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Delineating of the Utica Shale/Point Pleasant Formation Play System to Determine Influence of the Precambrian Basement in Northeastern Ohio

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Delineating of the Utica Shale/Point Pleasant Formation Play System to Determine Influence of the Precambrian Basement on Deposition in Northeastern Ohio

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ABSTRACT

The Utica Shale/Point Pleasant Formation system has recently become a highly developed unconventional target for oil and natural gas production, leading to an increased desire for knowledge of the controls on deposition of this system. Precambrian basement features have long been known to affect deposition of older strata near these features across Ohio, but the effects of far field tectonics is not fully agreed upon. Precambrian faults and lineaments are known to exist and have been mapped, but are thought to have ceased their influence on deposition by the time of the Knox unconformity during the Cambrian.

In the case of the Ordovician Utica Shale, Point Pleasant Formation, Trenton Limestone, and the Black River Group, many believe that the deposition of these strata were not affected by Precambrian faults/lineaments or other basement features, rather their main influence was changes in sea level due to basin loading, climatic changes, and localized uplift/subsidence. The objective of this study was to determine if the deposition of these younger strata were influenced by Precambrian faults and basement features. This was done by analyzing a group of oil and gas wells in Lorain, Cuyahoga Lake, Geauga, Ashtabula, Trumbull, Mahoning, Stark, Portage, Summit, Wayne, Ashland, and Medina counties in northeastern Ohio. Electric well logs from these wells were

added to Petra, a geological mapping program, and the tops of the Utica Shale, Point Pleasant Formation, Trenton Limestone, and the Black River Group were picked. These tops were then contoured into four structure maps and 4 isopach thickness maps. These maps were analyzed with known Precambrian faults and lineaments, along with known Precambrian basement features, to determine if these Precambrian influences affected the deposition of these Ordovician strata.

It is known that high spatial resolution structure maps show contour offsets across known and inferred structural features. It is also known that high spatial resolution isopach maps show thinning and thickening across known and inferred structural features. The purpose of this study was to take these methods and apply them to the Utica Shale/Point Pleasant Formation system in order to determine structural influence from the Precambrian basement on Ordovician strata in northeastern Ohio.

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1. INTRODUCTION

The Ordovician Utica Shale has long been known as a black, organic-rich, deep basin mudstone that is the source rock for many of the Paleozoic hydrocarbon plays across the basin. With recent improvements in technology, it has become an unconventional reservoir as well (Ryder, 2008; Patchen, et al., 2015). More correctly termed the Utica/Point Pleasant Play, it is a mixed siliciclastic-carbonate system consisting of the lower Trenton/Lexington limestones, Point Pleasant Formation, and Utica Shale, primarily targeted in eastern Ohio and western-northwestern Pennsylvania (Wickstrom et al.; 1992 Lavoie et al., 2014; Hickman, et al., 2015). Recent increases in exploration for production of hydrocarbons in the Upper Ordovician Utica Shale/Point Pleasant play within the Appalachian Basin has led to an increased desire to understand the deposition of this heterogeneous package.

The Utica Shale spans throughout the Appalachian Basin from Quebec through Pennsylvania into Indiana, while the Point Pleasant Formation is generally confined to Ohio, Pennsylvania, and eastern New York (Figure 1). Generally, this system decreases in carbonate content up-section. However, when examining core from within the Appalachian Basin near the current targeted drilling areas, there are heterogeneities both laterally and vertically, dismissing the layer-cake model of Ordovician shales (Smith, 2015; Bloxson, 2017). Mineralogy has been shown to change across the basin, with depocenters of dark, organic rich shale and light, carbonate rich shales (Bloxson, 2017), potentially caused by local variations in sea level as a result of tectonic controls or influx of storm debris from the nearby carbonate platforms. These pockets or depocenters are generally poorly understood, both their causes and distribution in the region (Hickman, et al., 2015; Smith, 2015).

The depositional arrangement of grains, changes in the depositional environment, and, to various degrees, diagenesis are largely responsible for changes in the physical properties of sedimentary strata. For example, a basin being loaded by deposition can lead to a decrease in porosity due to mechanical compaction and facilitate diagenesis. In contrast, an organic rich sediment that is not buried in a timely manner may lose total organic content (TOC) to the carbon cycle before being sheltered by the deposition of another layer. When properly sheltered, organic rich shales such as the Utica Shale are formed. Mapping the distribution of these organic rich shales shows that dark shale deposition is a part of the sedimentary cycle associated with orogenies and the formation of the adjacent foreland basins (Ettensohn and Lierman, 2012). Tectonic loading during an orogeny results in deformation of the lithosphere and the adjacent basin deepening due the down-warping (Ettensohn and Lierman, 2012). The adjacent peripheral bulge rebounds in response to the lithosphere deformation. This deepening foreland basin allows for the accumulation of fine-grained sediments, including organic rich source rocks, within the basin. Continued subsidence due to a combination of tectonics and sediment loading allow for expansion of the accommodation space for continued sediment accumulation and burial of already deposited, organic-rich fine-grained sediments (Ettensohn and Lierman, 2012). In contrast, relaxing of a basin often leads to uplift and thinning of a section by the removal of previously deposited section by erosion as uplift progresses. Reactivation of dormant faults can be another process that causes uplift and subsidence, which can also affect deposition by allowing more accumulation in subsiding sides and removal of sediments and refusal of accumulation on upthrown sides of a reactivated fault. These processes collectively fall under a category termed far field tectonics, referring to the effects of large-scale tectonics that can influence deposition in an area of interest that is some distance away from the tectonic epicenter.

