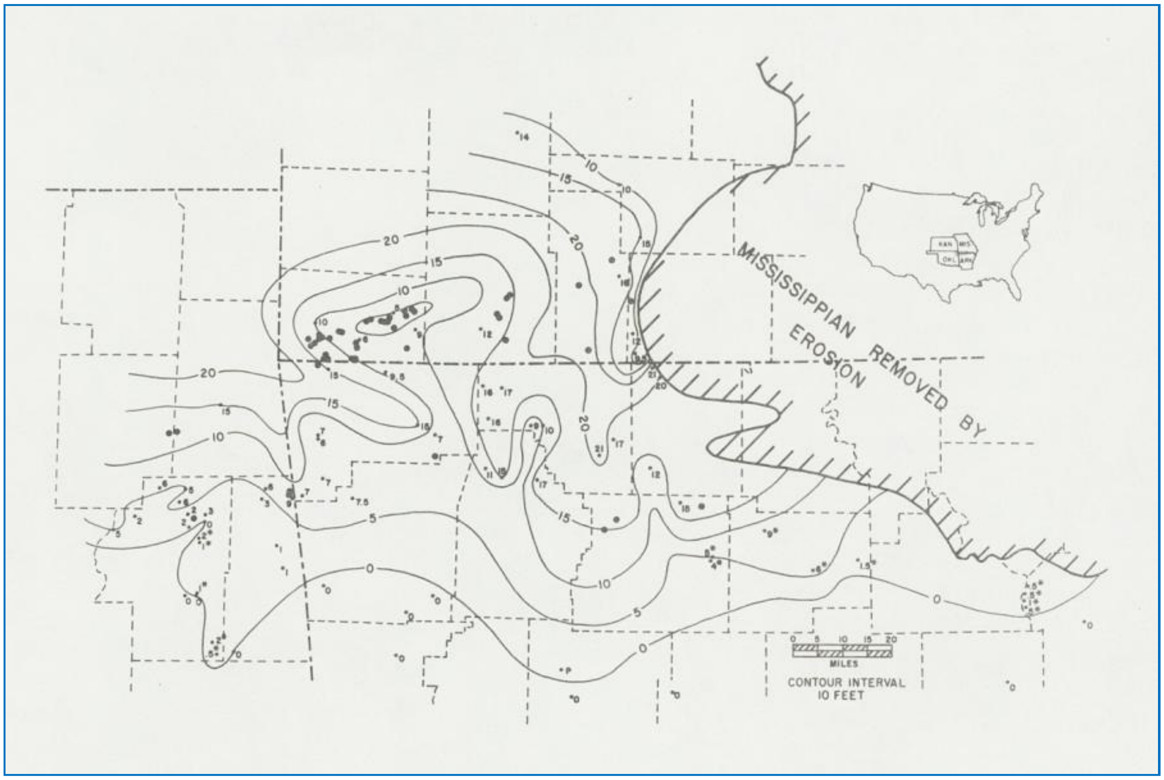

Figure 15. Isopach map of Compton Member, St. Joe Limestone with heavy dots indicating known Waulsortian Mound Locations (Manger and Thompson, 1982)

The Boone Formation (Mississippian-Osagean) is named after Boone County, Arkansas, although no type section has ever been proposed. In northern Arkansas, the Boone Limestone represents a thick interval (300-350 feet) of cherty limestone that rests conformably on top of the St. Joe Limestone. The lower portion of the Boone contains penecontemporaneous chert, while the upper Boone contains chert that was formed diagenetically (Manger, 2008).

In northeastern Oklahoma, the Reeds Spring and Keokuk Formations are equivalent with the lower and upper portions of the Boone formation, respectively. The Reeds Spring Limestone, named by Moore (1928) from exposures near Reeds Spring in southwestern Missouri, unconformably overlies the St. Joe Limestone (Huffman, 1958). The Keokuk Limestone, named by Owen (1852) from exposures near the town of Keokuk, Iowa, unconformably overlies the Reeds Spring Limestone according to Huffman (1958). No evidence for either unconformity exists (Manger, personal communication). The Reeds Spring Limestone consists of nearly equal amounts of thin, alternating, fine-grained, dense, thin-bedded limestone and dark-gray to blue-gray chert, while the Keokuk Limestone consists of massive white to buff fossiliferous chert.

The Mayes Group (Mississippian-Meramecian to Chesterian) unconformably overlies the Keokuk Formation (Huffman, 1958). The name Mayes was applied by Snider (1915) and taken from Mayes County, Oklahoma. The Mayes Group includes the Hindsville Limestone and the Moorefield Formation, which is composed of four members in Oklahoma; in ascending order, they are the Tahlequah, Bayou Menard, Lindsey Bridge, and Ordinance Plant Members (Huffman, 1958).

The Tahlequah Member takes its name from an exposure near Tahlequah, Oklahoma and ranges in thickness from 0-30 feet (Huffman, 1958). It is described as a massive, light to dark gray, medium-crystalline, glauconitic limestone with large scale cross-bedding developed locally. In some areas it contains nodules and stringers of whitish-tan chert. Just northwest of the study area, near Marble City on Sallisaw Creek (Section 13, T. 15 N., R. 23 E.), the Tahlequah Member overlies the Reeds Spring Limestone.

The Bayou Menard Member is named for exposures along Bayou Menard southeast of Muskogee and Fort Gibson (Section 19, T. 15 N., R. 20 E.) where it is composed of black, argillaceous limestones and interbedded black, calcareous shales (Huffman, 1958). The formation is highly fossiliferous, has a bituminous odor, and hollow fossil interiors have yielded traces of oil. Eastward, towards the vicinity of Stillwell, Oklahoma, the Bayou Menard Member intergrades with medium crystalline limestone of the overlying Lindsey Bridge Member.

The Lindsey Bridge Member is best developed along the north bank of the Grand River in the cliff east of the Lindsey Bridge in southern Mayes County, Oklahoma (Section 6, T. 20 N., R. 20 E.) (Huffman, 1958). It is characterized as a gray, medium-crystalline, locally oolitic, cross-bedded calcarenite that contains chert fragments ranging in size from pebbles to microscopic specks. The chert fragments are erosional remnants from Keokuk or Reeds Spring Limestone "knobs" that stood as islands and served as the local sources of the chert detritus. The size of the chert fragments are an indication of how close the area of deposition was to the local source. The Lindsey Bridge Member is believed to be conformable with the overlying Ordnance Plant Member.

The type locality for the Ordnance Plant member is located in the Ordnance Plant area of Pryor Creek and at the west end of Low Water Dam in Oklahoma (Sections 11 and 14, T20N, R19E) (Huffman, 1958). At the type locality, the Ordnance Plant Member can be broken into three intervals. The lower section is about nine feet thick and is composed of a blue to yellow siltstone; the middle section measures 15 feet thick and is composed of heavy bedded, fine-grained, dense, calcareous siltstone; and the ten feet thick upper section is a brown to black, platy, limestone and shale. From the type locality and towards the study area, the middle and upper sections of the Ordnance Plant Member thin and converge with the lower section. About six miles north of the study area at Stillwell Quarry (Section 26, T20N, R20E), the entire section is described as a yellow, platy, silty lithology with occasional interbeds of dense, blue calcareous siltstone. The Ordnance Plant Member is overlain unconformably by the Hindsville Limestone.

It should be mentioned that the Moorefield Formation was incorrectly carried by Huffman (1958) into Oklahoma from Arkansas and applied it to all strata lying between the Keokuk and Hindsville Limestones. The name Moorefield was originally proposed by Adams (1904) for exposures at Moorefield, Independence County, in northeastern Arkansas. At this locality, the Moorefield consists of black shale and siliceous limestone in its lower portion, which is succeeded by dark calcareous and phosphatic shales with black sideritic concretions (Manger, 2008). In northeastern Arkansas, the Moorefield is more than 300 feet thick and as it extends westward it thins before pinching out in the area of Limestone, Newton County, Arkansas. In western Arkansas, near the Arkansas-Oklahoma state line, limestones and shales are present that are coeval, but have nothing to do with the Moorefield of northeastern Arkansas. These limestones and shales extend into Oklahoma, and Ogren (1968) proposed that they be included with the Mayes group of Oklahoma.

UPPER MISSISSIPPIAN

Purdue and Miser (1916) named the Hindsville Limestone (Mississippian- Chesterian) for exposures near Hindsville, Arkansas and the name “Hindsville” carries into eastern Oklahoma. The Hindsville Limestone is considered a calcareous facies of the Batesville Sandstone of northern Arkansas and consists of a gray, medium crystalline, thick-bedded, oolitic and fossiliferous limestone (Huffman, 1958). Thicknesses of the Hindsville range from completely absent to as much as 50 feet, with the average being around 25 feet. The Hindsville Limestone is conformable with the overlying Fayetteville Shale.

The Fayetteville Shale (Mississippian-Chesterian) was named by Simonds (1891) for exposures in the vicinity of Fayetteville, Washington County, Arkansas. It can be divided into three intervals: the lower Fayetteville Shale member, the Wedington Sandstone Member, and the upper Fayetteville Shale member. The informally named lower and upper members consist of black shales, while the formally named Wedington Sandstone Member (Adams, 1904) is mostly characterized by fine to medium grained, moderately sorted, sub-rounded, multi-cycle quartz sand (Price, 1981). Thicknesses for the entire Fayetteville range from 10-400 feet in northern Arkansas (Giles and Jones, 1937) and the Wedington Sandstone ranges from 2-70 feet, but is generally less than 30 feet (Price, 1981). The Pitkin Limestone conformably overlies the Fayetteville Shale.

The Pitkin Limestone (Mississippian-Chesterian) was named by Adams (1904) for exposures near the Pitkin Post Office (now Woolsey) in Washington County, Arkansas. The Pitkin is a succession of shelf carbonates, including oolite, bioclastic carbonate, and carbonate mud, commonly in the form of thrombolite mounds (Webb, 1987). Dark gray, calcareous partings occur throughout and black fissile shale is present in the lower portions (Huffman, 1958). The Pitkin is succeeded unconformably by the Hale Formation and this contact represents the Mississippian-Pennsylvanian boundary.

PENNSYLVANIAN- MORROWAN

In this study area, the Hale Formation is the oldest formation of the Pennsylvanian System. The name Hale was given by Adams and Ulrich (1905) to the basal member of the Morrow Formation and when the Morrow was raised to group rank by Purdue (1907) the Hale became a formation. The Hale is subdivided into the Cane Hill and overlying Prairie Grove Members, both named by Henbest (1953) for roadcuts along Arkansas Highway 59 in southwestern Washington County. Almost immediately across the Arkansas-Oklahoma state line, the Cane Hill Member is absent, and presumably there is an increased duration of the Mississippian-Pennsylvanian boundary (Manger, 2008).

At its type-locality, the Cane Hill is about 40 feet thick and increases to almost 100 feet thick eastward across the Arkoma shelf. The Cane Hill Member is a noncalcareous unit composed of dark gray, silty shale interlaminated with thin-bedded, fine-grained sandstone and siltstone (Sutherland and Henry, 1977).

The Prairie Grove Member is typically a massively bedded, calcareous sandstone that displays large scale cross-bedding and exhibits a "honeycombed" weathering surface (Manger, 1979). At its type section, the Prairie Grove is about 100 feet thick and increases in thickness eastward across the Arkoma shelf. In Oklahoma, the Prairie Grove member is referred to as the Braggs Member of the Sausbee Formation (Sutherland and Henry, 1977). The contact between the Prairie Grove Member and the overlying Brentwood Member of the Bloyd Formation is conformable and gradational (Huffman, 1958).

Purdue (1907) named the Bloyd Formation as the upper division of the Morrowan Group after exposures on Bloyd Mountain, Washington County, Arkansas. The Bloyd Formation is made up of four formal members; in ascending order, the Brentwood (quartz sand-bearing high energy limestones and interbedded dark, commonly calcareous shales), Woolsey (light to dark colored, terrestrial shales and claystone often interbedded with siltstone), Dye (dark gray, concretionary shale), and Kessler (limestone, usually oolitic with an admixture of bioclastic grains, crinozoan detritus, and quartz sand) Members. Eastward from the type area, one informal member, the middle Bloyd (thick, quartz pebble-bearing sandstone) Sandstone, is recognized as equivalent to the Woolsey and Basal Dye Members (Manger, 2008). An unconformity between the Woolsey and Dye members separates the Bloyd formation into upper and lower divisions in Arkansas nomenclature. In the lower division, the Woolsey and Brentwood Members extend into Oklahoma as the Sausbee Formation, while in the upper division the Dye and Kessler Members extend into Oklahoma as the McCully Formation. The Bloyd Formation is overlain unconformably by the Atoka Formation.

PENNSYLVANIAN- ATOKAN

Taff and Adams (1900) named the Atoka Formation for exposures of non-coal bearing, alternating sandstones and shales in the eastern Choctaw coalfield in Oklahoma. No type-section exists, however, Sutherland and Manger (1984) have suggested exposures near Clarita, Oklahoma, which is about 18 miles northwest of Atoka, Oklahoma. Only two formally named members of the Atoka Formation exist, the Trace Creek Shale Member (Henbest, 1962) and the Greenland Sandstone Member (Henbest, 1953). Informal names and divisions have been applied to the sand intervals of the Atoka formation by petroleum geologists. This study will use names consistent with those used by the petroleum industry and the following (in ascending order) make up the lower division of the Atoka formation; the Spiro, Patterson, Hamm, Paul Barton, Dunn "C", Lower Jenkins, Upper Jenkins, and Sells sand intervals.

DEPOSITIONAL HISTORY

LOWER MISSISSIPPIAN

The interval that has been labeled in this study as the lower Mississippian can be packaged into two transgressive-regressive sequence packages. The first is a complete package and consists of all rocks from the top of the Chattanooga to the top of the Boone (Figure 6), and is bounded by unconformities. The second package consists of all rocks from the top of the Boone unconformity to the base of the Hindsville and prior to this study; rocks associated with the transgressive phase of this sequence were unidentified.

The Boone and St. Joe Formations were formed under similar shallow ramp conditions from lower Mississippian deposition that occurred as a result of a complete, third order, transgressive/regressive carbonate cycle. The St. Joe Formation was deposited as a chert-free limestone during the initial transgression interval and was followed by the chert-bearing Boone during the maximum flooding and highstand-regressive sequences. The lower Boone represents the maximum flooding interval, while the upper Boone represents the highstand/regressive sequence. Regression during the Meramecian produced a low-stand wedge confined to northeastern Arkansas (Moorefield Formation) and an unconformity at the top of the Boone.

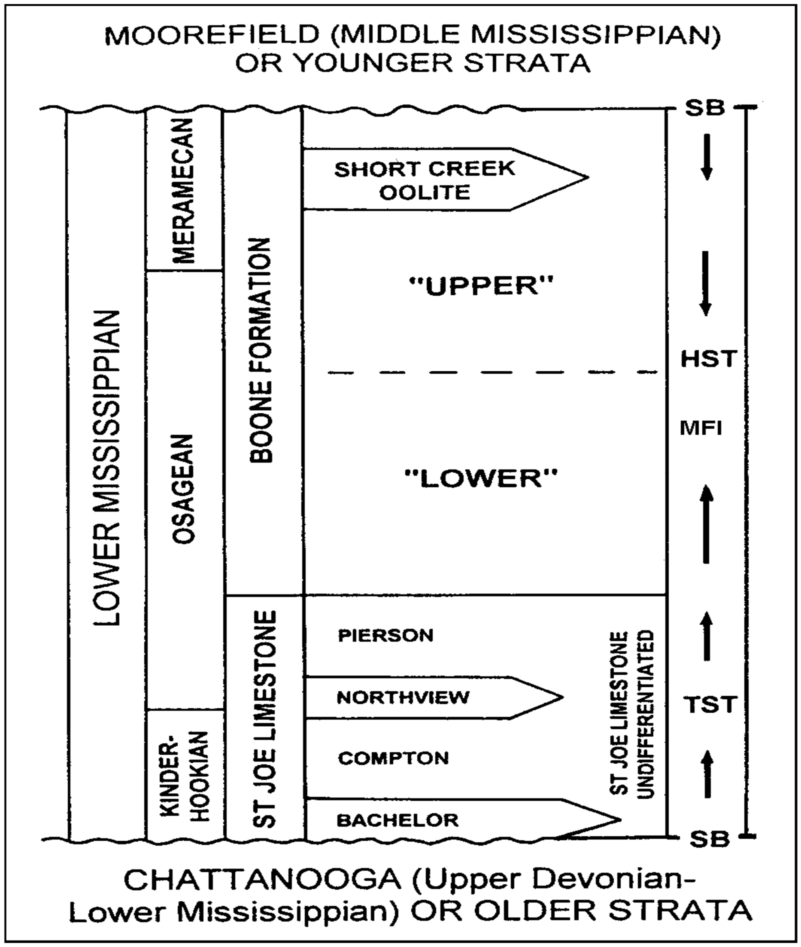

Figure 16. Lithostratigraphy and Sequence Stratigraphy, Lower Mississippian, Southern Ozarks (modified from Manger and Shelby, 2000)

The second lower Mississippian sequence (Figure 17) involves transgression over the eroded Boone surface and a subsequent regression of the Mayes carbonates (Turmelle, 1982). This sequence overlaps with what has been designated as the upper and lower Mississippian boundary in this study, so only the transgressive phase should be treated as lower Mississippian. Inundation of the Boone surface by marine waters led to the establishment of Mayes carbonates (Turmelle, 1982). Turmelle (1982) noted that a transgressive facies is not present at the base of the Mayes, suggesting inundation was a rapid event and conditions must not have been favorable for carbonate sedimentation. This idea hinges on the interpretation that Moorefield and Hindsville lithologies are facies of one another.

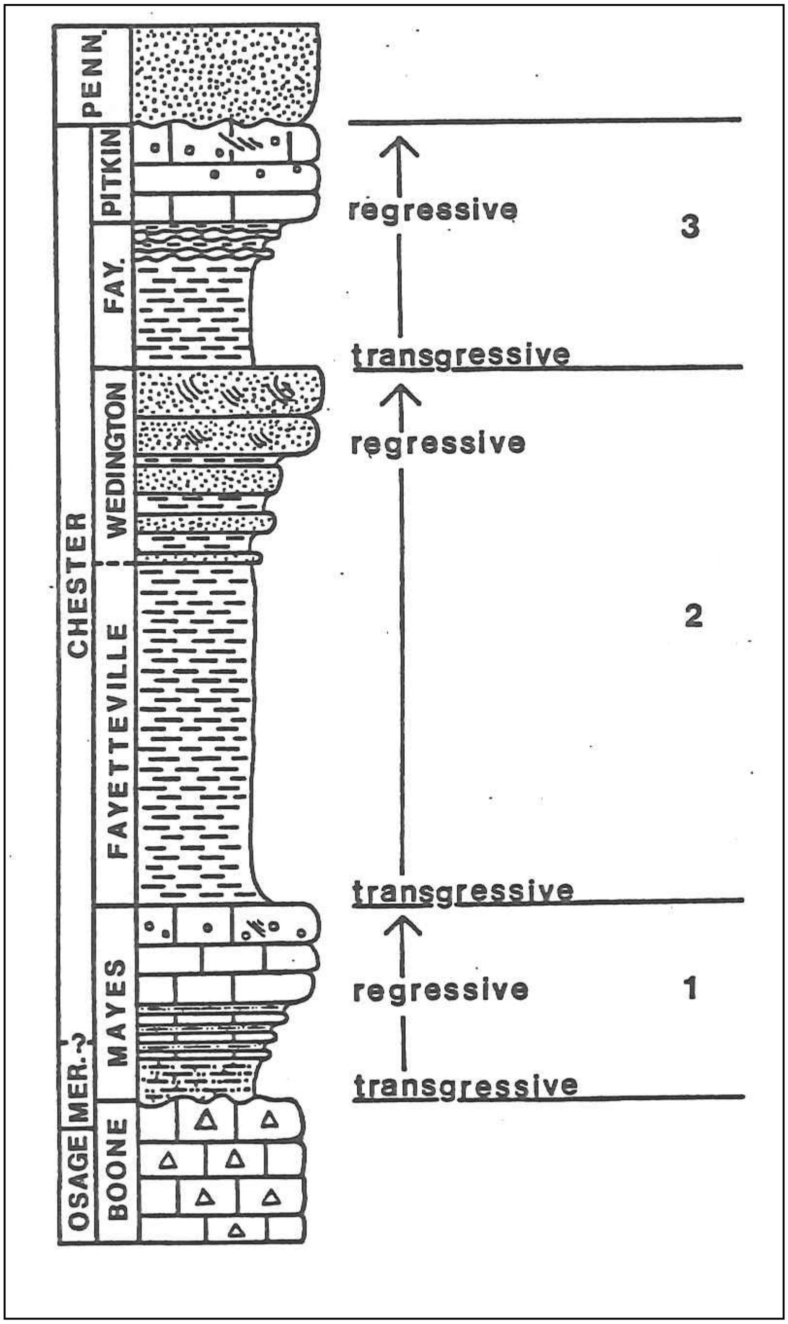

Figure 17. Upper Mississippian transgressive-regressive depositional events as described by Turmelle (Turmelle, 1982)

UPPER MISSISSIPPIAN

The upper Mississippian, as defined by this study, consists of all rocks between the base of the Hindsville and top of the Pitkin. It has been interpreted as one complete (Manger, 2008), or one partial and two complete (Turmelle, 1982), transgressive-regressive sequences.