Ohio has long been known to be affected by far field tectonics, yet there are relatively few known basement features within Ohio (Baranoski, 2013). Little has changed since the original delineation map of Ohio's Precambrian basement (Bass, 1960), beyond new dating and provinces found within the state (Baranoski, et al., 2009; Wickstrom, et al., 1985) and more detail adding to the overall structural relief of the basement. Within Ohio, there are roughly 43 faults or fault systems verified with seismic data across the state, along with two cross-strike structural discontinuities in eastern Ohio (Cambridge and Pittsburgh-Washington), and five miscellaneous structures that consist of impact structures, rifting zones or anomalies that are not fully understood. Overall, these structures are centered along the consortium for continental reflection profile (COCORP) line, a public seismic dataset that runs in central Ohio from west to east, simply because this is where data are present. Recently, Solis (2015) mapped the eastern portion of the state in high detail for the Silurian Dayton Formation, Devonian Onondaga Limestone, and Devonian Berea Sandstone. These maps show disruptions in structure within these formations that correspond to the same known faults in eastern Ohio, along with new potential structures across the state that follow the same general fabrics of the known fault systems (Figure 2). This suggests that there could be more faults or other types of structures previously unknown across Ohio that most likely originate from the Precambrian Basement and have been reactivated throughout time. Further detailed mapping of Paleozoic strata could provide insight into the Precambrian structures, and how they have reactivated over time to influence the Paleozoic strata.

Depositional trends of Utica Shale/Point Pleasant Play formations, Trenton Limestone, and Black River Group were defined to determine if the Precambrian basement and associated tectonics affected deposition of this mixed siliciclastic-carbonate system. This was done by detailed mapping using well logs across northeast Ohio to determine changes in structure and thickness for each of the formations. Formation boundaries were determined for the Utica Shale, Point Pleasant Formation, Trenton Limestone, and the Black River Group, and structure maps were generated based on these four tops. Isopach thickness maps were generated for the Utica Shale, Point Pleasant Formation, and Trenton Limestone, as well as a combined thickness map for the Utica/Point Pleasant. These maps were compared to regional faults/trends in the area of interest and basement features in the state of Ohio.

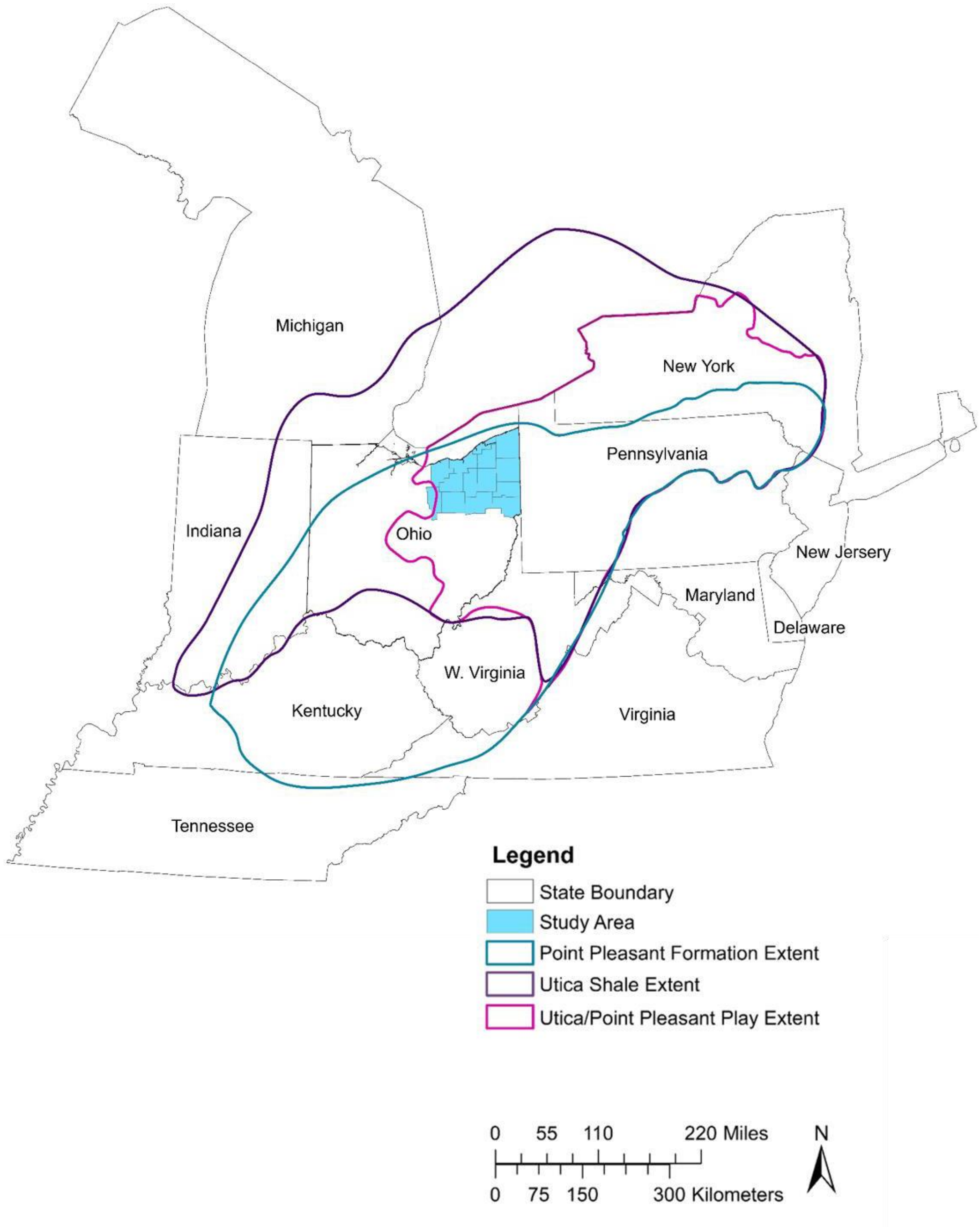

Figure 1: Regional extent of the Utica Shale and Point Pleasant Formation. Modified from Bloxson (2017) and Hickman et al. (2015).

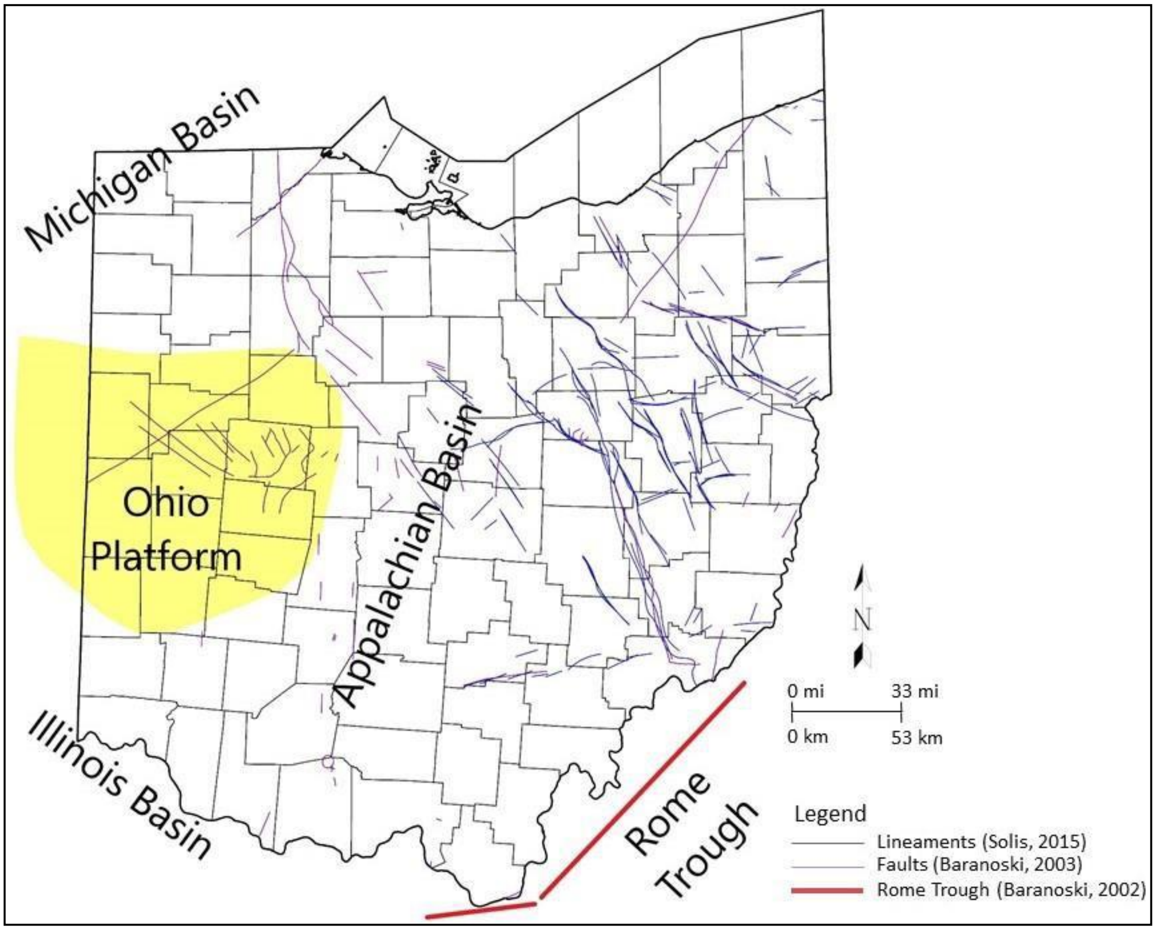

Figure 2: Map showing known Precambrian faults (purple), trends (blue) inferred from the Silurian Dayton Formation, Devonian Onondaga Limestone and Devonian Berea Sandstone, and major "pre-Ordovician" structural features in the study area associated with Precambrian basement rock

2. GEOLOGIC SETTING

The Ordovician Black River Group, Trenton Limestone, Point Pleasant Formation, and Utica Shale within northeast Ohio represent a tectonically active period, transitioning from warm-water carbonate platform to cool-water carbonate platform, and finally tectonic loading and basin subsidence. This system coincides with the Taconic Orogeny that occurred throughout the Middle to Late Ordovician Period (Ettensohn and Lierman, 2012).

Prior to Middle-Late Ordovician deposition of the Black River Group, the regional basin dynamics were extensional and passive (Patchen et al., 2006). Basin dynamics changed during the Middle-Late Ordovician to a compressional regime with the collision of the Taconic arc from the east (Patchen et al., 2006). During this evolution, the regional setting transformed into a shallow water carbonate ramp with epeiric seas transgressing over the area (Patchen et al., 2006). This ramp dipped southeast to eastward, and extended from the Michigan Basin and across the central Appalachian Basin (Patchen et al., 2006). The carbonate ramp led to the formation of a warm, shallow, tropical depositional environment that deposited the relatively uniform, shallow carbonate Black River Group across the region. (Patchen et al., 2006). The deposited carbonates are lithostratigraphically consistent across most of the Appalachian Basin region

(Patchen et al., 2006). During the time of Black River deposition, an elongated depocenter formed which would later become characteristic of the Appalachian Basin (Patchen et al., 2006).