Manger (2008) suggests the Chesterian series in northwestern Arkansas comprises a single, third-order Vail transgressive-regressive cycle bounded by type 1 erosional unconformities (Figure 18). The Hindsville Formation developed in the initial transgressive systems tract as a high-energy, bioclastic, oolitic limestone representing shallow, inner ramp, shoals (Manger, 2008). To the east, the Hindsville grades into the coeval Batesville Sandstone that was deposited in response to sediments being supplied from the ancestral Mississippi Embayment. As sea levels continued to rise the lower Fayetteville Shale blanketed the Hindsville-Batesville systems tract and represents a deeper muddy shelf environment as the sequence transformed to the maximum flooding interval. The Wedington Sandstone was deposited as a tidally influenced delta system during stillstand conditions towards the end of lower Fayetteville deposition. The upper Fayetteville succeeds the Wedington and along with the overlying Pitkin Limestone, represents the highstand systems tract.

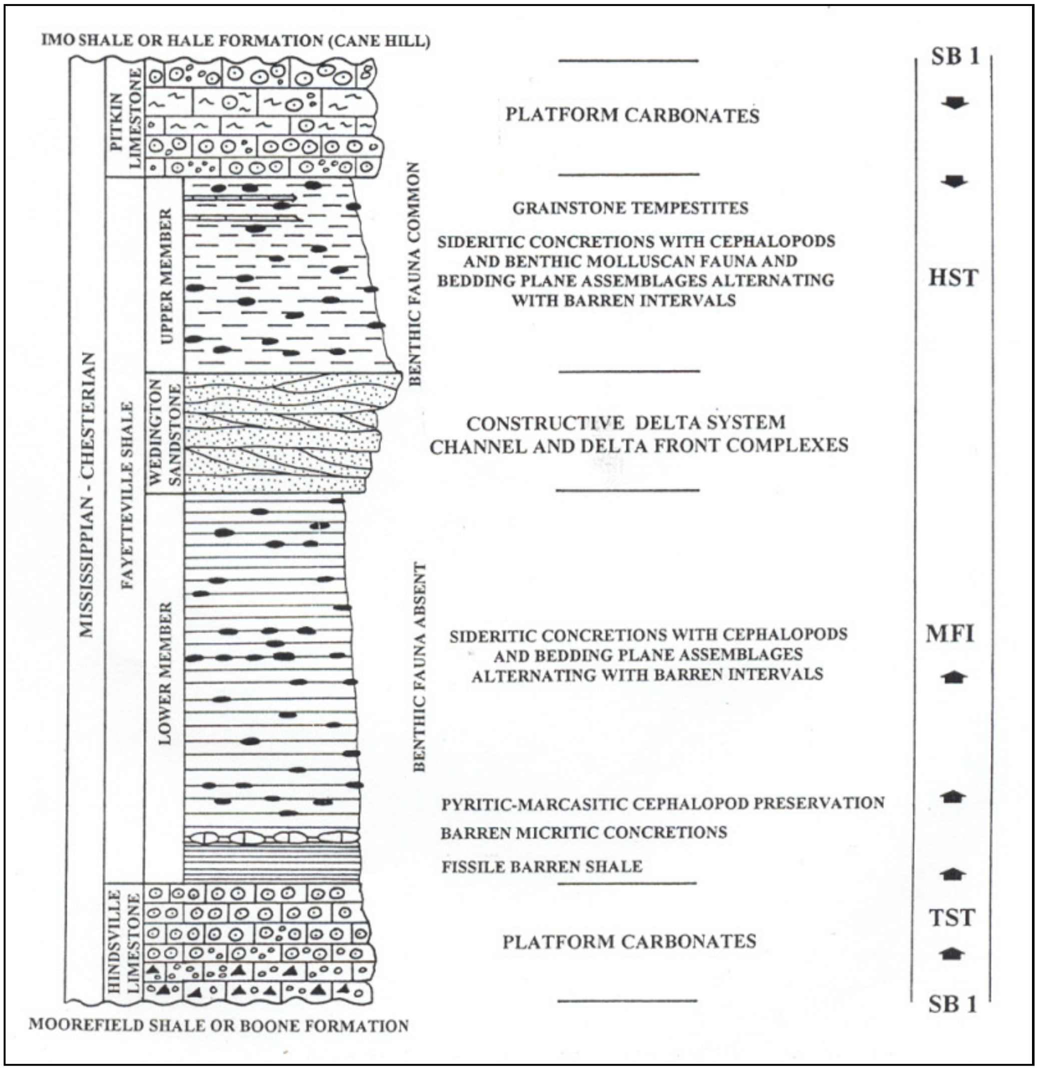

Figure 18. Sequence Stratigraphic and Depositional Summary of the Chesterian Lithostratigraphic Succession, Northwestern Arkansas (Manger, 2008)

The partial upper Mississippian sequence interpreted by Turmelle (1982) is the regressive phase of the same sequence previously mentioned as being responsible for Mayes deposition (Figure 17) in the lower Mississippian. This regressive phase allowed for the high energy deposition of the Hindsville Limestone.

The second sequence identified by Turmelle (1982) involved rapid transgression of seas over the Mayes group, abruptly ending carbonate deposition and allowing deposition of shale

(Figure 17). The basal portion of the Fayetteville contains beds of limestone, suggesting a transitional relationship between the Mayes and Fayetteville. Transgression was followed by progradation of the Fayetteville-Wedington delta system as the black, fissile shales of the Fayetteville are representative of outer shelf and prodelta deposits, while the Wedington includes upper deltaic environments (McNully and Jackson, 1974; Price, 1981).

The third lower Mississippian sequence identified by Turmelle (1984) began with rapid transgression after the deposition of the Wedington Sandstone and ended with regression that formed the Pitkin Limestone. The post-Wedington transgression was a result of upstream avulsion of fluvial systems that caused the abandoned delta to compact and subside. The diminished terrigenous output allowed for the accumulation of the carbonates of the Pitkin Limestone.

PENNSYLVANIAN MORROWAN

Two, third-order cycles dominated by siliciclastic deposition on the Arkoma Shelf represent the Morrowan Series (Manger, 2008). Maximum flooding and highstand conditions are marked by limestones and shales. Facies changes from siliciclastics in Arkansas to carbonates in Oklahoma indicate east-west delivery across the Arkoma shelf. Regression of the first Morrowan cycle is marked by terrestrial coal deposits. A type 1 unconformity caps the Morrowan depositional sequence at the Morrowan-Atokan series boundary. The Morrowan sequence includes the following systems tracts: Hale-Sausbee transgressive systems tract, Brentwood-upper Braggs-Brewer Bend highstand, Woolsey – “middle Bloyd” terrestrial sequence, and the Dye-Chisum Quarry transgression.

The Hale-Sausbee transgressive systems tract that began the Morrowan Series developed a tidal flat to tidally influenced, shelf siliciclastic sequence represented by the Cane Hill Member of the Hale Formation (Manger 2008). The Cane Hill is present across northern Arkansas but pinches out before reaching into Oklahoma where the Cane Hill interval is represented by an increased duration of erosion at the Pennsylvanian-Mississippian boundary. Sea level continued to rise and established longshore currents parallel to the shoreline (Figure 19) producing a thick sequence of cross-bedded, upper and middle shoreface sheet sands. These sands represent the Prairie Grove Member of the Hale Formation that on laps the Cane Hill Member and eventually the Mississippian-Pennsylvanian unconformity in northeastern Oklahoma where the interval is named the lower Braggs Member of the Sausbee Formation.

Maximum flooding of the Arkoma shelf is represented by alternations of grain-dominated carbonates and black shales assigned to the Brentwood Member of the Bloyd Formation in northwestern Arkansas and the upper Braggs and Brewer Bend Members of the Sausbee Formation in northeastern Oklahoma (Manger 2008). In northern Arkansas, most carbonates contain a significant amount of quartz sand, particularly in the lower parasequences. In Oklahoma, carbonate development was more extensive and deposition occurred under quieter conditions.

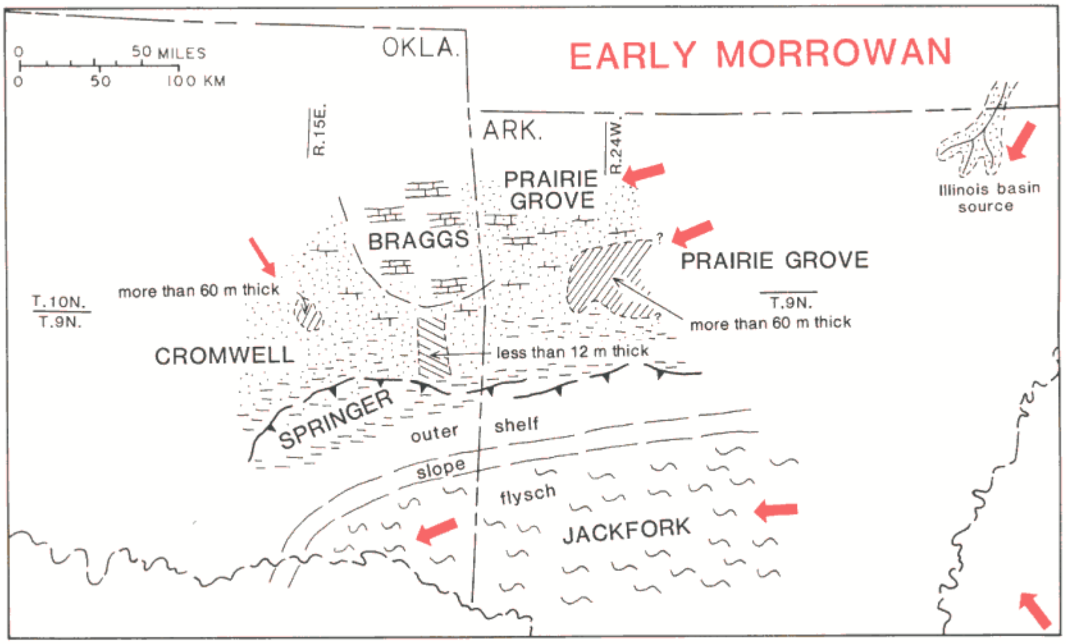

Figure 19. Early Morrowan Depositional Patterns and Paleogeography (Sutherland, 1988)

The highstand conditions of the Brentwood-Brewer Bend parasequences were followed by rapid regression (Manger 2008). In northeastern Oklahoma, the top of the Brewer Bend Member of the Sausbee Formation is marked by an unconformity and there is no record of deposition prior to the marine conditions that bury the unconformity. The Woolsey Member of the Bloyd Formation is a terrestrial shale sequence with one or two thin, bituminous coal seams that succeeds the Brentwood Member of the Bloyd Formation. The Woolsey is mostly confined to Washington and Benton Counties, Arkansas where its maximum thickness exceeds 100 feet (McGilvery and Berlau, 1981). East of Washington County and across most of north-central Arkansas (Figure 20), the Woolsey sequence is replaced by a thick, quartz pebble conglomeratic sandstone representing south-flowing braided stream systems on a near-strand coastal plain (Zachry, 1977).

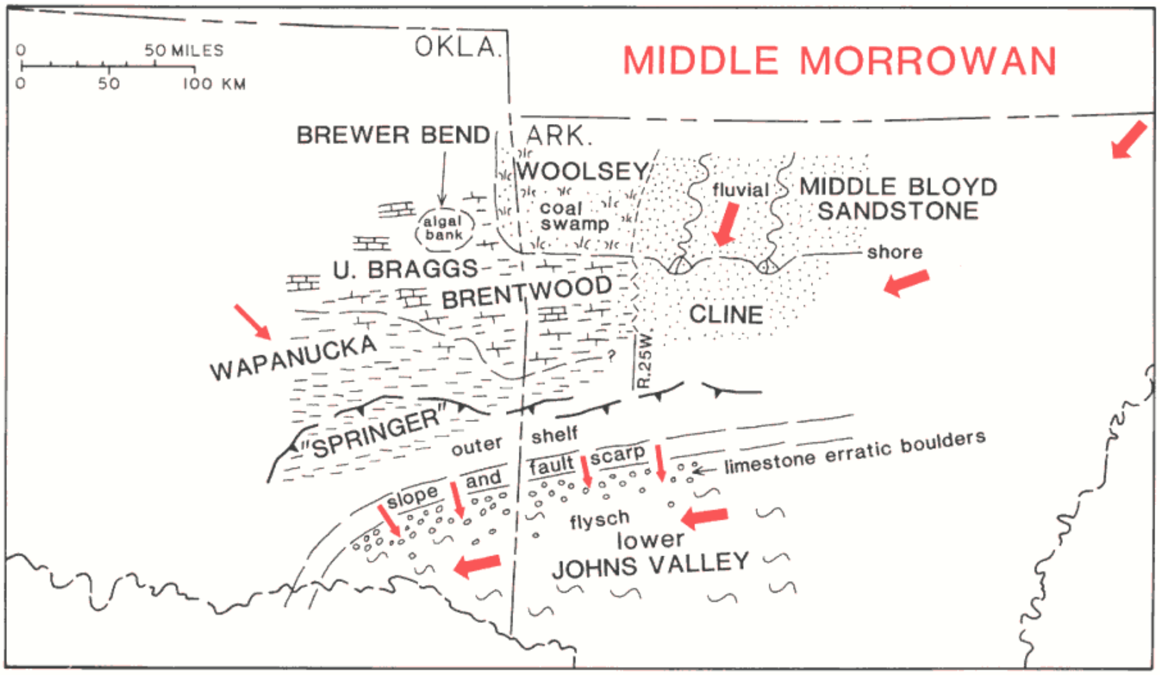

Figure 20. Middle Morrowan Depositional Patterns and Paleogeography (Sutherland, 1988)

Detritus left by the weathering and erosion of the of the Brentwood-Brewer Bend highstand deposits and the Woolsey terrestrial sequence were reworked by rising sea-levels (Manger 2008). Carbonates were again established in the Chisum Quarry Member of northeastern Oklahoma, but not to any extent in northwestern Arkansas, where dark, non-fossilliferous, platy shales blanketed the region. These shales exceed 100 feet in thickness in northwestern Arkansas, but they thin into northeastern Oklahoma, where shale "A" develops thicknesses from 30-40 feet. The upper Dye shale and shale "A" mark the maximum flooding interval of the second Morrowan cycle.

The highest Morrowan successions in northwestern Arkansas and northeastern Oklahoma are coeval, characterized by dark, noncalcareous, essentially non-fossilliferous platy shales, succeeded by thin limestones that are grain-dominated in their lower portions and mud-dominated in the higher intervals beneath the Morrowan-Atokan unconformity (Manger 2008). The Kessler Limestone of northwestern Arkansas commonly contains cross-bedded quartz sandstones with ooliths, reflecting a high energy depositional environment during highstand conditions (Figure 21). At the top of the Kessler section, lower energy levels produced algal mudstones and wackestones as deposition and regression reduced accommodation space establishing carbonate tidal-flat environments on the Arkoma shelf. Other than lacking quartz sand and shale, the Greenleaf Lake Member of the McCully Formation of northeastern Oklahoma is identical to the Kessler Member, Bloyd Formation (Manger, 2008). Highstand conditions of the second Morrowan sequence ended with falling sea-level and the development of a type-1 unconformity.

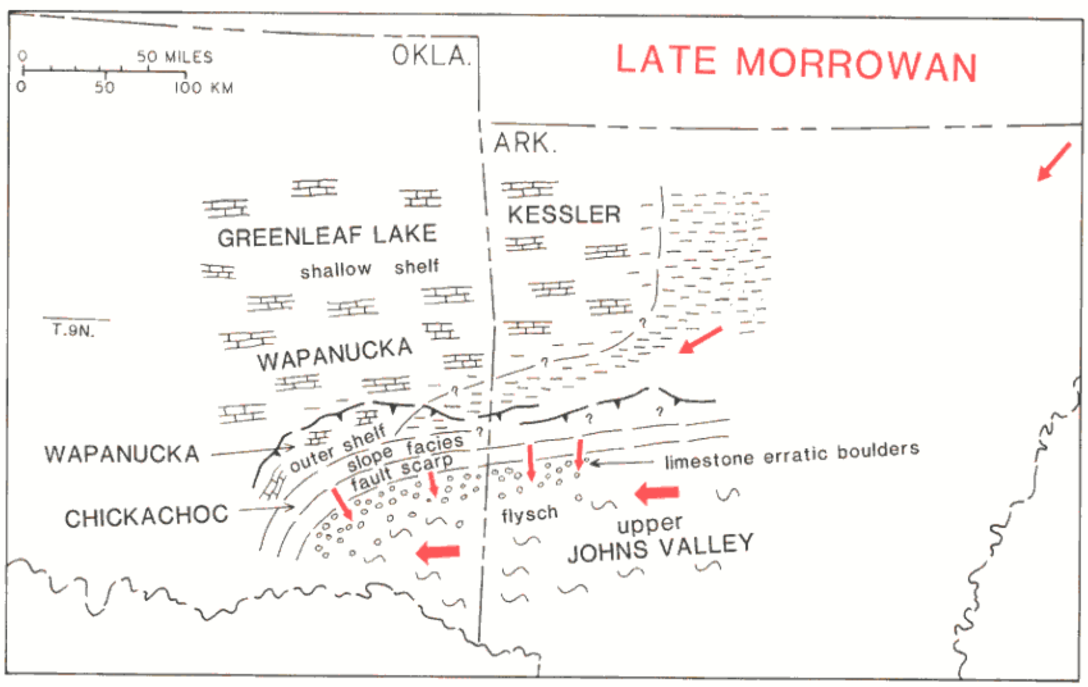

Figure 21. Late Morrowan Depositional Patterns and Paleogeography (Sutherland, 1988)

PENNSYLVANIAN LOWER ATOKAN

The lower Atokan overlaps the Morrowan unconformably and consists of alternating sandstone and shale intervals that accumulated on a stable shelf which extended into the modern part of the structural basin (Zachry, 1984). Sandstone deposition occurred as a result of regressive sedimentation in high destructive deltas and alternated with the transgression of open shelf conditions responsible for shale deposition. In Oklahoma, the Lower Atokan may be sourced from cratonic exposures to the northwest (Figure 22) (Houseknecht, 1987). The lack of clasts derived from the carbonates of the Ozark dome preclude north-south delivery suggesting distribution of the Lower Atokan sands must reflect east-to-west longshore currents producing longshore drift of sediment being brought to the area along the Mississippi Embayment (Figure 22).

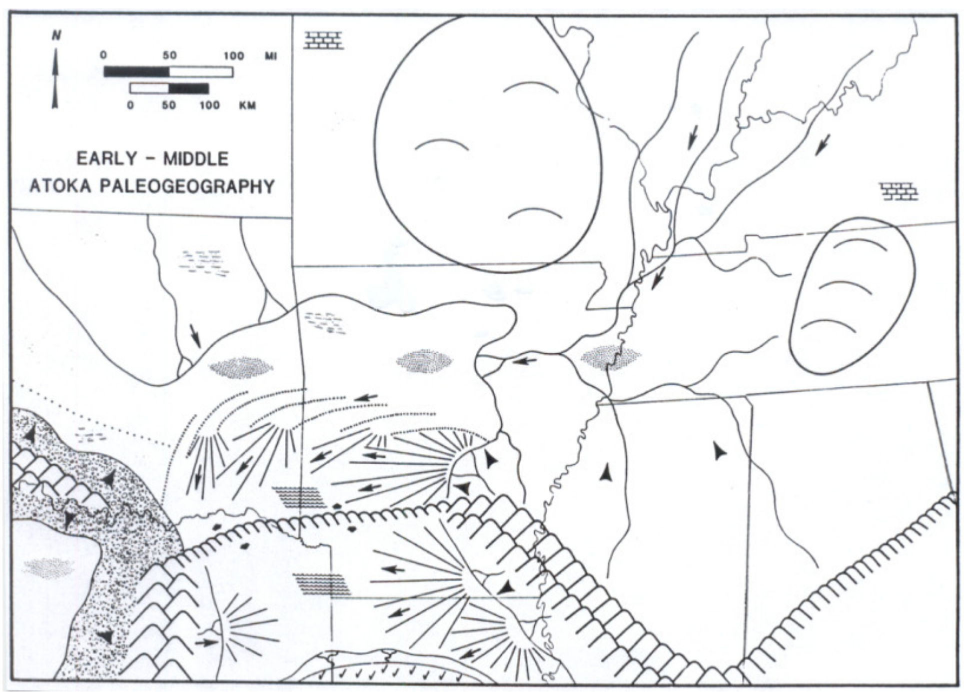

Figure 22. Early to Middle Atokan Paleogeography (arrows indicate paleocurrent directions), Southern Midcontinent (modified from Houseknecht, 1987)

DISCUSSION

DEVONIAN

Originally, there was no plan to include any rocks older than the Chattanooga Shale in this project. However, after generating structure and isopach maps for rock intervals and surfaces younger than the Chattanooga Shale, the Cason Shale surface (Figure 23) and Cason-Chattanooga interval (Figure 24) were investigated with the intention of gathering information that would help time the origin of the State Line Arch.