During the Middle Ordovician, the Appalachian Basin continued to evolve, and the more fossiliferous and coarser-grained Trenton Limestone began deposition across the northwestern portion of the continent (Patchen et al., 2006). Evolution included the formation of low-relief carbonate buildups that define the Trenton Limestone (Patchen et al., 2006). A marine transgression allowed for continued carbonate production across the region, consisting of temperate marine fossiliferous carbonates with significant regional changes to paleoclimate (Patchen et al., 2006). This formed a "ramp-like slope" that extended from the Indiana/Michigan region to the Central Appalachian Basin. The Black River ramp basin architecture remained during the earliest portion of Trenton deposition until the Taconic orogeny began to increase in intensity (Patchen et al., 2006). This change in orogenic intensity led to the formation of a bulge and trough in the basin, and to the formation of new complex carbonate platforms and sub-basins (Patchen et al., 2006). Increased volcanism during this time led to the deposition of potassium bentonite beds that are found throughout the region (Huff, 1983). The Millbrig bentonite bed is commonly used to distinguish the end of Black River deposition and the beginning of Trenton Limestone deposition on well logs, with a defining sharp decrease in neutron and density porosity occurring with a sharp increase in gamma ray API units (Patchen et al., 2006).

A conspicuous, linear feature named the Sebree Trough (Figure 3) extends from the western portion of Kentucky into the southwestern portion of Ohio and through the study area (Bloxson, 2017 and Patchen et al., 2006). This feature is a thin, trough-like depression that contains mostly clastic dark shale and is considered time equivalent to the Trenton and Lexington Limestones deposition. It has been delineated in the subsurface by a lack of Lexington Limestone deposition southwest of Ohio and is thought to extend throughout Ohio based upon electrofacies mapping (Kolata, 2001). It should be noted that the origin of the Sebree Trough and its regional extent is problematic to some researchers and is not fully understood (Patchen et al., 2006). Kolata et al (2001) stated that the Sebree Trough began to develop as a linear bathymetric depression situated over the failed late Precambrian-Early Cambrian Reelfoot Rift. Rising sea level caused the rift to descend into oxygen-poor oceanic conditions (Kolata et al., 2001). This shift into anoxic conditions created several of the characteristics that identify the Sebree Trough, such as cessation of carbonate sedimentation (Lexington Limestone), removal of carbonate substrate, and deposition of dark clastic shales (Maquoketa Shale) (Kolata et al., 2001). The trough is known to be surrounded on either side by the coeval carbonate platform (Trenton and Lexington Limestones), creating a significant, abrupt and extensive change in lithofacies across this linear feature (Kolata et al.,2001).

After deposition of the cool-water carbonate platforms across the region, there was an emergence of black and brown shales that marked a significant change in paleogeography (Patchen et al., 2006). These black shales formed as a result of clastic muds funneling into the depositional environment from volcanic arcs of the Taconic Mountains to the east (Patchen et al., 2006). The previously mentioned volcanic island arc system continued to migrate north through the Late Ordovician and continued supplying clastic sediments that would drown the carbonate platform in the Appalachian Basin (Patchen et al., 2006). These black and brown clastics were interbedded with calcareous sediments in the newly formed sub-basins to form the Point Pleasant Group and subsequently the Utica Shale, while clean carbonate sediments continued to be deposited in the shallow water carbonate platforms (Patchen et al., 2006). Further increasing intensity of the Taconic orogeny during late Utica deposition caused an increase in subsidence in the Appalachian Basin (Patchen et al., 2006). This increase in sea level and/or subsidence caused the Utica Shale to begin depositing on the previously mentioned shallow carbonate platforms as well (Patchen et al., 2006). The increase in sea level and/or subsidence continued, leading to infilling of the sub-basin region and complete drowning of the shallow water platforms (Patchen et al., 2006).

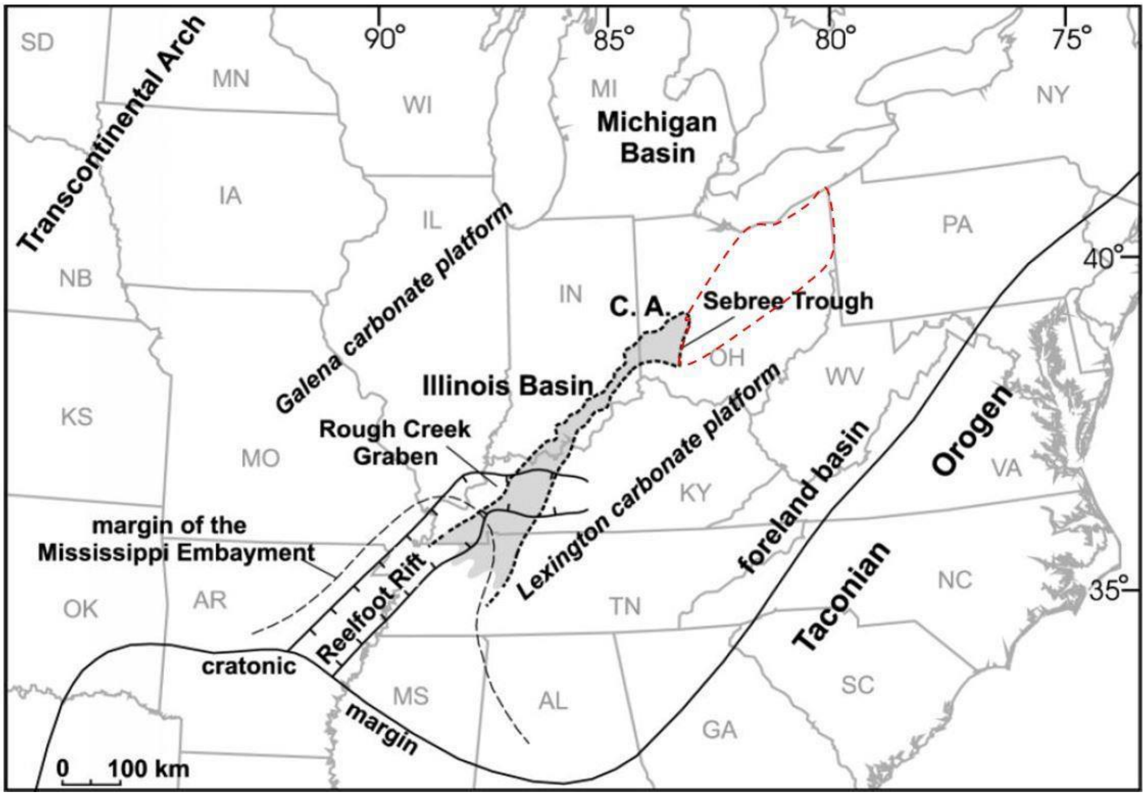

Figure 3: Sebree Trough location. Interpreted extent of Sebree Trough shown in dashed red. Modified from Bloxson (2019) and Kolata (2001).