The top of the Cason Shale was mapped to show structural features on the Cason surface (Figure 23). In the northern parts of T. 11 N., R. 25 E.-R. 27 E. in Oklahoma through T. 9 N., R. 32 W. in Arkansas, a dramatic increase in the depth of the Cason Shale is related to the Muldrow-Mulberry fault system (Figure 24). In T. 12 N.,R. 24 E. in Oklahoma, a less dramatic increase in the depth of the Cason Shale occurs and is related to the Cass fault system. In the very central part of the study area, in the areas surrounding T. 12 N., R. 27 E. in Oklahoma, a structural high related to the State Line Arch can be seen and gives evidence of the existence of the arch prior to post-Cason deposition.

The general overall trend of the Cason Shale to Chattanooga Shale isopach (Figure 24) shows a southward thickening of the entire interval in Oklahoma. In T. 10-11 N., R. 31 W. in Arkansas, an area of thickening is present with an area of thinning just to the east (Figure 24). Thinning of the interval occurs directly on the State Line Arch.

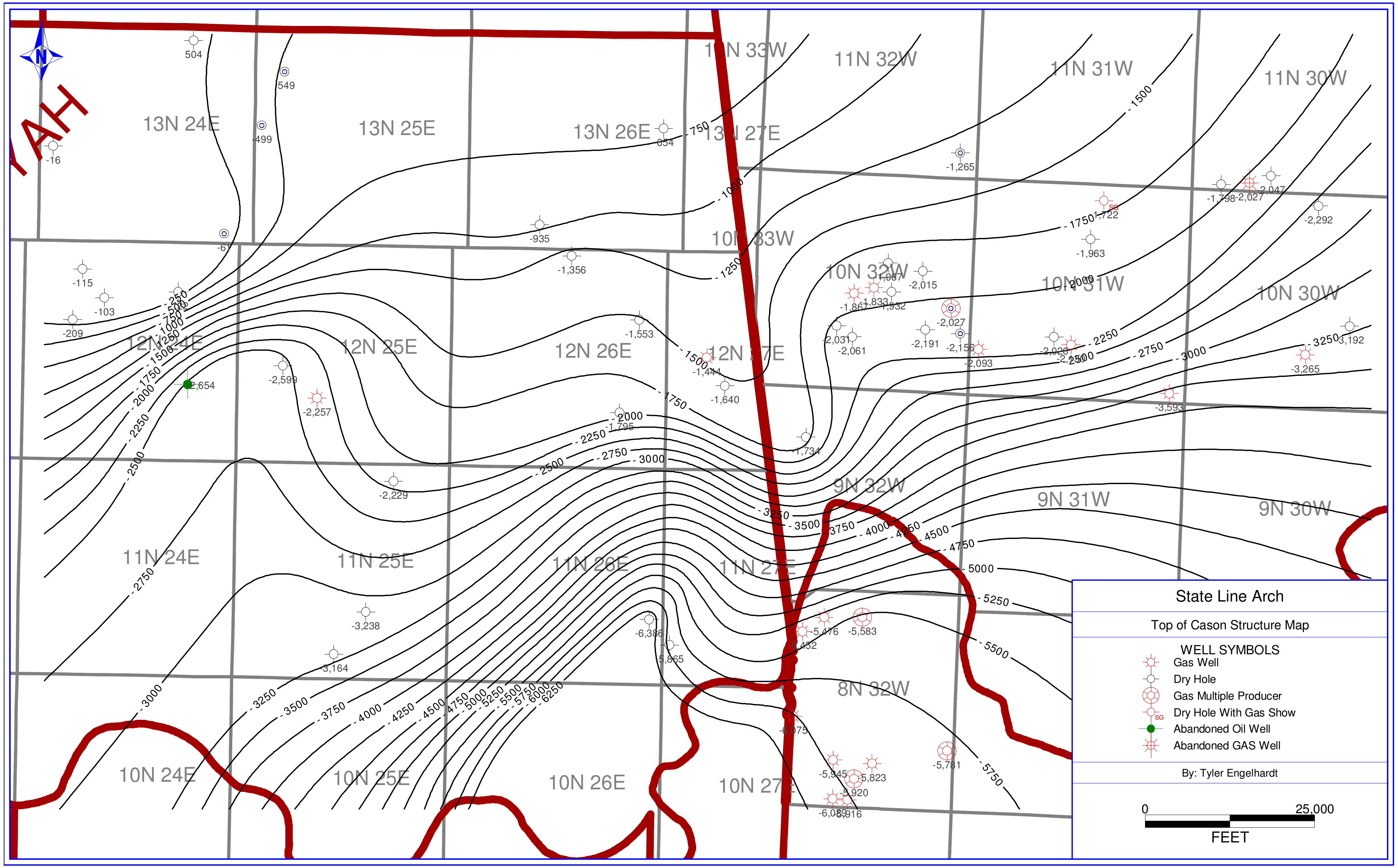

Figure 23. Top of Cason Shale Structure Map

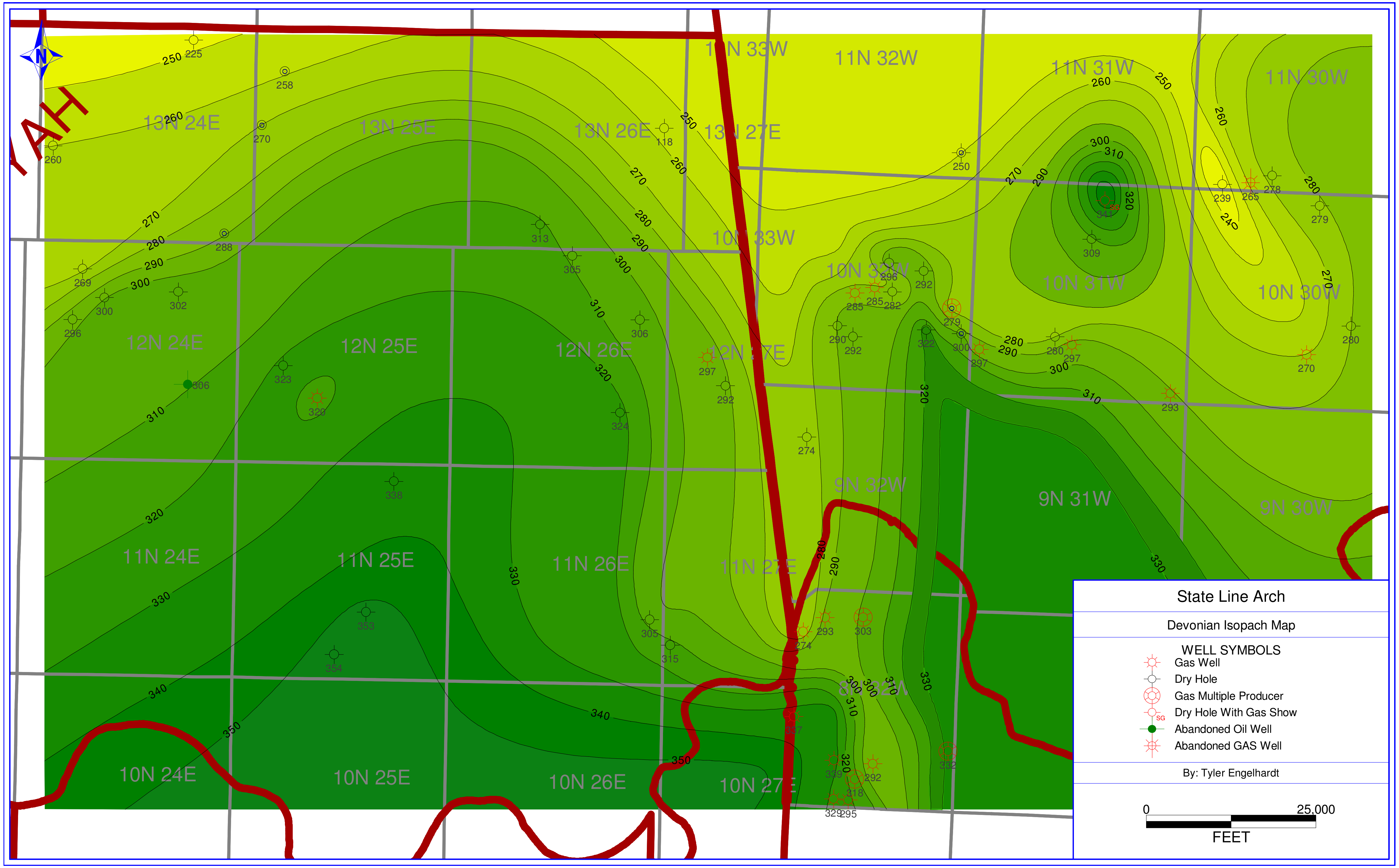

Figure 24. Devonian Isopach (Top of Cason Shale to top of Chattanooga Shale)

LOWER MISSISSIPPIAN

The lower Mississippian interval lies unconformably over the Devonian Chattanooga Shale and includes all rocks up to the base of the Hindsville Limestone. Maps generated to investigate this interval include a Chattanooga Shale structure map (Figure 25), a lower Mississippian isopach map (Figure 26), and a base of Hindsville Limestone structure map (Figure 27).

The Chattanooga structure map (Figure 25) shows the Mulberry-Muldrow and Cass Fault Systems in the same areas as the Cason structure map. The structural high of the State Line arch is also present in the Chattanooga structural map and can be seen on the downthrown side of the Mulberry-Muldrow fault system.

The lower Mississippian structure map (Figure 27) clearly shows the State Line Arch in its expected location. The Mulberry-Muldrow and Cass fault systems are present in the same location as in the earlier mentioned maps.

The lower Mississippian isopach (Figure 26) shows thickening on the State Line Arch in the study area from T. 13 N., R. 26 W. in Oklahoma at the northern extent to T. 8 N., R. 32 W. in Arkansas at the southern extent. This thickening is a result of a build-up of carbonates on the arch that began with the earliest Mississippian deposition.

The study area type log (Figure 27) shows approximately 30 feet of pure limestone sitting on the Chattanooga Shale. This limestone interval is interpreted as an equivalent to the St. Joe Limestone and is exclusive to the area surrounding the type log (Figure 35) as it appears in only one other log (Beland Heirs #2 Section 20, T. 12 N., R. 27 E.; located approximately one-half mile to the northeast) in the entire study area. This limestone interval is interpreted as a Waulsortian mound as the Waulsortian mounds commonly associated with the St. Joe Limestone produce locally anomalous thicknesses (Manger and Thompson, 1981). It should be noted that the Waulsortian mounds of southwestern Missouri and northeastern Oklahoma (Figure 15) are developed in direct alignment with the Spavinaw Arch. The Spavinaw Arch exhibits splaying in its southwestern extent and with the lack of well control along the Arkansas-Oklahoma state line (Figure 9), unidentified Spavinaw Granite basement structures may extend into the study area. The Compton interval isopach map indicates thickening along the northern part of the Arkansas-Oklahoma state line boundary and may provide evidence for an unidentified Spavinaw Arch structure along the state line if the development of Waulsortian mounds is in fact related to the Spavinaw Arch (Figure 9).

Immediately above the St. Joe Limestone on the type log (Figure 7), is about 80 feet of chert-bearing Boone Limestone. Overlying the Boone is about 130 feet of pure limestone, with the exception of two intervals at about 30 feet and 100 feet up-section where the PE curve reads values of about three and four barns/electron, respectively. The clean limestone interval is followed by a 15 feet shale interval, which is overlain by about 25 feet of shaley limestone to close out the lower Mississippian interval.

The pure limestone interval overlying the Boone represents transgression over the Boone surface and the development of this limestone interval is exclusive to the State Line Arch (Figures 33, 34). The structural nature of the State Line Arch provided a low-slope, shallow-sea environment favorable to carbonate platform growth during transgression. As the State Line Arch is traced southward, the pure limestone interval transitions into a shaley limestone as a result of deeper seas (Figure 36) and the same happens to the southwest (Figure 34). Eastward from the arch no pure limestone is present atop the Boone Formation and it is likely that the sensitive environmental conditions needed for carbonate growth were not present.

Turmelle (1982) noted the absence of a transgressive phase limestone associated with the seas that deposited the Mayes Group in Oklahoma and attributed their absence to rapid transgression. It is likely that Turmelle (1982) missed the transgressive phase limestone interval because his study was limited to surface studies north of where the transgressive phase limestones were deposited. The interval on the type log (Figure 7) from the shale overlying the pure limestone, up to the base of the Hindsville, accurately matches the shallowing upward sequence of the Mayes Formation in Oklahoma as described by Turmelle (1982), with the shale interval representing the maximum flooding interval and the shaley-limestone interval representing the highstand systems tract. Turmelle (1982) placed the Hindsville Limestone as the regressional phase of this systems tract, but the Hindsville more appropriately fits the overlying systems tract associated with the Fayetteville Shale and Pitkin Limestone. It is more likely that the shaley-limestone interval underneath the Hindsville represents the regressive phase of this systems tract.

Another area of lower Mississippian thickening is present (Figure 26) at the far eastern extent of the study area in T. 10 N.-T. 11 N., R. 30 W. Ingram (2009) noted areas of Mississippian stratal thickening along northwest trending Precambrian transfer faults. These faults created sags when reactivated during the Ouachita Orogen’s east-to-west tectonic translation across the platform allowing for accumulation of Mississippian sediments. No evidence for a structural high in this area (Figure 27) and no pure limestone overlying the Boone Formation indicate this thickening is completely unrelated to the State Line Arch.

An area of thinning is present in T. 10 N., R. 31 W. and thinning also occurs to the west of the State Line Arch (Figures 27, 34). Westward longshore currents flowing over the sediment-accumulating arch created starved basin conditions explaining the thinning the west, but the thinning to the east in T. 10 N., R. 30 W. remains enigmatic.

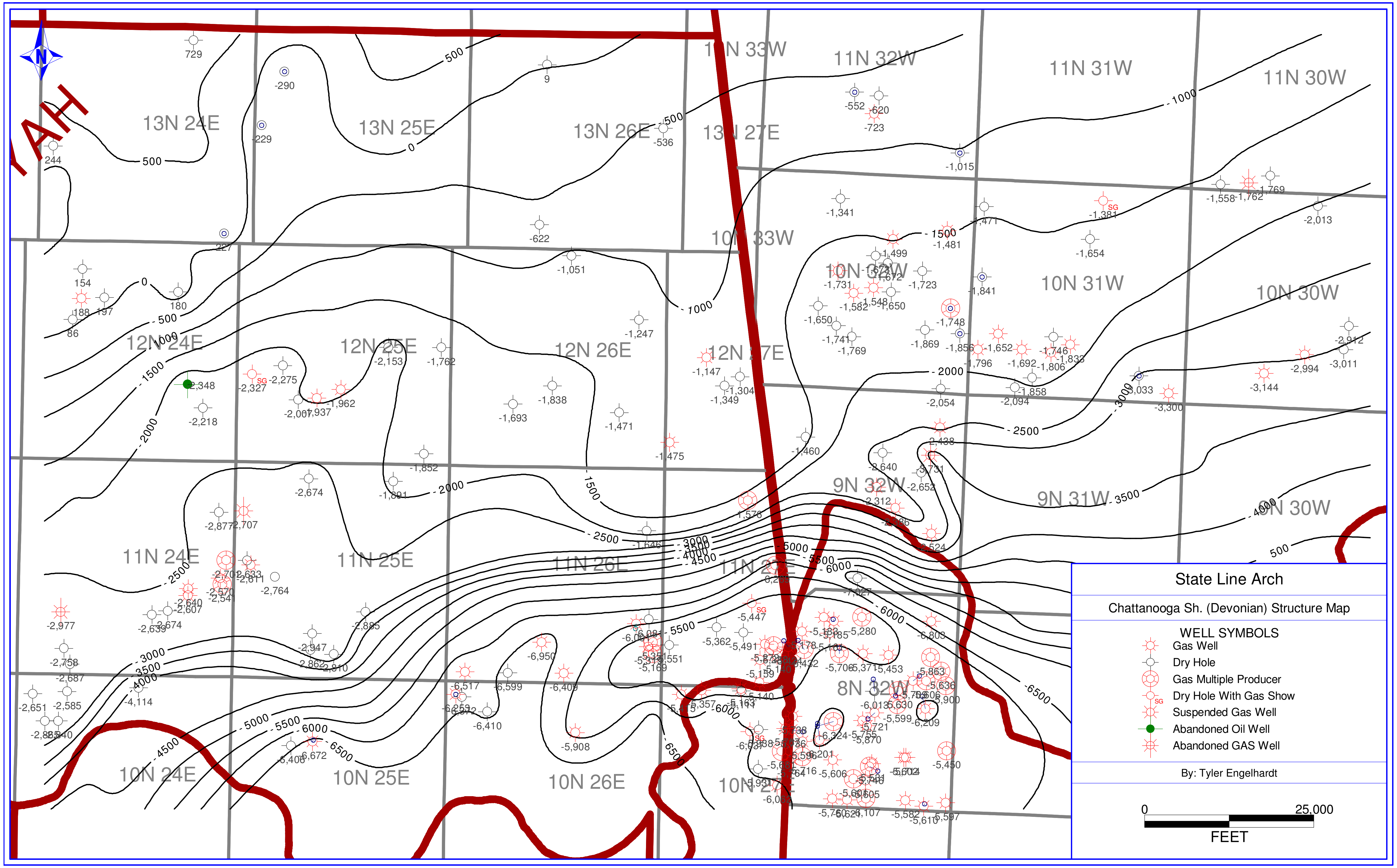

Figure 25. Chattanooga Shale Structure

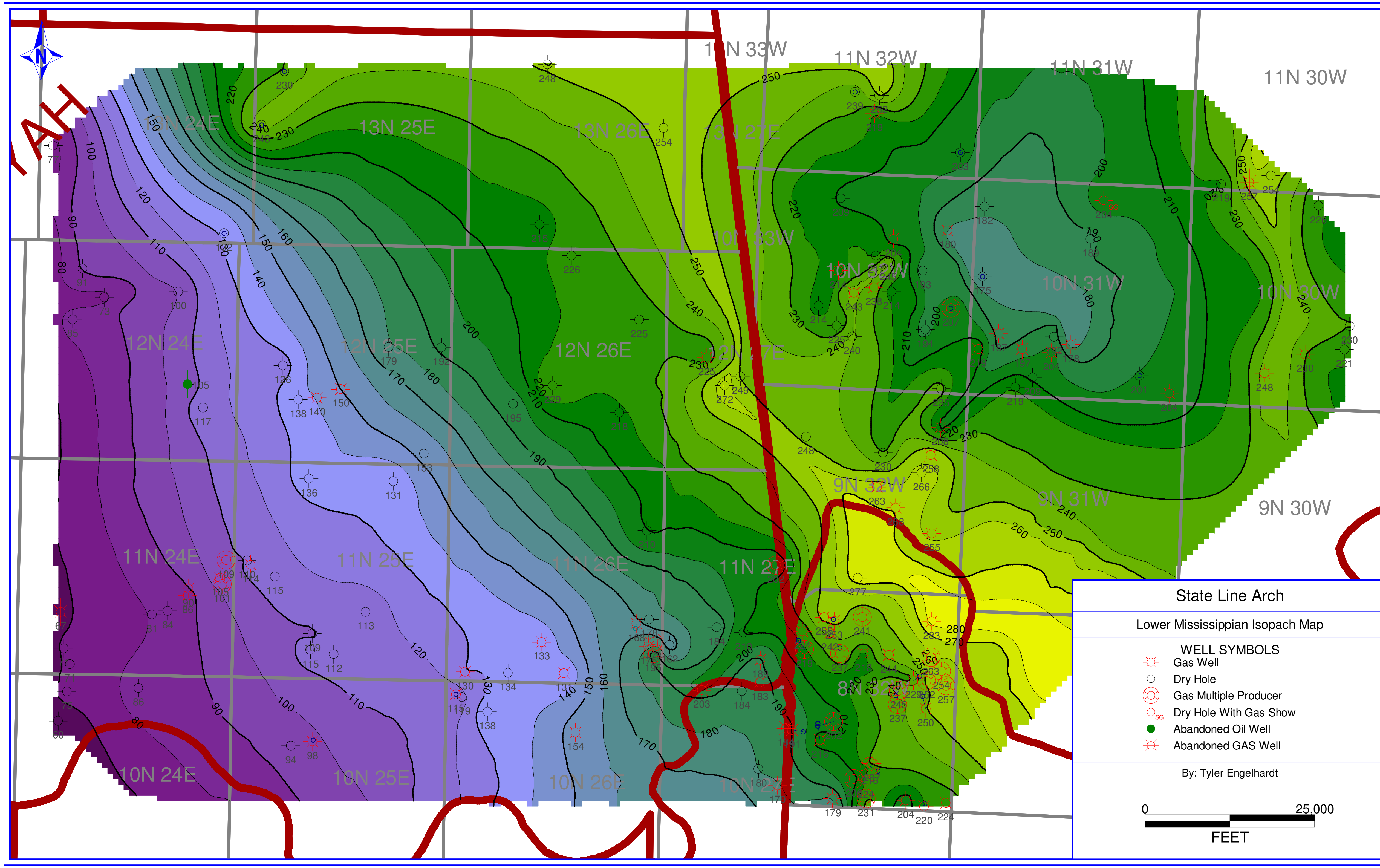

Figure 26. Lower Mississippian Isopach (Top of Chattanooga Shale to base of Hindsville Limestone)

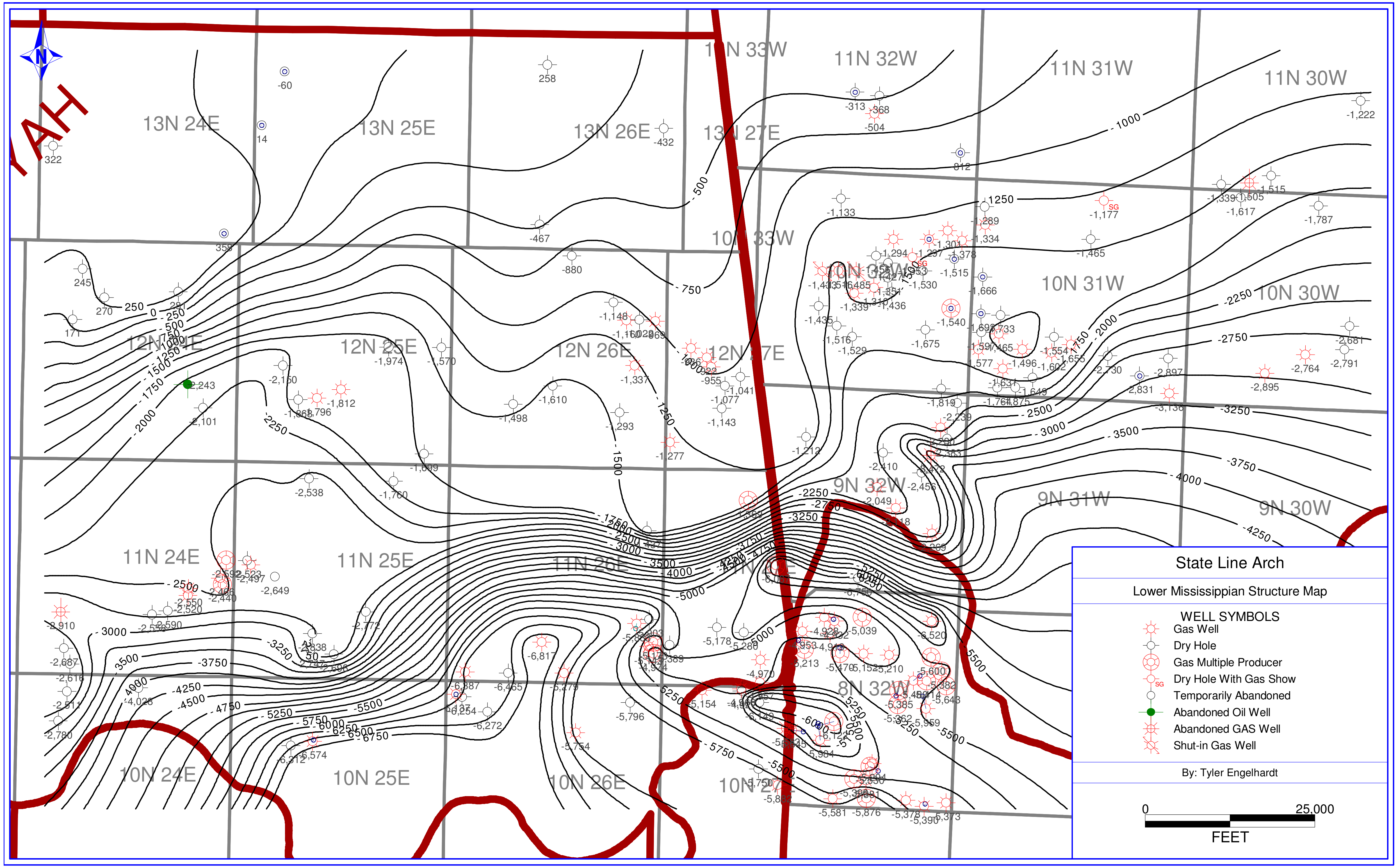

Figure 27. Lower Mississippian Structure Map (Base of Hindsville)

UPPER MISSISSIPPIAN

The upper Mississippian interval includes all rocks from the base of the Hindsville Limestone to the top of the Pitkin Limestone. A structure map of the top of the Pitkin (Figure 28) and an upper Mississippian interval isopach map (Figure 29) were generated to examine stratigraphic effects of the State Line Arch on the upper Mississippian interval.

The upper Mississippian structure map (Figure 28) clearly shows the State Line Arch in its expected location. The Mulberry-Muldrow and Cass fault systems are present in the same location as in the earlier mentioned maps.

Upper Mississippian thickening (Figure 29) on the State Line Arch indicates carbonates continued to build-up on the arch through the late Mississippian. East to west longshore currents created starved basin conditions responsible for thinning to the west of the arch. Thinning to the east of the arch in T. 10 N., R. 32 W. is enigmatic (Figures 29, 38).

Like in the lower Mississippian, thickening at the eastern extent of the study area (Figure 29) is unlikely related to the State Line Arch or a similar feature because there is no indication of a structural high present in the area. It is possible that the thickening in this area is related to sag along a reactivated, northwest trending transfer fault as described by Ingram (2008). Evidence for the sag on the structure map may be lacking due to an absence of well control (Figure 28).

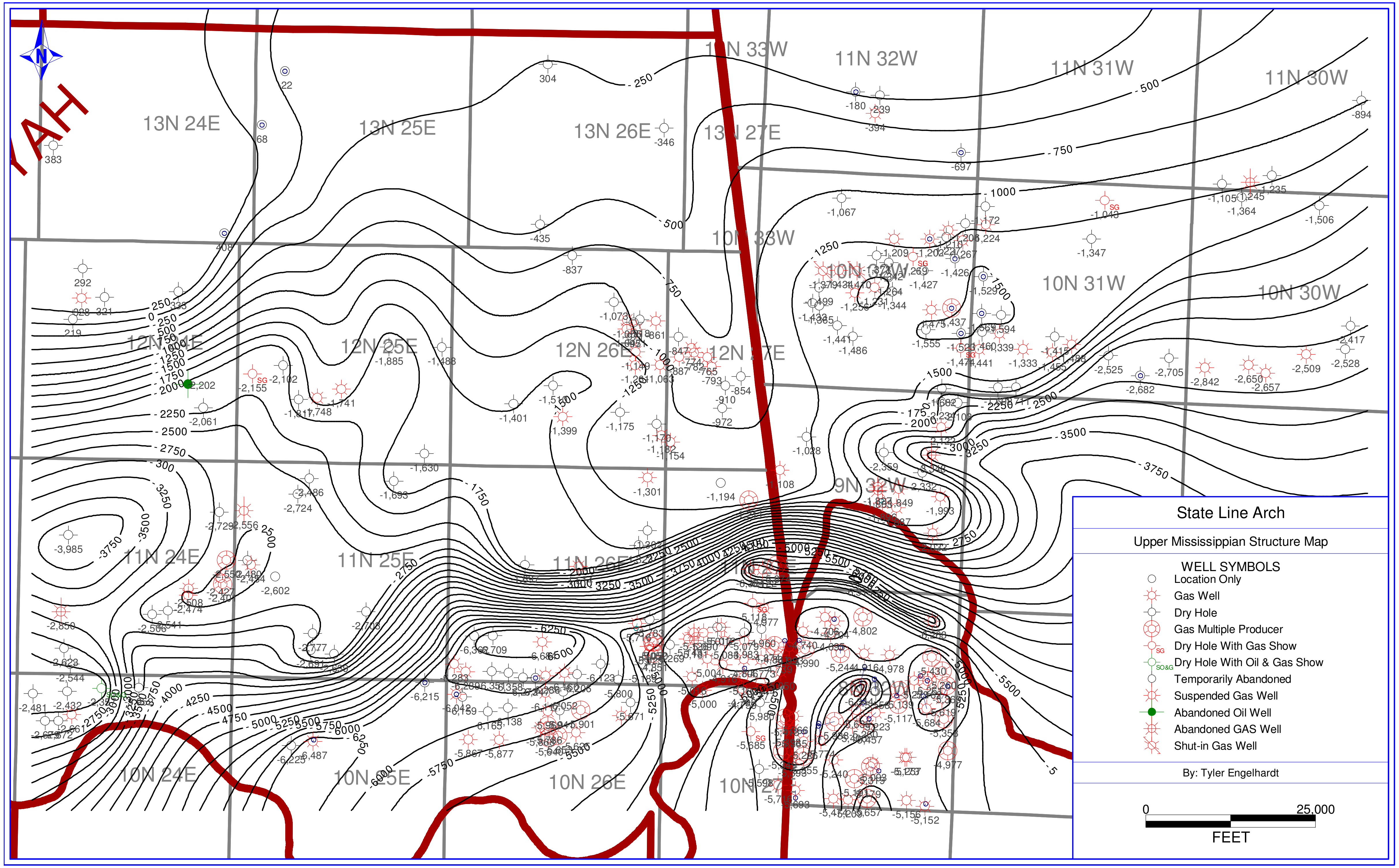

Figure 28. Upper Mississippian Structure (Top of Pitkin)

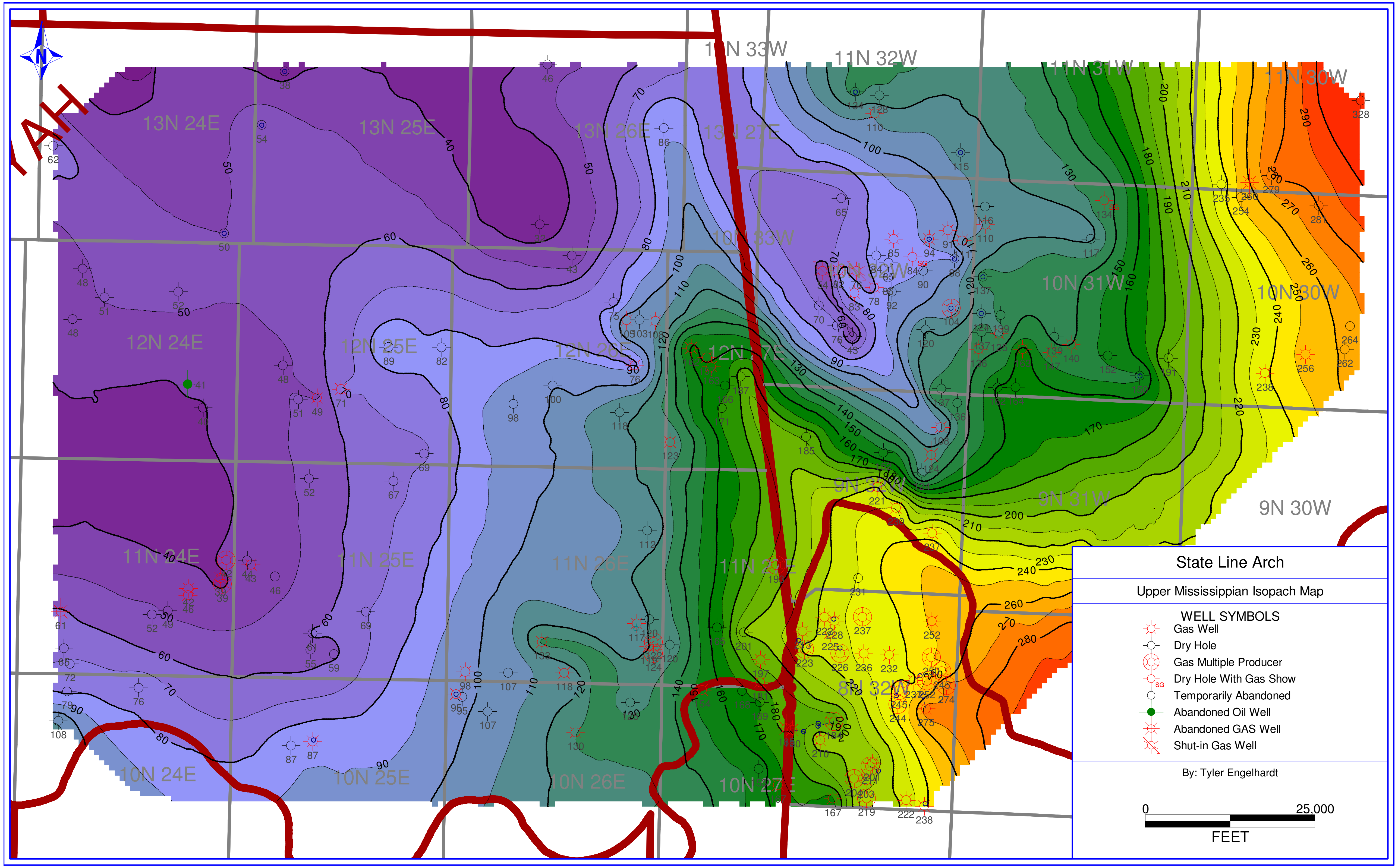

Figure 29. Upper Mississippian Isopach Map (Base of Hindsville to top of Pitkin)

PENNSYLVANIAN MORROWAN

The Pennsylvanian Morrowan interval includes all rocks from the top of the Pitkin Limestone to the top of the Kessler Limestone. A computer generated structure map of the top of the Kessler Limestone was produced and it reflected structural features almost identical to that of the upper Mississippian structure map (Figure 28), so it has been omitted from this study. A Pennsylvanian Morrowan interval isopach map (Figure 30) was generated to examine stratigraphic effects of the State Line Arch on the Pennsylvanian Morrowan interval.

Deposition of the Morrowan interval is less affected by carbonate buildups on the State Line Arch than the lower and upper Mississippian intervals (Figure 35). South and eastward thickening across the study area is consistent with Morrowan deposition across the rest of the Arkoma basin. Following a linear trend from the southeastern corner of T. 11 N., R. 26 E. to central T. 10 N., R. 31 W. there are several series of thickening and thinning features across the arch (Figures 30, 39). It is difficult to understand the relationship of the thickening and thinning to the arch due to distortion of the arch by the Muldrow-Mulberry fault system, but it appears that thinning is occurring at the top of the arch in T. 11 N., R. 27 E. with thickening on the eastern and western flanks (Figures 30, 39).

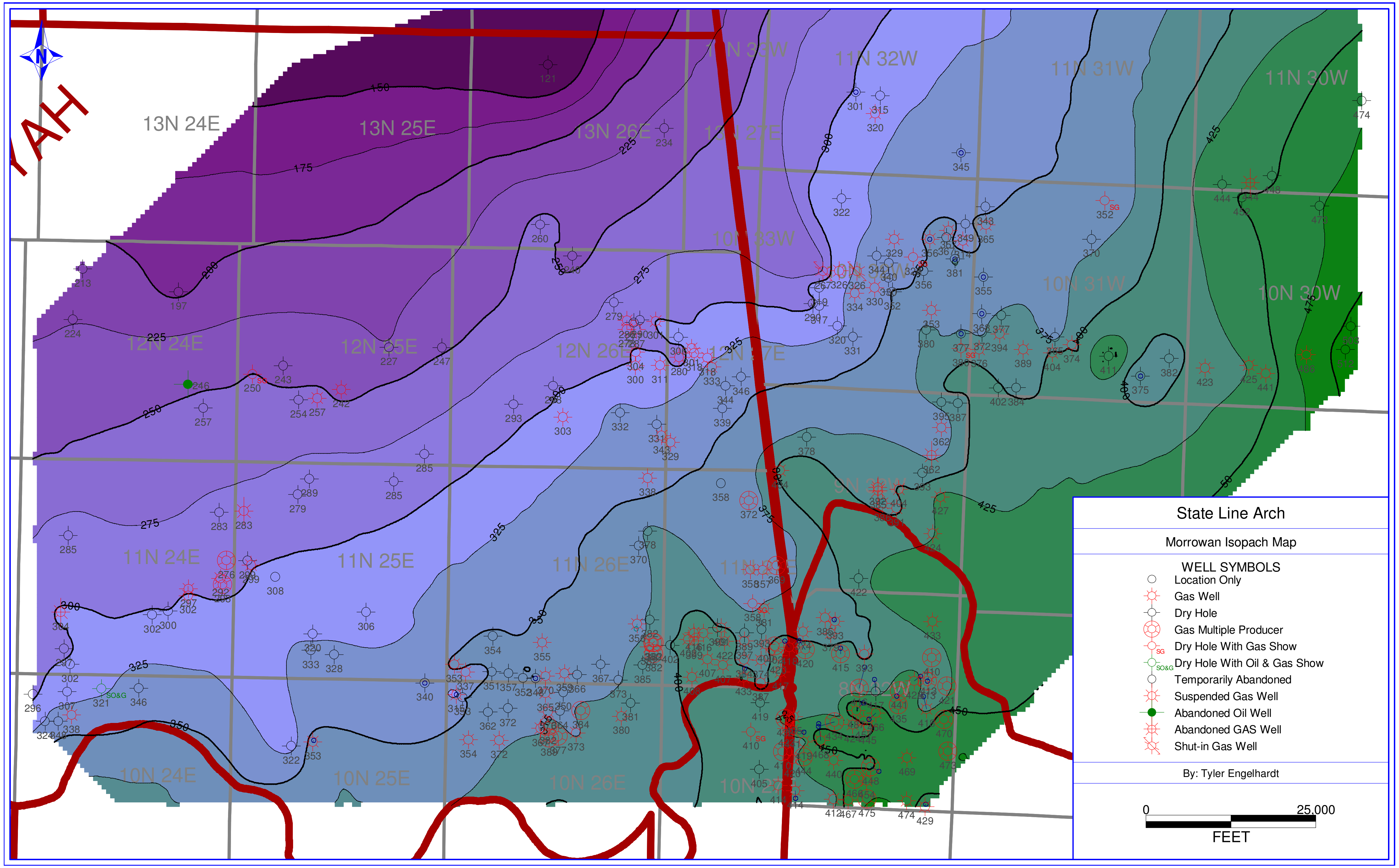

Figure 30. Pennsylvanian Morrowan Isopach Map (Top of Pitkin to top of Kessler)

PENNSYLVANIAN LOWER ATOKAN

The Pennsylvanian lower Atokan interval includes all rocks from the top of the Kessler Limestone to the top of the Sells sand interval. A structure map of the top of the Sells sand was produced and it reflected structure almost identical to that of the upper Mississippian structure, so it has been omitted from this study. A lower Atokan interval isopach map was generated to examine stratigraphic effects of the State Line Arch on the lower Atokan interval.

In the study area, the lower Atokan interval displays an overall thickening trend to the southeast (Figure 31) that is consistent with rest of the Arkoma basin. Thickening of the lower Atokan interval at the top of the State Line Arch in the northern part of T. 12 N., R. 27 E. is on the downthrown side of a small fault and is likely related to basinward growth on that fault. On the eastern side of the arch there is an area of lower Atokan thickening in the central part of T. 10 N., R. 32 W. (Figure 31) that may represent an accumulation of sediments that were unable to be carried over the arch by the east-to-west currents (Figure 22).

An interesting phenomenon unrelated to the arch in the lower Atokan interval can be observed in T. 11 N., R. 26 E. and T. 11 N., R. 27 E. An area of thickening trending east-west suggests growth along the southern margin of the Mulberry-Muldrow fault system (Figure 31). This growth of lower Atokan sediments on the downthrown side of the fault system could indicate movement on the fault during lower Atokan time. Southward from the area of growth, thinning occurs parallel to the line of thickening, followed by more thickening to the south. This feature may represent a roll-over anticline structure (Figure 39).