3. STRATIGRAPHY

The Black River Group is known to be a primarily brown to gray fine-grained limestone with fossiliferous zones (Ives, 1960). The Black River Group tends to be finer grained and contains fewer fossils that represent warm-water deposition compared to the overlying Trenton Limestone, whose fossil content represents cool-water deposition across the platform (Ives, 1960). The trace amount of fossils present in the Black River Group include brachiopods, crinoids, trilobites, gastropods, and bryzoans (Patchen et al., 2006). The basal unit of the Black River Group is described as a green to gray calcareous shale transitional unit, which contains sandy and pyritic intervals and localized lenses of dolomite or limestone (Ives, 1960). The Group consists of the upper Black River Limestone member and lower Gull River Limestone member, however these members are grouped together for the purpose of this study, as the Point Pleasant Formation and Utica Shale are the main formations of interest (Shafer et al., 1994). On geophysical logs, the contact between the Black River Group and Trenton Limestone is often determined by the presence of potassium bentonite beds (Patchen et al., 2006). The most commonly used potassium bentonite bed is the Millbrig bed found at the top of the Black River Group and marks the change from the less fossiliferous mudstone lithology of the Black

River Group to the more fossiliferous, coarser grained packstone lithology of the Trenton Limestone (Patchen et al., 2006). Burrows and stylolites are commonplace in the mudstones of the Black River Group (Patchen et al., 2006). The Black River Group is laterally equivalent to the High Bridge Group of Kentucky and the Stones River Group of Tennessee (Patchen et al., 2006).

The Trenton Limestone overlies the Black River Group and is described as primarily a brown to gray, fossiliferous packstone (Ives, 1960). The uppermost portion of the Trenton Limestone consists of 5 to 10 feet of fractured dolomite (Ives, 1960). The mineralogy is mainly carbonate, with most of the matrix containing calcite with trace amounts of clay minerals in some Trenton Limestone samples (Patchen et al., 2006). The basal unit of the Trenton Limestone consists of a black carbonaceous/dolomitic shale bed roughly 3 feet in thickness (Ives, 1960). The Trenton Limestone is laterally equivalent to the Lexington Limestone of Kentucky (Patchen et al., 2006). Typical fossils include brachiopods, crinoids, trilobites, gastropods, and bryzoans (Patchen et al., 2006). The upper Trenton Limestone ends with a gradational contact into the overlying Point Pleasant Formation in the study area of northeastern Ohio, however in other areas the contact is sharp due to subaerial exposure or subsea processes (Patchen et al., 2006).

The Point Pleasant Formation consists of interbedded shales, siltstones, and limestones (Bloxson, 2017). It contains more overall carbonate content compared to the Utica Shale, and decreases in overall carbonate content up section (Bloxson, 2017; Smith, 2015). The calcareous shales of the Point Pleasant Formation have been known to contain sparse fossils and are gray to brown to black in color (Bloxson, 2017). The limestones beds of the Point Pleasant Formation are described as gray grainstones (Bloxson, 2017). Typical mineralogy of the shales of the Point Pleasant Formation consists of quartz, illite, chlorite, muscovite, pyrite, micrite, and trace amounts of hematite and calcite (Bloxson, 2017; Ohio Division of Geological Survey, 1976). The limestones of the Point Pleasant Formation contain mostly calcite with sparse illite, chlorite, and quartz (Bloxson, 2017; Ohio Division of Geological Survey, 1976; Smith, 2015). The siltstones contain quartz, feldspar, and trace amounts of illite, chlorite, and other mixed clay minerals (Bloxson, 2017; Ohio Division of Geological Survey, 1976; Ohio Division of Geological Survey, 1989a, b). Fossilized burrows, brachiopods, trilobites, crinoids, and gastropods are common throughout (Bloxson, 2017; Ohio Division of Geological Survey, 1989a, b; Ohio Division of Geological Survey, 1976). The Point Pleasant Formation in southeastern Ohio contains sufficient TOC (avg. 2.4 wt %), gas filled porosity (avg. 4.75%), and proper mineralogy (normalized clay value of 32%) to be an economic unconventional play (Brinkley, 2016). TOC content can reach upwards of 7% in the Point Pleasant Formation across Ohio, however typically ranges between 2-4% (Eble, et al., 2015). Thickness of the play can reach 300 ft in Ohio, yet thickens to over 700 ft in Pennsylvania (Patchen et al., 2006). In Pennsylvania, TOC can reach upwards of 4.85%, although typically varies between 0.5-3.0% (Ebel, et al., 2015). It should be noted that the Point Pleasant Formation and the Utica Shale are often difficult to distinguish in core/electric log/outcrop, and researchers often describe the two units as one system. The Point Pleasant Formation is laterally equivalent to the Clays Ferry Formation of Kentucky, while in New York it is referred to as the Indian Castle Shale (Hickman et al., 2015).