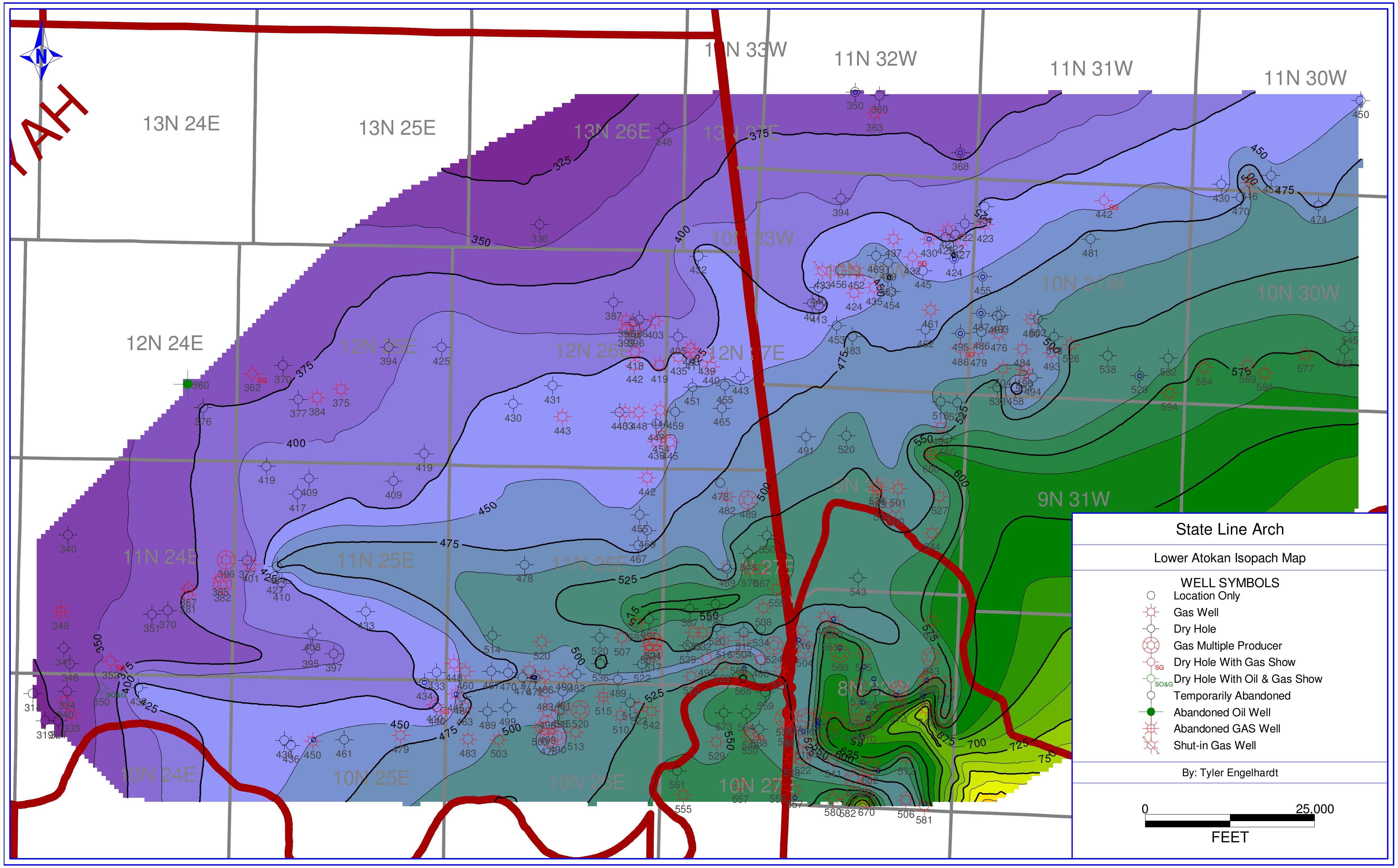

Figure 31. Lower Atokan Isopach Map (Top of Kessler to top of Sells)

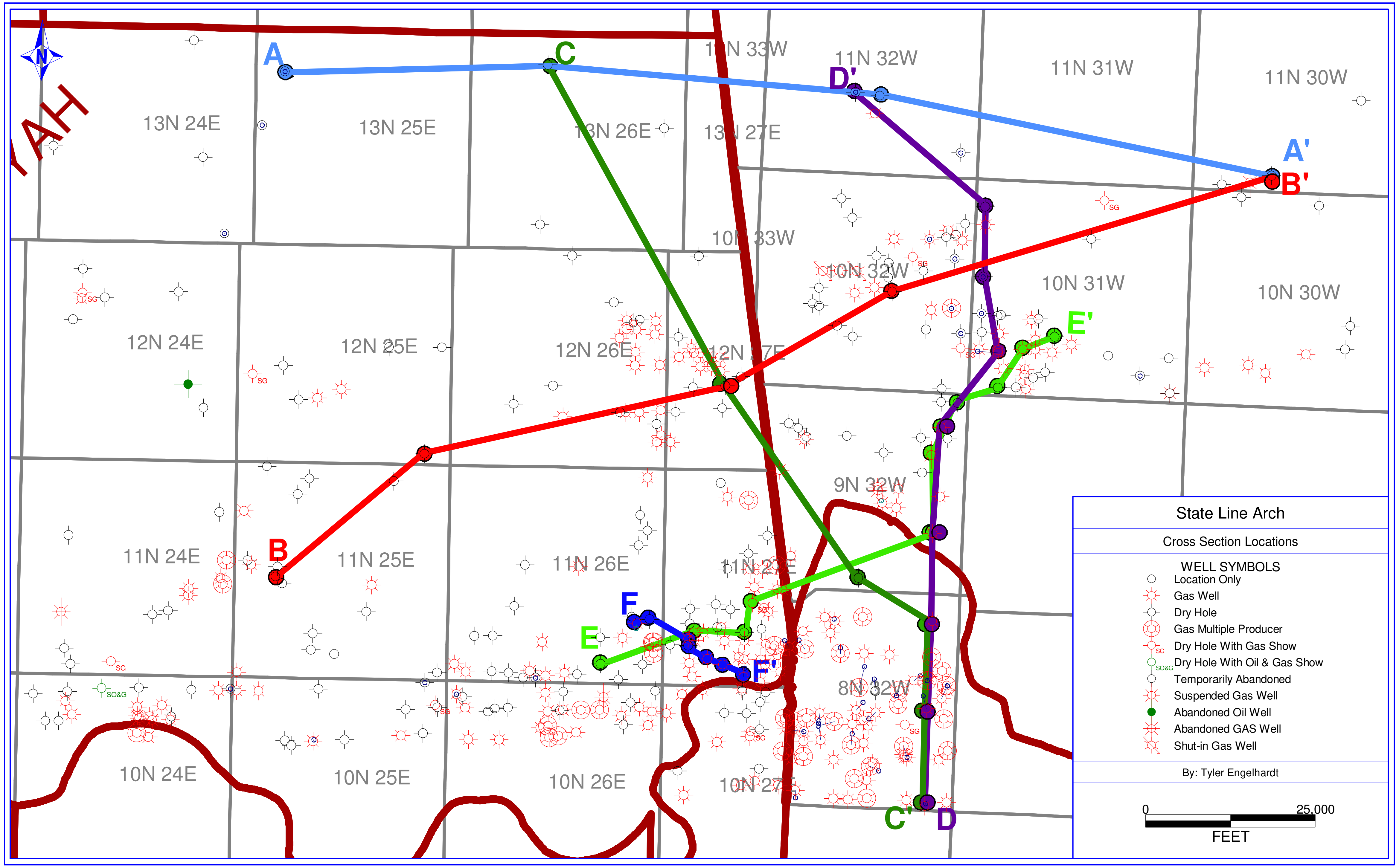

Figure 32. Map of Cross-Section Locations

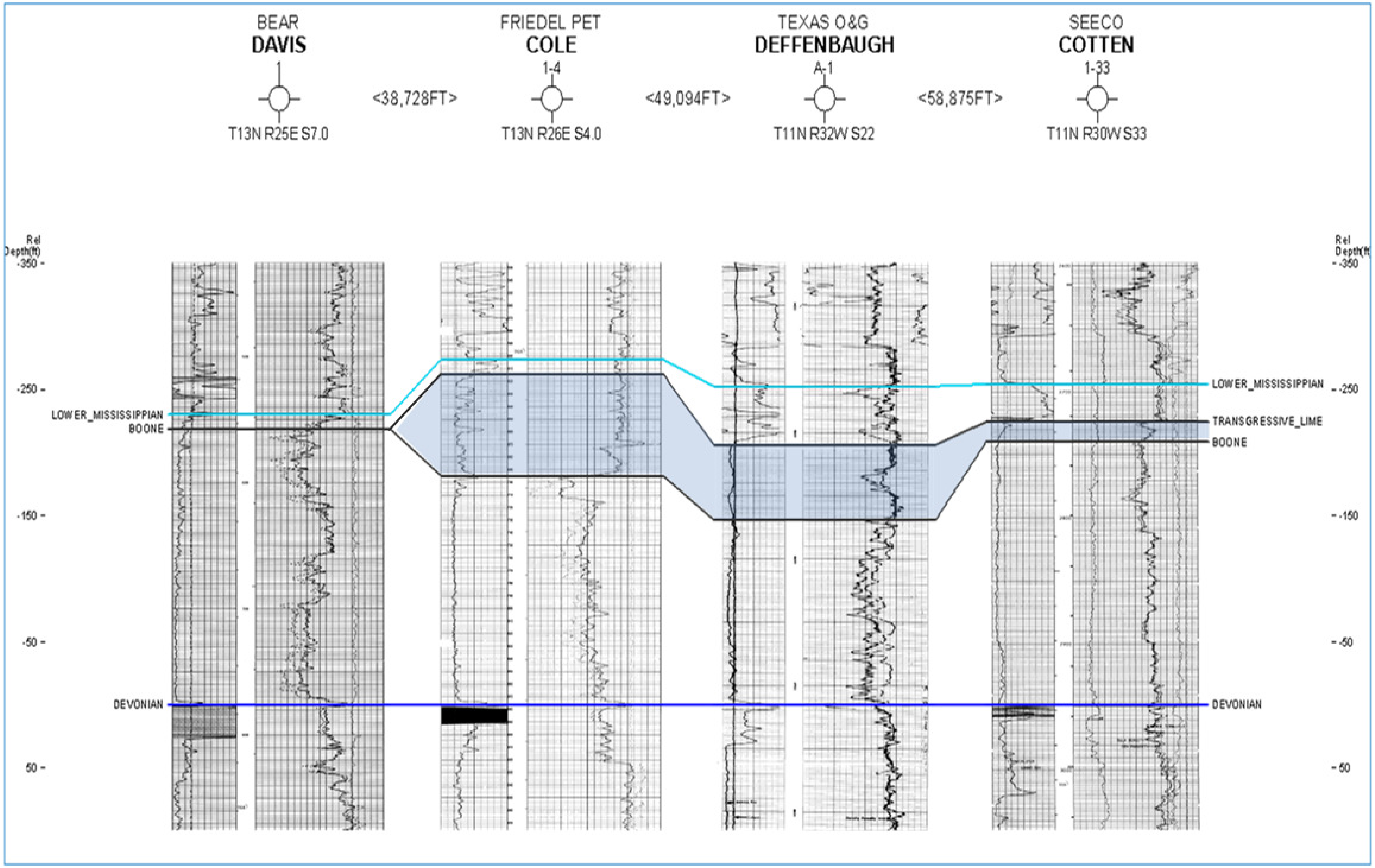

Figure 33. Cross-Section A-A' Lower Mississippian

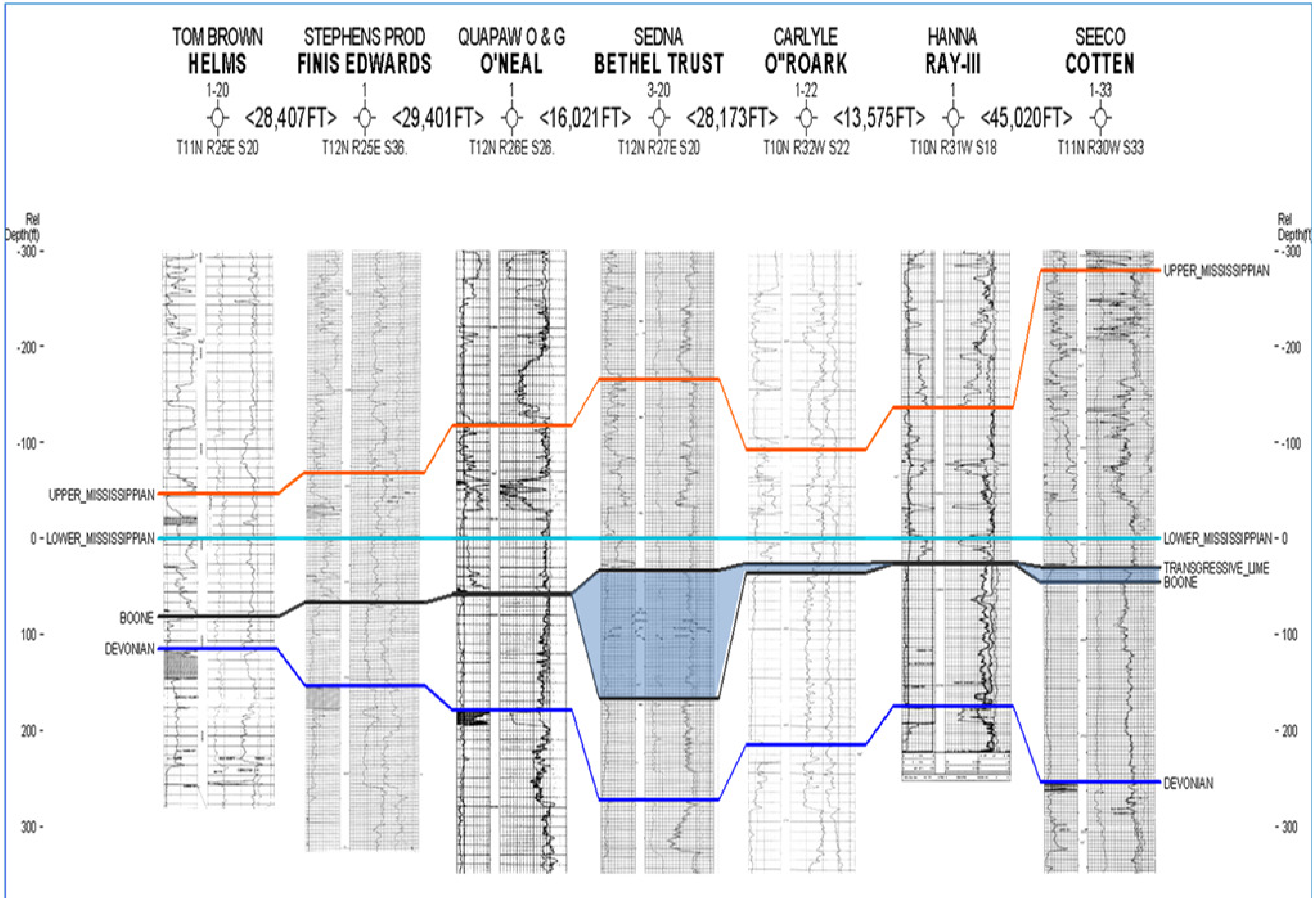

Figure 34. Cross-Section B-B’ Mississippian

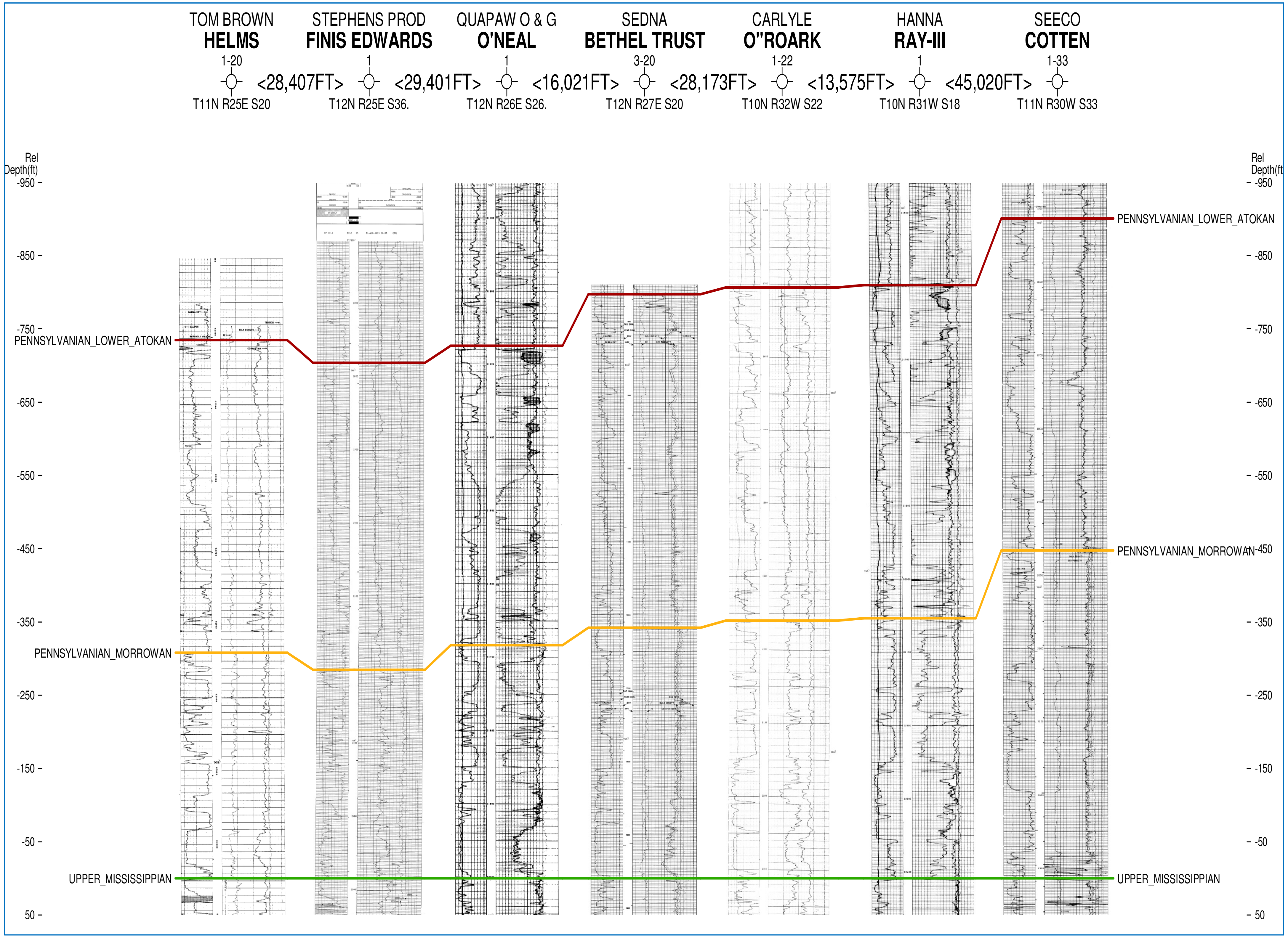

Figure 35. Cross-Section B-B’ Pennsylvanian

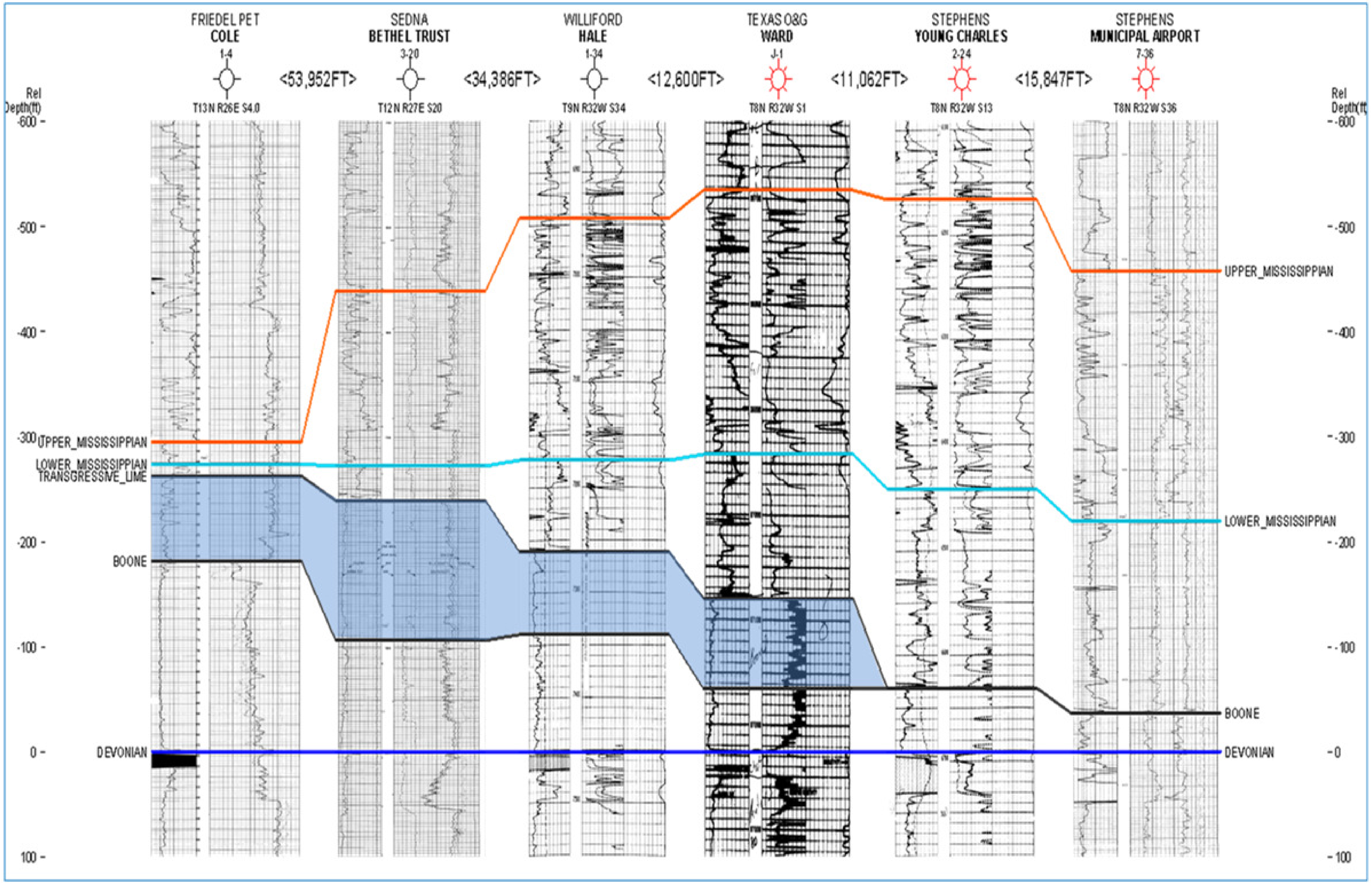

Figure 36. Cross-Section C-C’ Mississippian

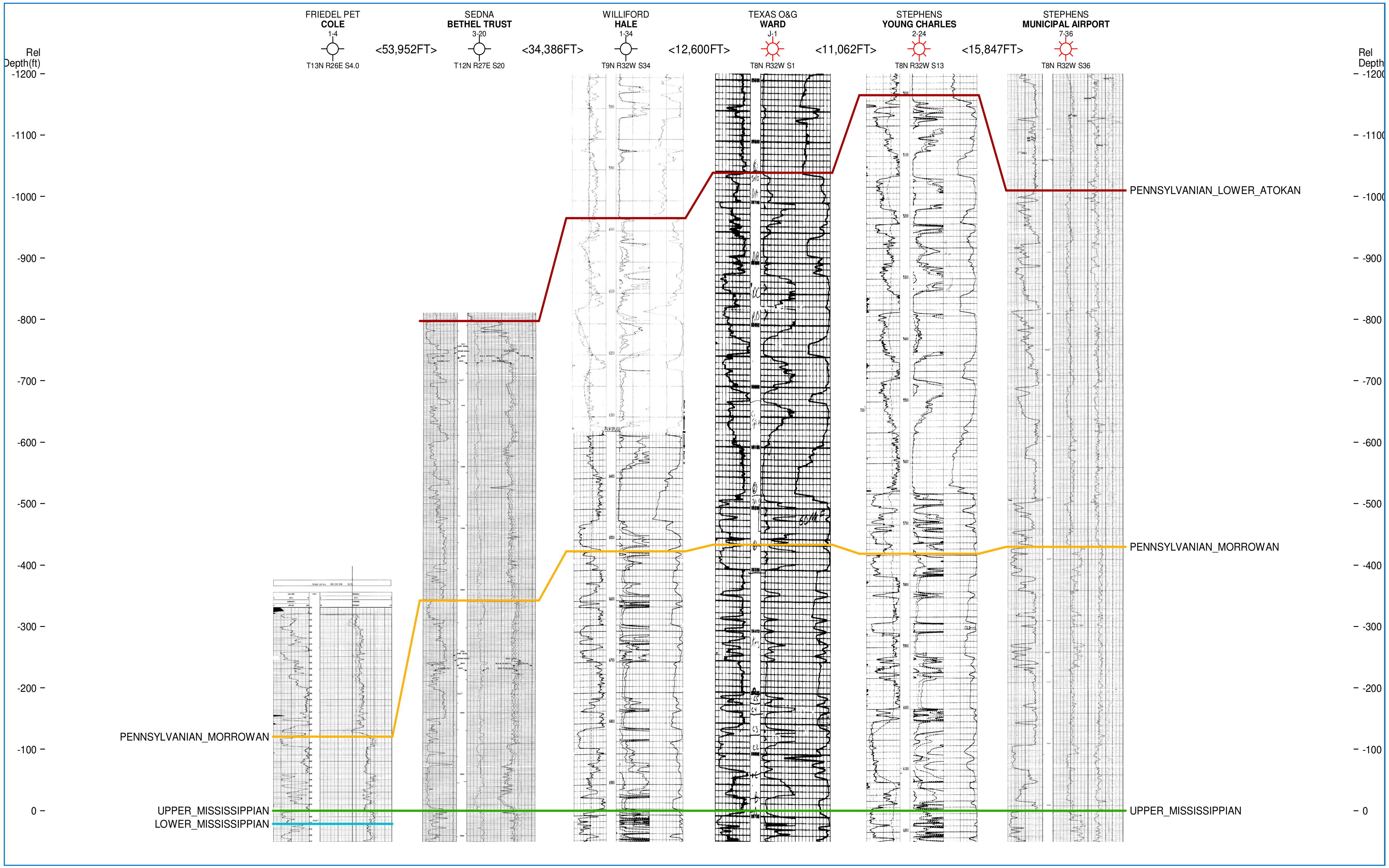

Figure 37. Cross-Section C-C' Pennsylvanian

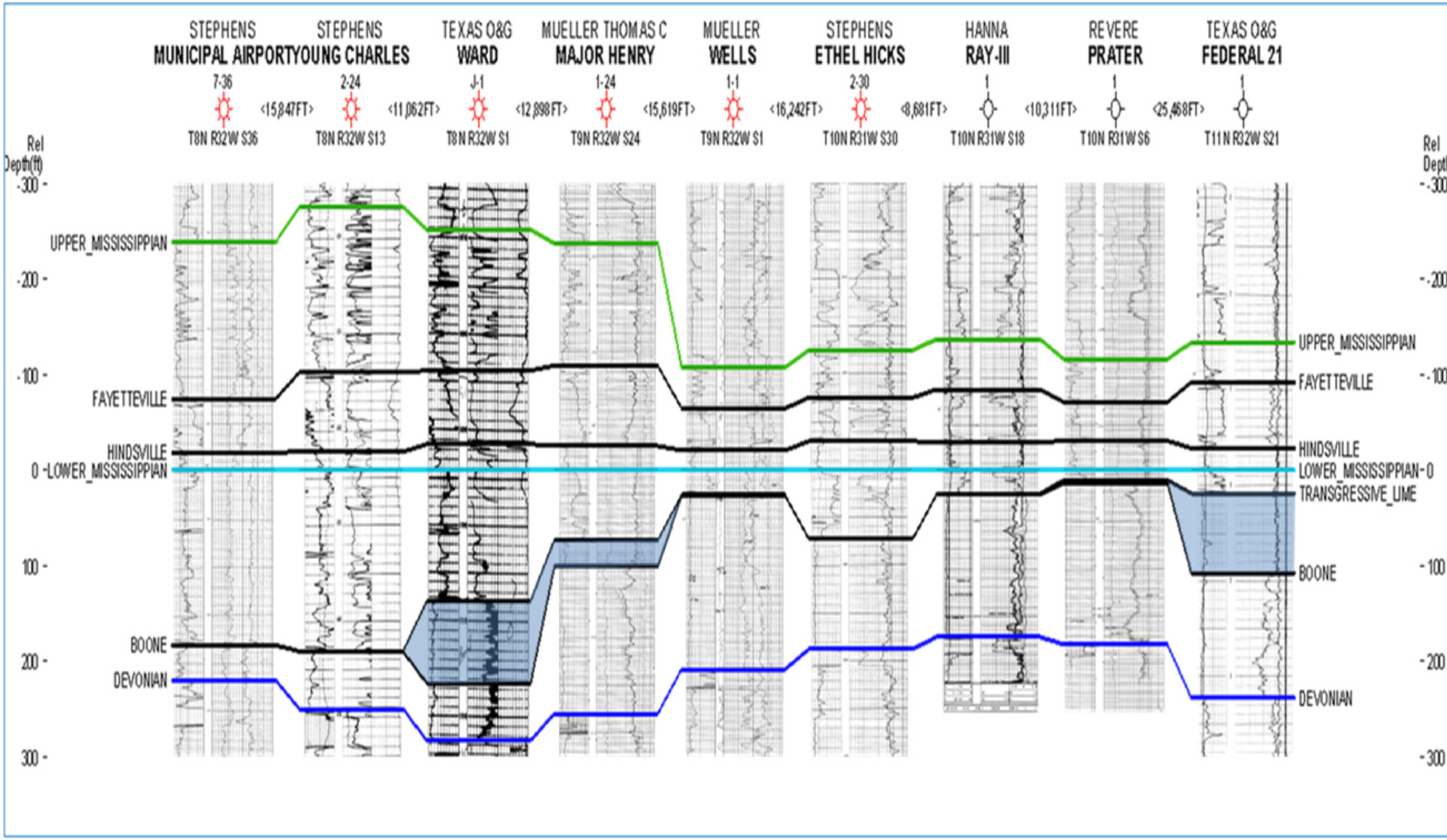

Figure 38. Cross Section D-D’ Mississippian

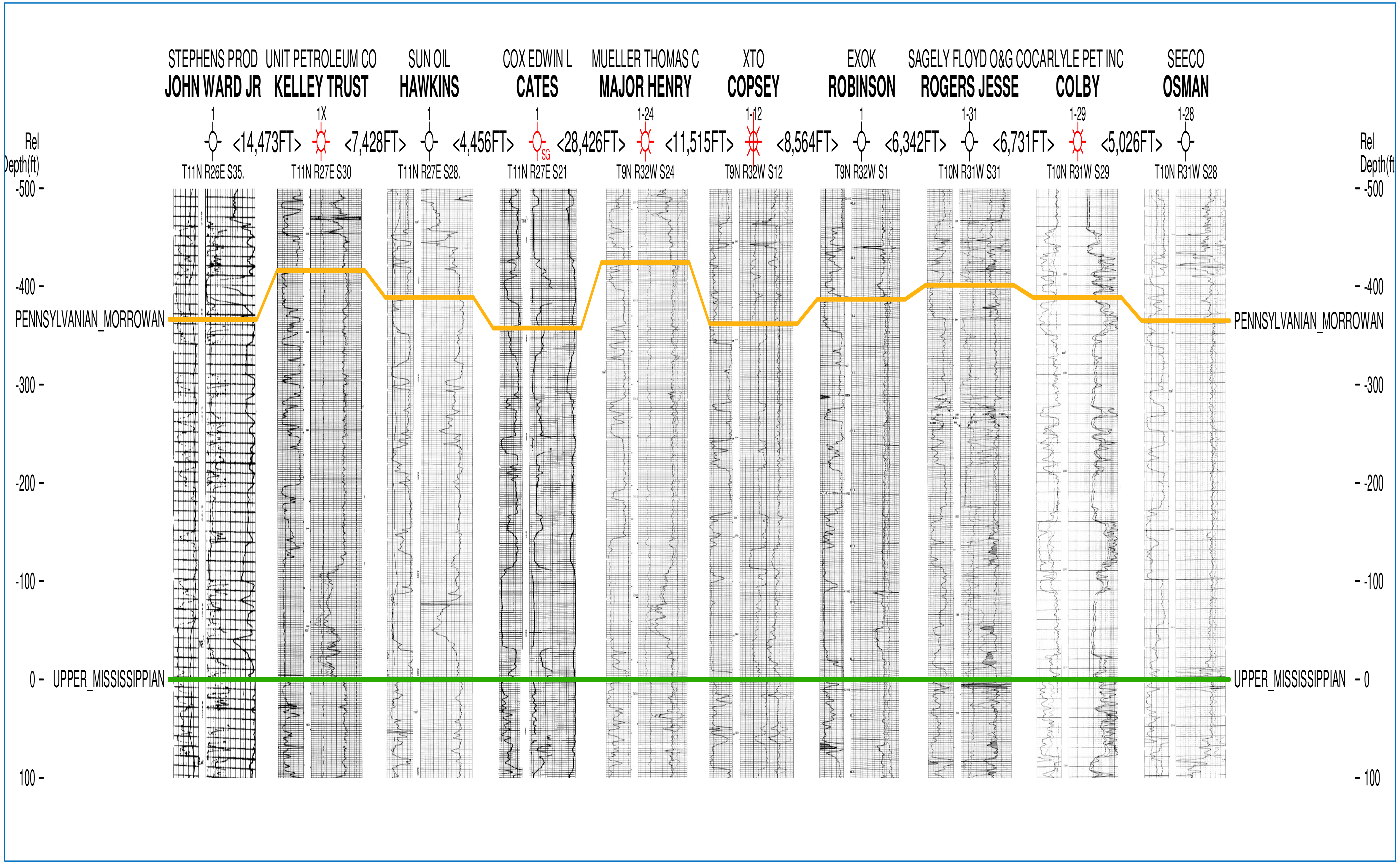

Figure 39. Cross-Section E-E' Morrowan Thickening and Thinning

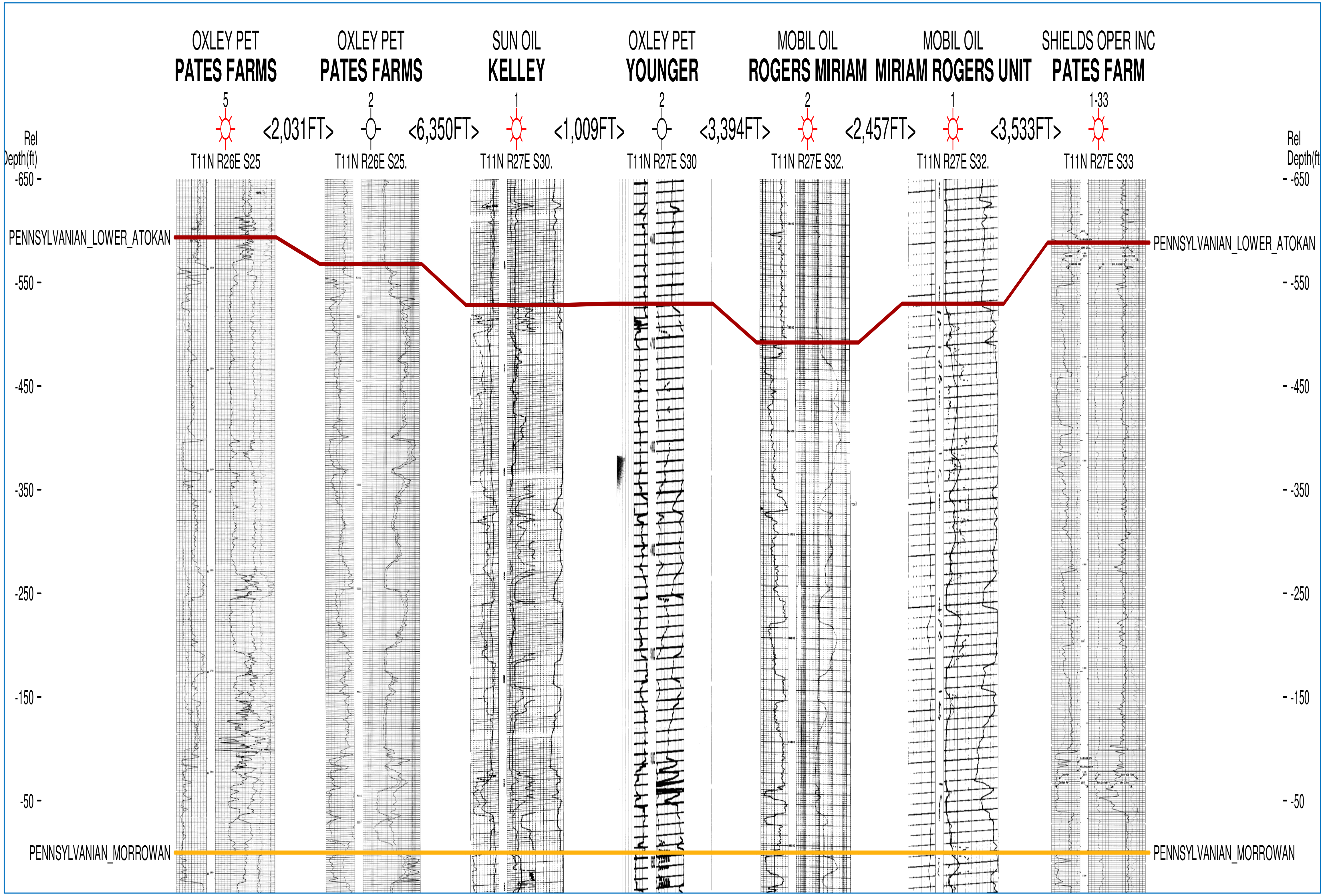

Figure 40. Cross-Section F-F' Lower Atokan growth and possible rollover structure

CONCLUSIONS

- Unidentified Spavinaw Granite structures may extend further south than known structures.
- Development of Lower Mississippian Waulsortian mounds may reflect the presence of Precambrian basement structures.
- An entire transgressive-regressive sequence is represented between the Boone and Hindsville Formations.
- The State Line Arch provided environmental conditions favorable for carbonate build-up throughout the entire Mississippian interval.
- Limestone overlying Boone Formation represents a previously unidentified transgressive phase limestone related to the Mayes sequence.
- Thickening in eastern extent of study could be related to thickening along northwest trending, Precambrian-aged, transfer faults that were reactivated during the Ouachita Orogeny.
- Lower Atokan growth on downthrown side of Muldrow-Mulberry fault system indicates Lower Atokan fault movement.
- A roll-over anticline structure may exist south of Muldrow-Mulberry fault system.