The Utica Shale, like the Point Pleasant Formation, has been described as ranging from interbedded clastic and calcareous shales, to fully clastic siltstones, to limestones (Bloxson, 2017). The Utica Shale is commonly black to brown in color with sparse fossils throughout the calcareous portions of the formation (Bloxson, 2017). Small concentrations of micrite have been found in the Utica Shale, however the shale is mainly calcareous in mineralogy (Patchen et al., 2006). Similar mineralogy and fossils are found between the Utica Shale and the underlying Point Pleasant Formation. Typical mineralogy of the shales of the Utica Shale consists of quartz, illite, chlorite, muscovite, pyrite, micrite, and trace amounts of hematite and calcite (Bloxson, 2017; Ohio Division of Geological Survey, 1989a, b; Ohio Division of Geological Survey, 1976). The limestones of the Utica Shale contain mostly calcite with sparse illite, chlorite, and quartz

(Bloxson, 2017; Ohio Division of Geological Survey, 1989a, b; Ohio Division of Geological Survey, 1976). The siltstones contain quartz, feldspar, and trace amounts of illite, chlorite, and other mixed clay minerals (Bloxson, 2017; Smith, 2015, Ohio Division of Geological Survey, 1989a, b; Ohio Division of Geological Survey, 1976). Fossilized burrows, brachiopods, trilobites, crinoids, and gastropods are common fossils found in the formation Bloxson, 2017; Smith, 2015, Ohio Division of Geological Survey, 1989a, b; Ohio Division of Geological Survey, 1976). Hummocky cross-stratification can be found in the Utica Shale in the Appalachian Basin (ODNR Portage County Core). Across southeastern Ohio, the Appalachian Basin Oil & Natural Gas Research Consortium and partners determined that the Utica Shale contained insufficient TOC (< 1 wt. %), gas-filled porosity (<2%), and mineralogy (normalized clay value of 49%) to be an economic unconventional play (Brinkley, 2016). In other areas, such as New York, the Utica shale contains properties to be an economic unconventional reservoir (Eble, et al., 2015). A generalized stratigraphic column can be found in Figure 4.

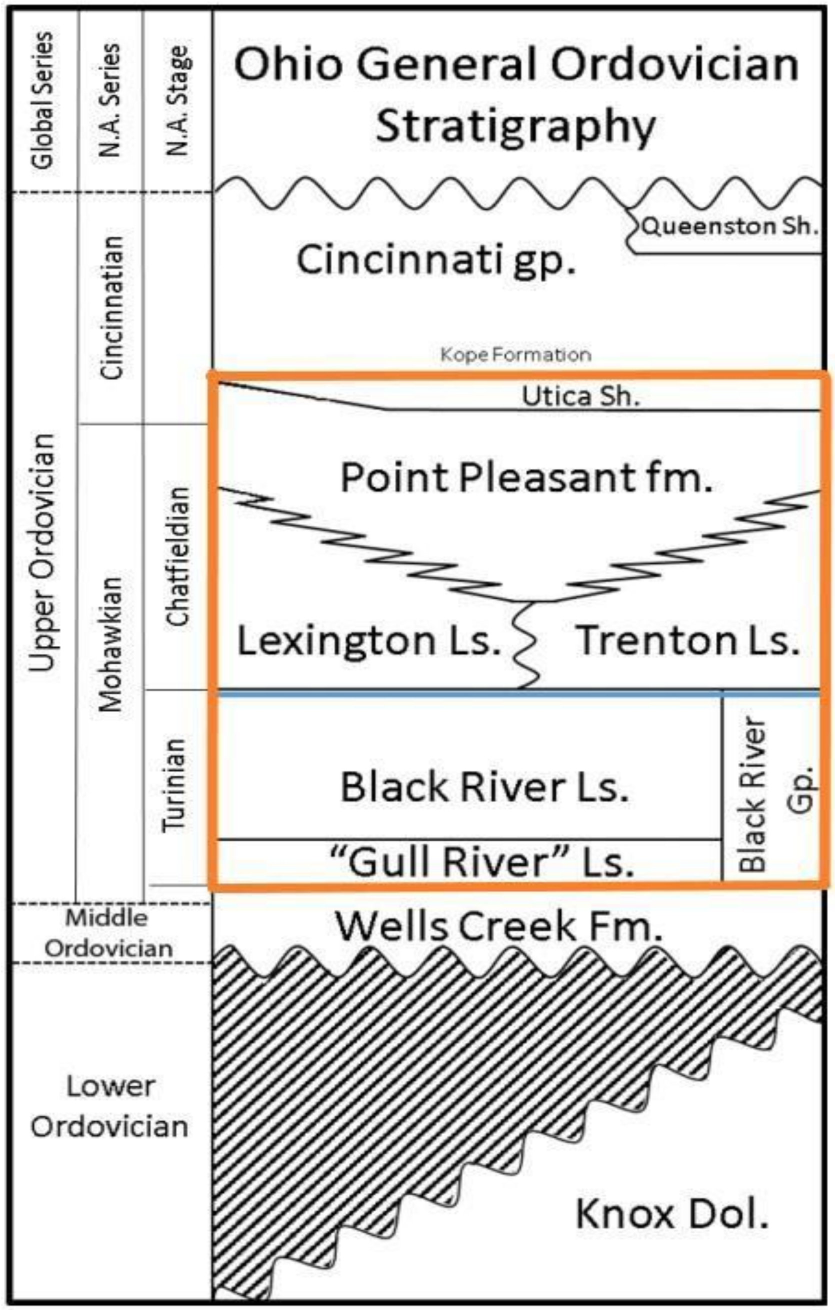

Figure 4: Generalized stratigraphic column of the study area and time of interest. Modified from Bloxson (2017). Orange box denotes target strata.