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APPENDICES

UWI (API Num)	Well Label	Operator	Lower Atokan	Pennsylvanian Morrowan	Upper Mississippian	Lower Mississippian	Devonian	Cason
3033002050000	10N-31W-3 R E ELLIS 1	LONE STAR PROD COMP	1167	1609	1961	2095	2299	2640
3033002230000	9N-32W-15 J S RICHMOND 1	SAGELY FLOYD	1406	1935	2320			
3033055580000	9N-32W-18 T I GREENSTREET 1	CITIZENS GAS		1505	1908			
3033066600000	11N-30W-3 CRADDOCK EST 1	TRUMBO DONALD		149	568			
3033100360000	9N-32W-8 NANCY ORR 1	DIAMOND SHAM	678	1169	1548	1732	1980	2254
3033100390000	10N-32W-28 MASTERS L P 1	FERGUSON	1649	2132	2463	2506	2746	3038
3033100430000	10N-30W-27 WILLIAMS 1-27	ARKANSAS WESTERN GAS	2301	2878	3364	3619	3849	4120
3033100450000	10N-30W-26 BRUCE 1-26	ARKANSAS WESTERN GAS	2274	2836	3348	3611	3831	
3033100480000	11N-32W-27 W & S DEFFENBAUGH 1	TEXAS O&G	787	1150	1470	1580	1799	
3033100500000	11N-32W-22 DEFFENBAUGH A-1	TEXAS O&G	660	1020	1334	1463	1715	
3033100530000	11N-32W-21 FEDERAL 21 1	TEXAS O&G	699	1049	1350	1483	1722	
3033100560000	9N-32W-29 HAUERT 1-29	MALKA PROD CO		5778				
3033100860000	10N-30W-23 RACKLEY 1-23	SEECO	2249	2794	3297	3561	3792	4072
3033100930000	10N-31W-28 OSMAN 1-28	SEECO	1501	1787	2152	2291	2483	2763
3033100960000	10N-31W-36 STARBIRD 1-36	BROCK	2521	3115		3619	3783	4076
3033101040000	10N-31W-30 PHILLIPS 1-30	BROCK	1445	1924	2300	2436	2655	2952
3033101080000	10N-31W-30 ETHEL HICKS 2-30	STEPHENS	1305	1781	2174	2300	2487	
3033101090000	10N-32W-15 MILLER 1-15	CARLYLE	1470	1929	2269	2354	2599	2894
3033101100000	10N-32W-25 MARKER 1-25	BROCK	1540	2035	2412		2745	3045
3033101120000	10N-31W-28 KELLY 1-28	CARLYLE PET INC	1314	1807	2211	2358	2562	
3033101130000	10N-32W-26 FITE 1-26	CARLYLE	1559	2021	2401	2521	2715	3037
3033101150000	10N-32W-21 BROWN 1-21	XTO	1508	1876	2211	2294	2537	2822
3033101230000	11N-30W-23 LEO KLAGES 1-23	MCRAY C E & ASSOC	991	1441	1915	2243		2787
3033101240000	10N-31W-29 COLBY 1-29	CARLYLE PET INC	1338	1823	2211	2374	2570	
3033101270000	10N-30W-3 JOHN OPITZ 1-3	MCRAY C E & ASSOC	1356	1830	2303	2584	2810	3089

UWI (API Num)	Well Label	Operator	Lower Atokan	Pennsylvanian Morrowan	Upper Mississippian	Lower Mississippian	Devonian	Cason
3033101280000	10N-31W-10 W R TAYLOR 1-10	MCRAY C E & ASSOC	1354	1835	2204	2322	2511	2820
3033101540000	10N-31W-28 FORTNER 1-28	CARLYLE PET INC	1393	1769	2143	2310	2488	2785
3033101550000	10N-32W-22 OROARK 1-22"	CARLYLE	1505	1959	2312	2404	2618	2900
3033101560000	9N-32W-15 U S TRUST CO 1	TXO PROD CORP	1397	1920	2312	2534	2797	
3033101580000	10N-32W-22 OROARK 2-22"	XTO	1433	1868	2198	2277	2515	2800
3033101590000	10N-31W-18 RAY-III 1	HANNA	1599	2054	2409	2546	2721	
3033101720000	10N-32W-20 STEIN 1-20	CARLYLE	1451	1864	2180	2250	2465	
3033101730000	10N-31W-32 NEILSON 1-32	CNG PRODUCING CO	1638	2096	2480	2644	2863	
3033101740000	10N-32W-36 SCOTT 1	CNG	2001		2446	2583	2818	
3033101800000	10N-31W-30 PHILLIPS 1-30	CIRCLE SEVEN	1459	1945	2318	2455		
3033101920000	10N-30W-33 EDWARDS 1	EXOK INCORPORATED	2388	2982	3423	3661	3910	
3033101970000	10N-30W-29 ARNOLD 1	EXOK INCORPORATED	2362	2931	3356			
3033102050000	10N-32W-15 MILLER 1-15	LYONS & LYONS	1375	1858	2187	2274		
3033102090000	10N-32W-16 MCMASTER J T 1-16	MUELLER,	1540	1992	2319	2394		
3033102150000	10N-32W-11 RAGON 1-11	ENTERPRISE RES	1354	1784	2140	2235		
3033102210000	10N-32W-12 MASSEY 1-12	LYONS & LYONS	1380	1802	2159	2250	2430	
3033102230000	10N-32W-10 LITTLE RASCAL 1-10	ENTERPRISE RES	1200	1636	1966	2051	2256	
3033102240000	10N-32W-20 HARRISON CROFFORD 1-2	ENTERPRISE	1459	1899	2218			
3033102350000	10N-32W-14 BIG RASCAL 1-14	ENTERPRISE	1473	1905	2203	2287		
3033102360000	10N-32W-13 JACQUELINE 1-13	BARFIELD	1559	1983	2364	2453		
3033102370000	10N-32W-17 CAMPBELL 1-17	ENTERPRISE	1445	1878	2145	2199		
3033102420000	10N-32W-9 BRINK 1-9	ENTERPRISE RES		1781				
3033102470000	10N-31W-7 BLUEBERRY HILL 1-7	ENTERPRISE	1467	1851	2216	2326		
3033102700000	9N-32W-1 BARNARD 1-1	LOMBARD	1959	2477	2872			
3033102740000	10N-31W-19 PARKER SALLYE 1-19	ENTERPRISE	1513	2000	2367	2491		
3033102870000	9N-32W-14 U S TRUST 2-14	ENTERPRISE RES INC	1348	1849	2253			
3033103040000	9N-32W-8 CROW 1-8	ENTERPRISE	805					
3033103050000	9N-32W-8 OLIVERIA 1-8	ENTERPRISE	744					

UWI (API Num)	Well Label	Operator	Lower Atokan	Pennsylvanian Morrowan	Upper Mississippian	Lower Mississippian	Devonian	Cason
3033103070000	9N-32W-1 ROBINSON 1	EXOK	1980	2503	2889	3025		
3033103120000	10N-32W-15 BAGGETT 1-15	BARFIELD	1374	1843	2187	2270	2487	
3033103370000	10N-31W-20 PARKER 1	REVERE CORP	1640	2142				
3033103550000	9N-32W-22 U S TRUST A" 1"	TERRY ENERGY INC	1419	1970	2374			
3033103740000	10N-31W-32 NEILSON 1-32	HENRY PETROLEUM INC	1663	2157		2529	2738	
3033104140000	9N-32W-12 NORTHRIDGE 1-12	SEECO INCORPORATED	2107	2657		2982		
3033104190000	11N-30W-32 GILKER 1-32	SEECO	1467	1943	2387	2647	2904	3169
3033104290000	11N-30W-33 COTTEN 1-33	SEECO	1513	1967	2414	2694	2948	3226
3033104350000	11N-30W-31 FRANCE 1-31	SEECO	997	1428	1872	2106	2325	2565
3033104370000	10N-30W-5 GILKER 2-5	SEECO	1536	2006	2459	2712		
3033104550000	10N-31W-32 NIELSEN 1-32	YALE OIL CORPORATION	1560	1841				
3033104750000	10N-31W-25 WOMACK 1	REVERE CORP	2477	3010	3391	3583		
3033104760000	10N-31W-27 PRICE 1-27	REVERE CORP	2060	2599	3010	3215		
3033104810000	9N-32W-23 LEES CREEK 1-23	MUELLER THOMAS C	1413	1912	2303	2534	2802	
3033104830000	9N-32W-24 MAJOR HENRY 1-24	MUELLER THOMAS C	1618	2162	2586	2823	3078	
3033104850000	10N-31W-6 PRATER 1	REVERE	1356	1787	2129	2246	2428	
3033104860000	10N-32W-4 MULLICANE 1	REVERE	1150	1543	1865	1931	2139	
3033104870000	10N-32W-16 PALMER 1	REVERE	1478	1934	2260	2342	2557	
3033104910000	9N-32W-13 BREEDEN 1-13	MUELLER T C OF CRWFR	1639	2165	2592			
3033104990000	9N-32W-10 WELLNITZ 1-20	MUELLER T C OF CRWFR			2784	2835	3065	
3033105050000	9N-32W-11 RICHMOND 1-11	MUELLER	2739					
3033105060000	9N-32W-14 BELL 1-14	MUELLER T C OF CRWFR		2461	2854	2978	3174	
3033105070000	9N-32W-1 WELLS 1-1	MUELLER	1805	2298	2660	2768	2976	
3033105170000	10N-32W-12 HIGHTOWER 1-12	CRAVENS	1457	1794				
3033105180000	10N-32W-24 YOUNG 1-24	XTO		1970	2317	2420	2628	2907
3033105210000	10N-32W-12 HIGHTOWER 2-12	CRAVENS	1460	1887	2201	2312		
3033105220000	10N-31W-20 FIELDS 1-20	SHIELDS ENERGY INC	1631	2111				
3033105230000	10N-31W-32 NIELSEN 2-32	SAGELY FLOYD O&G CO		2133				

UWI (API Num)	Well Label	Operator	Lower Atokan	Pennsylvanian Morrowan	Upper Mississippian	Lower Mississippian	Devonian	Cason
3033105240000	10N-31W-31 ROGERS JESSE 1-31	SAGELY FLOYD O&G CO	1433	1965	2367	2529		
3033105250000	9N-32W-12 COPSEY 1-12	XTO	2883	3483	3845	3969	4228	
3033105270000	10N-31W-19 WESTBROOK 1-19	SHIELDS ENERGY INC	1339	1832	2209	2348		
3033105290000	10N-31W-31 BROWN 2-31	YALE OIL CORPORATION	1497	2001		2446		
3033105310000	10N-32W-23 BREEDEN 1-23	CRAVENS	1550	2011	2363			
3033105360000	9N-32W-9 ORR 1	KLABZUBA	1393	1913				
3033105370000	11N-32W-36 JOHNSON 1-36	CRAVENS	1082	1449	1794	1909	2112	2362
3033105390000	10N-31W-32 NIELSEN 3-32	YALE OIL ASSOC INC	1639	2143				
3033105410000	10N-32W-20 STEIN 1-20	SHIELDS	1445	1853	2143			
3033105420000	10N-32W-12 WHITAKER 1-12	SHIELDS	1179	1602	1950			
3033105480000	10N-32W-25 FRANKLIN 1-25	XTO	1533	2019	2399			
3033105510000	10N-31W-19 PRESTON 1-19	TAYLOR R C CO INC	1329	1826				
3033105600000	10N-31W-35 BELLER 1-35	CRAVENS OIL	2429	2958	3334	3483	3685	
3033105660000	10N-30W-30 GRIFFIN 1-30	MUELLER T C OF CRWFR	2473	3057	3481			
3033105730000	10N-32W-28 ATWELL 1-28	XTO	1568	2021	2342	2417	2642	2932
3033300220000	10N-32W-14 TOM MOWERY 1	GULF OIL	1545	1989	2333	2436	2629	2921
3131000080000	8N-32W-13 FREE FERRY ESTATE 1	STEPHENS	4805	5383	5804	6078	6335	
3131000200000	8N-32W-24 YOUNG 1	STEPHENS	4838	5408	5878			
3131000380000	8N-32W-26 HARD-SCRABBLE CO CL 1	STEPHENS	4985					
3131100680000	8N-32W-35 MUNICIPAL AIRPORT 3	STEPHENS	4781	5286	5621	5843	6047	
3131100750000	8N-32W-26 HRDSCRBBL CNTRY CLB 2	STEPHENS	4921	5493	5772		6229	
3131101790000	8N-32W-22 ACME BRICK 1	TEXAS O&G	5004	5590	5817		6312	
3131101920000	8N-32W-12 JEFFREY A-1	TEXAS O&G	4893	5436	5846	6016	6279	
3131102000000	8N-32W-1 WARD J-1	TEXAS O&G	5652	6258	6690	6942	7225	
3131102010000	8N-32W-34 AIRPORT 81 1	HANNA	4776	5308	5715		6127	6422
3131102450000	8N-32W-10 DALE A SAWYER 1	ARCO	4406	4981	5374	5610	5829	
3131102600000	8N-32W-27 KELLEY /A/ 1	TXO	4948		5799	6000	6237	6529
3131102680000	8N-32W-9 GORDON FANNIE I 1	ARCO	4396	4746	5126	5350	5592	

UWI (API Num)	Well Label	Operator	Lower Atokan	Pennsylvanian Morrowan	Upper Mississippian	Lower Mississippian	Devonian	Cason
3131102740000	8N-32W-21 LARCO 1	TXO	5459	6086	6520	6704	6906	
3131102760000	8N-32W-28 PORTER /D/ 1	TXO	4892	5433	5783		6149	6488
3131102830000	8N-32W-20 PORT AUTHORITY 1	TXO	4870	5376	5781		6153	6490
3131102860000	8N-32W-33 CHURCH B" B-1"	TXO	4968	5548	5959	6066	6245	6574
3131102940000	8N-32W-26 HARDSCRABBLE CC 3-26	STEPHENS	4982		5808		6237	
3131102970000	8N-32W-4 MITCHELL 1-4	STEPHENS	4254	4749	5134	5356	5611	5904
3131103010000	8N-32W-34 AIRPORT 83 1	HANNA	4885	5315	5700	5902	6126	
3131103060000	8N-32W-23 ARCO CENTRAL MALL 1	ARCO	4603	5215	5650	5895	6132	
3131103110000	8N-32W-8 FT SMITH 1	TXO	4551	5055	5415	5638	5857	
3131103140000	8N-32W-34 WELCOME TO MILLERTI 1	HANNA	5026	5696	6171	6390	6621	
3131103190000	8N-32W-14 ONEAL 1-14"	ARCO	4740	5272	5712	5958	6203	
3131103210000	8N-32W-3 FT SMITH TOWNSITE 1-3	ARCO	4499		5260	5497	5738	6041
3131103270000	8N-32W-22 ACME BRICK 2	TXO	4977	5587	6032		6445	
3131103310000	8N-32W-8 ROGERS KAY 3-5	STEPHENS	4286	4802	5176	5389	5614	5888
3131103320000	8N-32W-9 GORDON FANNIE I 2	ARCO	4696	5276	5691	5917	6153	
3131103330000	9N-32W-34 HALE 1-34	WILLIFORD	5979	6522	6944	7175	7452	
3131103340000	8N-32W-11 VICK 1-11	ARCO			5453	5685	5928	
3131103630000	8N-32W-15 PARK AVENUE 1	TXO	5032	5629	6046		6503	
3131103740000	8N-32W-32 HENRY 1	SAMSON	5227	5784	6198			
3131103950000	8N-32W-29 FORSGREN 1	SAMSON	4919	5458	5878		6249	
3131104020000	8N-32W-29 NEWELL C-1	TXO	4729	5248	5667		6037	
3131104350000	8N-32W-22 ACME BRICK 3	TXO	5004	5588	5819		6317	
3131104760000	8N-32W-36 MUNICIPAL AIRPORT 5	STEPHENS				5816	6040	
3131104920000	8N-32W-13 YOUNG CHARLES 2-24	STEPHENS	5001	5747	6166	6441	6691	
3131105120000	8N-32W-22 ACME BRICK 4	SONAT	4914	5508	5932			
3131105330000	8N-32W-29 FORSGREN 2	OZARK O&G	4837	5358	5802		6163	
3131105640000	8N-32W-22 ACME BRICK 5	SONAT	5064	5663	6150			
3131105720000	8N-32W-4 MITCHELL 2	STEPHENS	4243	4743	5137	5365	5618	

UWI (API Num)	Well Label	Operator	Lower Atokan	Pennsylvanian Morrowan	Upper Mississippian	Lower Mississippian	Devonian	Cason
3131105810000	8N-32W-22 FREE FERRY 1	SONAT	5868	6443	6860			
3131106170000	8N-32W-34 AIRPORT 94 1"	HANNA	4829	5330	5726	5931	6136	6455
3131106470000	8N-32W-13 FREE FERRY ESTATES 2	STEPHENS	4822		5672	5794	6048	
3131106490000	8N-32W-20 PORT AUTHORITY 2	SONAT	4827	5333				
3131106810000	8N-32W-21 LARCO 2	SONAT	5048	5630				
3131106920000	8N-32W-21 PORTER D" 3"	SONAT	5216	5821	6289	6499	6716	
3131107100000	8N-32W-25 SENGEL 2	STEPHENS		4964	5436		5909	6241
3131107880000	8N-32W-36 MUNICIPAL AIRPORT 7-36	STEPHENS	4599	5179	5609	5847	6067	
3131110600000	8N-32W-13 FREE FERRY ESTATES 4	STEPHENS	5138		6056			
3131111130000	8N-32W-20 PORT AUTHORITY 3	CHESAPEAKE	4818	5358	5800	5980	6171	
35079200170000	10N-27E-9 ARKANSAS VALLEY 1	SUN OIL	5155	5697	6107		6459	
35079202040000	10N-27E-5 JESSIE GREEN 1	SUN OIL COMPANY	5625	6198				
35079202070000	10N-27E-4 KATHERIN COBB BAKER 1	HANNA OIL & GAS CO	5445	6009				
35079202160000	11N-27E-34 ARK VALLEY FARMS 1-34	STEPHENS PROD	4522	5043	5460			
35079203330000	10N-27E-5 GEREN 1	COTTON PET			5415	5569	5772	
35079203430000	10N-27E-16 BOOZMAN 1-16	HADSON OHIO OIL		5704	6110	6262	6443	
35079203890000	10N-27E-15 FORSGREN 1-15	DAVIS JOSEPH D CO	5275	5831	6245	6411	6591	
35079204980000	10N-27E-9 YOUNG 1-9	WILLIFORD ENERGY CO	5081	5618			6369	
35079204990000	10N-27E-10 SOSEBEE 1-10	WILLIFORD ENERGY	4916	5446	5869	6054	6238	
35079205060000	10N-27E-4 LEFLORE A" 1"	TXO PROD		5979	6398	6567		
35079205430000	10N-27E-10 SINGLETON A" 1"	TXO PROD		5538	5948		6280	
35079205650000	10N-27E-3 ARKANSAS VALLEY FAR 2	STEPHENS PROD	4881	5416	5848			
35079208070000	10N-27E-16 EVANS 1	UNIT PET	5621	6178				
35079209400000	10N-27E-4 ROBERT YOUNG 1	SONAT EXPL			5179	5347	5531	
35079215480000	10N-27E-9 GAMBLE 1-9	MUELLER THOMAS C LTD	5137	5687				
35079215630000	10N-27E-4 INDIAN NATIONS 1-4	STEPHENS PRDCTN CO	5238	5796				
35079216130000	10N-27E-19 JLH 1-19	SHIELDS	5834	6259				
35079301810000	10N-27E-8 ARKANSAS VALLEY 1	SUN OIL	5418	5947				

UWI (API Num)	Well Label	Operator	Lower Atokan	Pennsylvanian Morrowan	Upper Mississippian	Lower Mississippian	Devonian	Cason
35135000020000	12N-25E-19 CHEEK 1	HARRIS BRUCE	2138	2500	2750		2922	
35135000040000	13N-25E-15 BURKE-MCBEE 1	FOSTER T JACK						1105
35135000050000	11N-25E-20 HELM 1	WHEELER BERT	2396	2806				
35135000070000	11N-24E-17 RAMM UNIT 1	PAN AMERICAN	3851	4190	4475			
35135000160000	12N-27E-18 O CATES 1	CARTER OIL	694	1059	1366			
35135000270000	10N-24E-5 ROY H WILLIAMS 1	CARTER OIL	2230					
35135200020000	11N-27E-21 CATES 1	COX EDWIN L		5190	5548		5877	
35135200060000	10N-26E-1 CROWE UNIT 1	SUPERIOR OIL	5487	5659				
35135200070000	10N-26E-7 JAMES D GALLOWAY 1	HAMON JAKE L	5496	5978	6333			
35135200090000	10N-26E-2 JOHN A REINHART UNT 1	CONTINENTAL OIL	5422	5937				
35135200120000	11N-27E-29 DICKENS 1	SUN OIL		5038	5439			
35135200140000	11N-27E-30 KELLEY 1	SUN OIL	4641	5170	5572			
35135200150000	11N-27E-28 HAWKINS 1	SUN OIL	4605	5120	5509	5710	5921	
35135200160000	10N-25E-1 ERNEST FOUTS 1	SUN OIL	5852	6261				
35135200170000	11N-27E-32 MIRIAM ROGERS UNIT 1	MOBIL OIL	4410	4939	5346			
35135200190000	10N-26E-9 ELLIS COAN 2	STEPHENS PROD	5415	5918	6286			
35135200210000	10N-26E-8 MARIE COAN 1	STEPHENS PROD	5464	5966	6338			
35135200230000	10N-26E-3 MUMEY 1	MONSANTO CO	5575	6090				
35135200250000	10N-26E-5 FRANK LEE 1	STEPHENS PROD	5702	6201	6573			
35135200270000	11N-26E-33 MARR 1	MONSANTO CO	6006	6483				
35135200280000	10N-24E-8 ROBERT COPELAND 1	STEPHENS PROD	2527	2848	3197	3305	3365	
35135200300000	10N-25E-8 BRANT 1	MONSANTO CO	6126	6562				
35135200330000	11N-27E-28 HAWKINS 1	THE HEADINGTON CO	4511	5015	5412			
35135200360000	11N-27E-31 WYLY 1	YOUNGBLOOD J LEE	4582	5100				
35135200390000	11N-27E-33 KATHARINE BRADY UT 1	MOBIL OIL	4342	4847	5232			
35135200430000	13N-26E-13 CURTSINGER 1	ANSCHUTZ CORP	434	782	1016	1102	1206	1324
35135200440000	10N-26E-3 VAUGHAN 1	HEADINGTON CO	5501	6022	6405			
35135200450000	10N-27E-6 MIZE 1	LEE CLAYTON E		5069			5843	