4. METHODS

A well log evaluation and mapping study was conducted to determine potential Precambrian basement controls on deposition of the Upper Ordovician strata. The study areas consisted of Lorain, Cuyahoga Lake, Geauga, Ashtabula, Trumbull, Mahoning, Stark, Portage, Summit, Wayne, Ashland, and Medina counties in Ohio. 5,860 wells were originally loaded into IHS Petra for analysis, however wells were eliminated based on lack of presence of a log and if a well was drilled deep enough to pass through the target formations, leaving 189 wells (Figure 5) for analysis. Formations boundaries of the Utica Shale, Point Pleasant Formation, Trenton Limestone, and the Black River Group were determined (Figure 6). Structure maps were contoured by hand at 100' contour intervals for the Utica Shale, Point Pleasant Formation, Trenton Limestone, and the Black River Group. Isopach thickness maps were contoured by hand at 10' contour intervals for the Utica Shale, Point Pleasant Formation, and the Trenton Limestone. A combined Utica/Point Pleasant isopach map was contoured by hand to depict the period of primarily shale deposition in the study area. Areas of thinning and thickening in the isopach maps, and areas of disruption in the structure maps were then compared against known structures in the area.

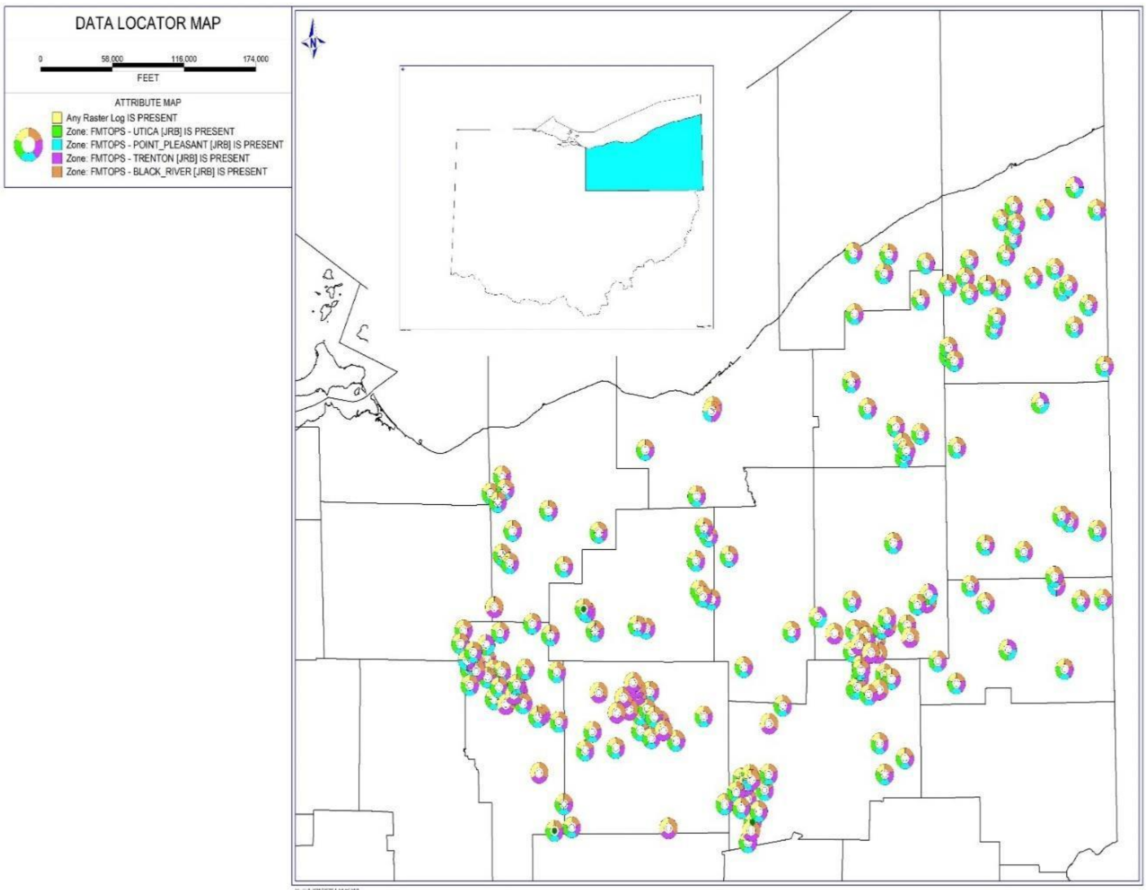

Figure 5: Data Map showing the wells used for analysis. The symbol highlight identifies the tops that were picked for each well. Green=Utica, blue=Point Pleasant, purple=Trenton, brown=Black River, yellow=a raster log was present and able to be used.