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35135200460000	10N-26E-6 MORGAN 1	JOHNSON E LYLE	5806	6268				
35135200490000	11N-24E-23 B & F RANCH 1	STEPHENS PROD	2522	2903	3205	3251	3338	
35135200500000	11N-27E-21 KELLY 1	OXLEY PET	4480	5018	5399			
35135200520000	11N-27E-20 MIRIAM 1	MONSANTO CO	6368	6952				
35135200550000	11N-27E-30 BRADY /B/ 1	TEXAS O&G	4673	5208	5607			
35135200590000	11N-26E-32 E C ROWLAND 2	STEPHENS PROD	6006	6476	6834	6941	7075	
35135200600000	11N-24E-27 NOAH MAYNARD 1	STEPHENS PROD	2573	2924	3227	3279	3360	
35135200610000	10N-25E-1 YUTTERMAN 1	DAVIS JOE D	5803	6243				
35135200620000	10N-25E-10 HUMPHRIES 1	STEPHENS PROD	6499	6920				
35135200650000	11N-26E-31 CLUCK 1	STEPHENS PROD	5982	6442	6779	6877	7007	
35135200660000	10N-24E-8 POWELL /C/ 1	TEXAS O&G	2523	2856	3194			
35135200680000	11N-26E-34 JIM ANGEL 1	STEPHENS PROD	5764	6254	6613	6732	6862	
35135200720000	10N-26E-5 ROBERTS /C/ 1	TEXAS O&G	5778	6266	6628	6735	6873	
35135200750000	11N-27E-16 HAWKINS 1	SOUTHERN UNION EXPLO	5618	6185	6542			
35135200770000	10N-26E-1 BURVA PATES 1	COX EDWIN L	5123					
35135200780000	10N-24E-6 HIEBELER 1-6	SERVICE DRLG	2392	2706	3001		3171	
35135200790000	11N-27E-20 PATES UNIT 1-20	MALKA PROD		5802				
35135200800000	11N-27E-17 HODGES 1	SOUTHERN UNION EXPL	6737	7226				
35135200810000	11N-27E-15 CATES 1	SOUTHERN UNION EXPL		5930	6299	6492	6694	
35135200830000	11N-26E-32 ROWLAND 3	STEPHENS PROD	6016	6483	6834			
35135200840000	11N-26E-30 BLACKARD 1	SAMSON RESOURCES	6433		6874			
35135200850000	10N-25E-2 LEE-DAVIS 1	LOBAR OIL	6032					
35135200860000	11N-26E-29 CONDREN 1-29	STEPHENS PROD	6326	6840	7194			
35135200870000	11N-26E-35 JOHN WARD JR 1	STEPHENS PROD	5669	6204	6571			
35135200880000	10N-24E-5 DEDRICK 1	JOHNSON E LYLE	2476	2816				
35135200900000	11N-26E-36 ROGERS 36-1	HAWKINS O&G	4717	5239	5624			
35135200920000	10N-24E-7 JACKSON CPC140	CIMARRON PET	2534	2853	3177		3363	
35135200930000	11N-26E-35 PATES 35-A	RICKS EXPL	5371	5860	6233			

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35135200940000	10N-26E-1 CROWE 1	TEXAS O&G	5204	5721	6102	6227		
35135201010000	11N-26E-26 KELLEY 1-26	WENEXCO INC	6005	6465				
35135201020000	12N-24E-23 HOLLIS CPC-16	CIMARRON PET	2173	2532	2778	2819	2924	3230
35135201030000	12N-24E-9 HOMES CPC-14	CIMARRON PET			522	573	646	946
35135201060000	10N-24E-3 JESSE B FARGO UN 1	ARCO O&G	3632	4070	4416	4492	4578	
35135201080000	11N-25E-6 DILLARD 1	BROACH RESOURCES	2790	3209				
35135201100000	13N-24E-19 CRAWFORD CPC-17	CIMARRON PET			465	526	604	864
35135201120000	11N-24E-32 FARGO 1-32	DYCO PET	2410	2758	3060	3132	3203	
35135201150000	11N-27E-21 KELLEY 3	OXLEY PET	4407					
35135201170000	12N-24E-11 MARTIN 1	IREX CORP		320	517	569	670	972
35135201200000	12N-25E-20 B B B 1	HANNA O&G	2096	2467	2710	2758	2883	3207
35135201210000	11N-25E-36 BROOKS 36-1	WHITMAR EXPL	6091	6399				
35135201220000	12N-26E-29 AUSTIN ONEAL 1-29	STEPHENS PROD	1516	1946	2239	2336	2531	
35135201270000	11N-27E-9 WOFFORD 1	SOUTH UNION	6242	6792				
35135201340000	11N-25E-22 COOK 1-22	HOLD OIL	2063					
35135201370000	11N-27E-22 HARPER BERT 1	STEPHENS PROD		5650				
35135201380000	12N-25E-28 FEDERAL LAND BANK O 1	HUNT OIL	1759	2143	2400	2448	2589	2909
35135201400000	11N-27E-19 BUIE FARMS 1	ARKOMA PROD	6359	6946				
35135201410000	11N-24E-24 WILDHORSE 1-24	STEPHENS PROD	2362	2747	3040	3079	3183	
35135201440000	11N-24E-13 FULLER 1	STEPHENS PROD	2463	2860	3135	3177	3286	
35135201450000	11N-24E-23 B & F RANCH 2-23	STEPHENS PROD	2503	2871	3168	3210	3300	
35135201460000	11N-27E-31 WEEKS 1-31	SLAWSON DONALD C	4520	5042	5449			
35135201490000	12N-25E-29 TOM AND ECHO RIDER 1	STEPHENS PROD	1774	2150	2404	2455	2594	
35135201500000	11N-25E-18 RANDOLPH 1-18	STEPHENS	2383	2761	3060	3103	3213	
35135201510000	11N-27E-28 HAWKINS 2	HEADINGTON OIL	4460	4994	5387			
35135201560000	10N-26E-4 HALLUM 2-4	LYSANDER RESOURCES	5719	6202	6567			
35135201580000	12N-25E-21 TOUTZ HEIRS 1	STEPHENS PROD	1833	2209	2450	2521	2671	
35135201600000	11N-26E-33 ROWLAND 4	STEPHENS PROD	5865	6351	6721			

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35135201630000	11N-25E-4 GREEN GILBERT 1	STEPHENS PROD	2451	2860	3048	3100	3236	
35135201640000	11N-26E-34 OWENS 1-34	LYSANDER RESOURCES	5813	6296	6661			
35135201650000	11N-27E-33 OPIE-CATES 1	TXO PROD	4326	4811	5185	5382	5571	
35135201680000	11N-26E-25 PATES FARMS 1	OXLEY PET	4576	5097	5478	5601	5779	
35135201690000	10N-25E-12 BARROW 1-12	TERRA RESOURCES	5982					
35135201700000	11N-27E-16 HAWKINS 2-16	DANIEL-PRICE EXPL	5877	6447	6805			
35135201770000	12N-26E-26 O'NEAL 1	QUAPAW O & G	1275	1684	2002	2120	2298	2622
35135201800000	11N-27E-29 PATES 1-29	KAISER-FRANCIS OIL	4567	5083	5505			
35135201810000	11N-27E-32 ROGERS MIRIAM 2	MOBIL OIL	4515	5007	5414			
35135201830000	10N-26E-3 MUMEY 1	HEADINGTON OIL	5662	6143	6492			
35135201840000	11N-26E-25 PATES FARMS 2	OXLEY PET	5286	5854	6236	6356	6534	6839
35135201850000	11N-25E-27 SALLY B 1	STEPHENS PROD	2585	3018	3324	3393	3506	3859
35135201860000	11N-27E-28 MOFFETT 1	D-PEX OPERATING		4901	5301		5699	
35135201870000	11N-26E-36 MIRIAM 1	OXLEY PET	4579	5096	5479	5602	5797	
35135201890000	11N-25E-2 PARKER W 1	ARKLA EXPL	1879	2288	2573	2640	2771	3109
35135201910000	11N-26E-25 PATES FARM 3	OXLEY PET	4575	5099	5479			
35135201930000	12N-25E-13 AEC MITCHELL 1-13	ARKLA EXPL	1610	2034	2282	2364	2556	
35135201940000	11N-26E-28 BROWN 1	D-PEX OPERATING	6351	6871	7161	7294	7427	
35135201960000	11N-27E-30 YOUNGER 1	OXLEY PET		5290	5693	5813	5975	6289
35135201980000	11N-26E-12 BROOKS 1	OXLEY PET	1085	1545	1900	2035	2244	
35135201990000	10N-25E-9 DAILY 1-9	ENRON O&G	6192	6642	6995	7082	7180	
35135202040000	10N-26E-10 MUMEY 1-10	MUELLER THOMAS C	5219	5709	6086			
35135202050000	11N-25E-18 RANDOLPH 1-18	STERLING OIL	2335	2736	3035	3078	3192	
35135202100000	11N-27E-30 YOUNGER 2	OXLEY PET	4667	5196				
35135202130000	12N-24E-17 CHEEK B 1	SULLIVAN & CO		262	486	534	619	914
35135202150000	11N-25E-20 HELMS 1-20	TOM BROWN	2412	2839	3146	3193	3308	
35135202160000	11N-25E-28 WILSON 1-28	BROWN TOM	2551	2959	3279	3340	3449	
35135202170000	11N-24E-29 KUMPE 1	PARK AVENUE EXPL	2979	3327	3631	3691	3758	

UWI (API Num)	Well Label	Operator	Lower Atokan	Pennsylvanian Morrowan	Upper Mississippian	Lower Mississippian	Devonian	Cason
35135202210000	10N-26E-9 COAN E E 4	STEPHENS PROD	5209	5684	6073			
35135202220000	11N-24E-12 VAN DELINDER O R 1-12	STERLING OIL OF OKLA		3019	3302		3450	
35135202230000	11N-25E-33 LOWREY 33-1	SEPCO	2388	2785	3113	3172	3284	3638
35135202260000	11N-27E-27 RODGERS KAY 4	STEPHENS PROD	4326	4850	5252		5659	
35135202340000	11N-25E-7 BURROW 1-7	STERLING		2853	3106		3257	
35135202350000	11N-27E-33 BRADY 2	JMC EXPL	4386	4909				
35135202360000	11N-27E-34 ARKANSAS VALLEY FAR 3	STEPHENS PROD		4843	5162		5563	
35135202370000	11N-24E-26 MAYNARD 1-26	SOUTHWESTERN ENERGY					3311	
35135202380000	11N-25E-5 NEAL 1-15	SEPCO	2735	3152	3331			
35135202430000	11N-24E-32 WILDHORSE MOUNTAIN 1	WEISER-BROWN OPERATI	2519	2860	3157	3221	3292	
35135202440000	11N-26E-26 SHADY GROVE 1	HOOVER/WILSON	4917	5424				
35135202450000	10N-25E-8 BRANT 81	ENRON O&G	5974	6410	6733	6820	6914	
35135202460000	11N-26E-31 CLUCK 2	STEPHENS PROD	6020	6469	6821			
35135202470000	11N-24E-26 MAYNARD 2-26	SOUTHWESTERN ENERGY	2487	2857	3157	3206	3290	
35135202500000	10N-26E-1 CROWE 2	FREEDOM ENERGY	5875	6426				
35135202510000	11N-27E-33 LEFLORE LILLIE 1	SONAT EXPL		4810	5197	5377	5560	
35135202520000	10N-26E-4 WATTS 1-4	NEW JERSEY NATURAL R	5571	6076	6451			
35135202550000	10N-26E-9 COAN E E 6	STEPHENS PRDCTN CO	5335	5834	6216			
35135202560000	10N-26E-3 SHARP 1-3	HEADINGTON OIL	5571	6066	6431			
35135202620000	12N-25E-36 FINIS EDWARDS 1	STEPHENS PROD	1780	2200	2484	2553	2706	
35135202630000	12N-26E-11 PINE MOUNTAIN 1	HOOVER WILSON	1186	1581	1867	1972		
35135202660000	11N-27E-33 BRADY 3	JMC EXPL	4367	4875				
35135202670000	12N-26E-12 UERLING 1	HOOVER/WILSON EXPL&P	997	1382	1672	1776	2001	2307
35135202680000	10N-24E-5 BIG COUNTRY 1	HANNA O&G	2357	2617	2923	3002	3076	
35135202690000	12N-26E-14 HAWKINS 1	HOOVER WILSON	1180	1579	1857			
35135202700000	12N-26E-13 BELL 2	HOOVER/WILSON EXPL&P	1249	1667	1971			
35135202710000	12N-26E-13 BELL 1	HOOVER WILSON	1066	1462	1749			
35135202720000	12N-26E-12 UERLING 2	HOOVER/WILSON EXPL&P	1115	1509	1786			

UWI (API Num)	Well Label	Operator	Lower Atokan	Pennsylvanian Morrowan	Upper Mississippian	Lower Mississippian	Devonian	Cason
35135202750000	12N-27E-19 WARNER 1	HOOVER/WILSON EXPL&P	729					
35135202780000	11N-27E-16 HAWKINS 3	OXLEY PET	6477	7025				
35135202790000	11N-26E-25 PATES FARMS 4	OXLEY PET	4564	5071	5453	5571	5747	
35135202830000	12N-26E-24 KEITH 1-24	HOOVER/WILSON EXPL&P	1286	1728	2028	2104		
35135202840000	12N-27E-18 HOPKINS 1	HOOVER/WILSON EXPL&P	650	1055	1357	1519		
35135202850000	12N-27E-17 CATES 1	HOOVER/WILSON EXPL&P	704	1143	1461	1618	1843	2140
35135202860000	12N-27E-20 BETHELL TRUST 1	HOOVER/WILSON EXPL&P	673	1113	1447	1609		
35135202870000	11N-26E-25 PATES FARMS 5	OXLEY PET	5282	5889	6249	6367	6534	
35135202890000	11N-27E-4 WHEELER 1	HANNA O&G	849	1339	1710	1868	2075	
35135202900000	12N-27E-29 BELAND HEIRS 1	HOOVER/WILSON EXPL&P	1028	1493	1832	2003		
35135202920000	12N-26E-3 ARMER 1	HOOVER/WILSON EXPL&P		1262	1502	1545	1716	2021
35135202930000	12N-27E-6 STRANG TRUST 1	HOOVER/WILSON EXPL&P	1618	2050				
35135202970000	12N-26E-12 UERLING 3	HOOVER WILSON	739	1142	1443	1551		
35135202990000	10N-25E-11 BRANT 2-11	STEPHENS PROD	5749	6227				
35135203010000	11N-27E-5 RUSSELL 1-5	YALE	1027	1509				
35135203040000	11N-26E-1 CREWSON 1	OXLEY	1358	1800	2138			
35135203050000	12N-26E-11 PINE MOUNTAIN 2	KLABZUBA O&G INC	1151	1473	1752	1827		
35135203060000	12N-27E-21 BELAND HEIRS 2	KLABZUBA	871	1093	1439	1626	1889	
35135203140000	11N-26E-12 ELLA 1	OXLEY	1413	1868				
35135203160000	12N-26E-25 BUIE W H 1-25	YALE	1044	1491	1822			
35135203170000	11N-27E-30 KELLEY TRUST 1X	UNIT PETROLEUM CO	4605	5138	5554			
35135203180000	11N-26E-15 BRANNON 1-15	YALE		1759	2104			
35135203200000	12N-27E-18 HOPKINS 2	KLABZUBA O&G INC	603	1014	1332			
35135203220000	10N-26E-2 CROW ESTATE 1	HOOVER-WILSON EXP&PR	5180	5690	6070			
35135203230000	12N-26E-21 GHOLSTON 1	KLABZUBA	1770	2100	2318	2418	2646	
35135203240000	10N-26E-11 CROWE ESTATE 1-11	DEKA	5122	5606				
35135203250000	12N-27E-20 BETHELL TRUST 2	KLABZUBA	638					
35135203260000	11N-26E-13 GAGE 1-13	SHIELDS	1203	1670	2017			

UWI (API Num)	Well Label	Operator	Lower Atokan	Pennsylvanian Morrowan	Upper Mississippian	Lower Mississippian	Devonian	Cason
35135203280000	12N-24E-5 POLASEK 1-15	ARKANA		399	612	659	750	1019
35135203300000	12N-26E-36 BUIE 1-36	ARKANA	1314	1750				
35135203310000	11N-25E-33 STIMSON 33-1	TIDEMARK	2540	2935	3268	3324	3439	
35135203320000	13N-26E-32 HILL 1	KLABZUBA	451	787	1047	1079	1234	1547
35135203330000	13N-26E-4 COLE 1-4	FRIEDEL PET		460	581	627	876	
35135203340000	11N-27E-5 GENEVIEVE 1-15	YALE OIL	1053	1531	1889			
35135203350000	11N-26E-16 BREEDLOVE 1-16	YALE OIL	1509	1987	2327			
35135203360000	11N-27E-27 RODGERS K 6	STEPHENS PRDCTN CO		4996	5413		5844	
35135203370000	11N-25E-17 HELMS 1-17	TIDEMARK	2604	3088				
35135203380000	12N-27E-18 HOPKINS 3	KLABZUBA	960	1395	1675			
35135203390000	11N-27E-29 PATES FARMS 2-29	KAISER-FRANCIS	4565	5097	5514			
35135203400000	11N-27E-29 PATES 1-29	WEISER BROWN	4514	5035	5434	5599	5783	
35135203430000	12N-24E-25 GEORGE 1	KLABZUBA	1973	2349	2606	2646	2763	
35135203440000	12N-26E-27 SUTTON 1	KLABZUBA	1421	1864	2167			
35135203450000	12N-26E-25 BUIE 2-25	YALE	994	1438				
35135203470000	12N-27E-31 BUIE W H 1-31	ARKANA	1181	1626	1955	2078	2276	
35135203480000	12N-26E-25 HOLMES 1-25	KLABZUBA OIL	1171	1618				
35135203490000	12N-26E-26 ALLEN 1-26	KLABZUBA	1232	1664				
35135203500000	10N-26E-5 SUZANNE 1-15	YALE OIL	5832					
35135203510000	12N-26E-24 ACQUISTAPACE 1-24	KLABZUBA	825	1244	1555			
35135203520000	11N-27E-22 HARPER BERT 2	STEPHENS PRDCTN CO	5289	5844				
35135203530000	12N-27E-30 LANELE MARY 1-30	JEC	929	1387				
35135203560000	12N-26E-36 BUIE 2-36	JEC OPERATING LLC	1209	1663	2006			
35135203580000	11N-26E-33 ROWLAND 5-33	SHIELDS	5874	6346	6694			
35135203590000	10N-25E-1 BIG BAYOU 1	HANNA	5919	6353	6694			
35135203600000	10N-26E-6 MORGAN 2-6	SHIELDS	5758	6204	6518	6613	6729	
35135203610000	13N-24E-36 LONG 1	BEAR PROD			507	557	688	976
35135203620000	13N-25E-7 DAVIS 1	BEAR			507	545	775	1034

UWI (API Num)	Well Label	Operator	Lower Atokan	Pennsylvanian Morrowan	Upper Mississippian	Lower Mississippian	Devonian	Cason
35135203630000	13N-25E-21 PRICE 1	BEAR PROD			517	571	814	1084
35135203650000	11N-26E-33 KELTON 1-33	SHIELDS	5917	6393	6745			
35135203660000	12N-27E-19 WARNER 2-19	KLABZUBA	946	1397				
35135203670000	11N-27E-33 PATES FARM 1-33	SHIELDS OPER INC	4591	5179	5612			
35135300040000	13N-24E-2 TRIBEL 1	CONTINENTAL OIL					188	413
35135300050000	10N-26E-10 REINHART M J 1	CONTINENTAL OIL	5172	5685	6058	6187	6341	
35135600010000	10N-24E-4 FARGO 1	HUBER J M CORP	2211	2531	2852			
35135600050000	12N-25E-14 LEWIS 1	PHILLIPS PET	1957	2351	2478	2567	2746	
35135600130000	11N-24E-33 J F JACKSON UNIT 1	HUMBLE OIL & REFININ	2278	2629				
3033105570000	10N-32W-12 HIGHTOWER 3-12	CRAVENS	1534	1826	2194			
3131111800000	8N-32W-27 KELLEY A" 4-27"	CHESAPEAKE	5038	5640	5952	6163	6379	
35079217360000	10N-27E-18 COBB 1-18	SHIELDS OPER INC	5900	6461				
35135203700000	12N-27E-20 BETHEL TRUST 3-20	SEDNA	761	1218	1560	1727	1999	2290
35135203710000	11N-24E-24 WILDHORSE 2-24	STEPHENS PRDCTN CO	2455	2787	3080	3119	3220	
35135203750000	10N-26E-6 SHIM 2-6	SEDNA	5794	6273	6627	6722	6840	
3131113760000	8N-32W-14 UAFS 1-14D	HIGHLAND		5270	5698	5905	6134	
35135203860000	12N-24E-8 MARBLE CITY 8-1	C & M EXPL LLC			537		677	
3131114020000	8N-32W-13 FREE FERRY ESTATES 5	STEPHENS	4757	5199	5612	5864	6056	
3131114190000	8N-32W-13 FREE FERRY EST 6D	STEPHENS	4860	5298	5711			
35079221000000	10N-27E-4 YOUNG ROBERT 2-4	SHIELDS OPER INC	4854		5204	5372	5569	

***All values are sub-sea depths**