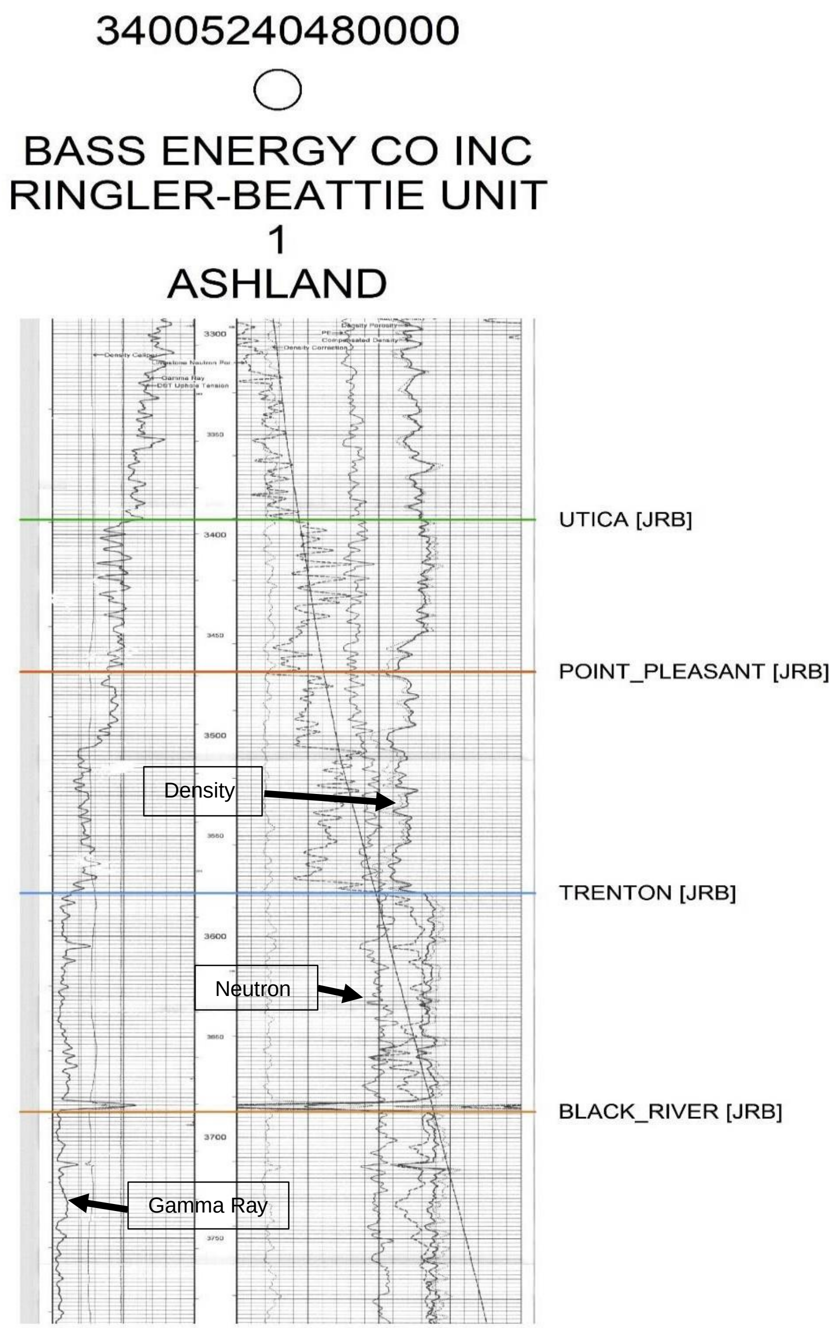

Figure 6: Type Log from Ashland County, southwestern portion of study area

5. RESULTS

The structure maps of the four strata mimic each other closely, dipping towards the southeast. The Black River Group structure map (Figure 7) follows the previously noted regional trend, with the highest point being -2400’ (-732m) subsea in the northwest and -6800’ (-2073m) subsea in the southeast. The Trenton Limestone structure map (Figure 8) is shallowest at -2300’ (-701m) subsea in the northwest and the deepest at -6600’ (-2012m) subsea in the southeast. The Point Pleasant Formation (Figure 9) is shallowest at -2300’ (-701m) subsea in the northwest and the deepest at -6500’ (-1981m) subsea in the southeast. The Utica Shale (Figure 10) is shallowest -2200’ (-671m) subsea in the northwest and deepens to -6400’ (-1951m) subsea in the southeast. These highest/lowest values pertain to the highest/lowest value contour line near the edge of the mapping area in the described directions.

Lineaments from Solis (2015) that were determined through the Devonian Dayton Formation, Onondaga Limestone, and Berea Sandstone appear to have small disruptions on the structure contours of the Ordovician target strata. The Middleburg Fault in Cuyahoga and Ashtabula Counties appears to have a slight disruption through the Trenton, Point Pleasant Formation and Utica Shale.

The main lineament trending through Median and Wayne Counties also influences the structure map, creating an apparent low-relief high. Finally, the Akron-Suffield fault system in Summit, Portage and Stark Counties also appears to have created offset in the area.

The generated isopach maps do not display the same general trend for each target strata, contrary to the structure in the region. The Trenton isopach map (Figure 11) shows an area of regional thinning near the center of the area of interest, with a thinnest mapped value of 70’ (21m) and a thickest mapped value of 160’ (49m) in the far northeastern corner of the state. The Point Pleasant isopach map (Figure 12) shows the thickest portion to be 170’ (52m) thick near the center of the area of interest, while the thinnest area is 40’ (12m) thick in the far northeastern corner of the state. The Utica isopach map (Figure 13) shows an area of regional thickening, with the thickest portion being 130’ (40m) thick near the center of the mapping area, and the thinnest portion being 60’ (18m) thick in the northwestern portion of the mapping area. The combined Utica/Point Pleasant isopach map (Figure 14) shows a broad regional thickening near the center of the mapping area, with the thickest portion being 260’ (79m) thick, and the thinnest portion being 110’ (34m) in the northeastern portion of the mapping area.

An area of thickening carbonate was noted in the Trenton Limestone isopach map (Figure 11), with the area of thickening appearing to be bounded on the northeastern and southwestern flank by the previously mentioned Devonian lineaments. In the same general area, there is an area of rapid Point Pleasant thickening in the northeastern corner that appears to trend along the Middleburg Fault. It was noted that the B-B' along strike cross section (Figure 16) through this area shows the thinning Trenton and thickening Point Pleasant, but also of note is that the base of the Point Pleasant appears to be more carbonate rich in this area of Point Pleasant thickening. In the same northeastern corner of the Utica Shale isopach map, an area of rapid thinning was noted over the area of rapid Point Pleasant thickening. In the overall described area bounded by Devonian lineaments, thinning of siliciclastics in the Utica Shale isopach map was noted, and this finding is corroborated with the B-B' along strike cross section showing overall Utica thinning through this region
(Figure 16).

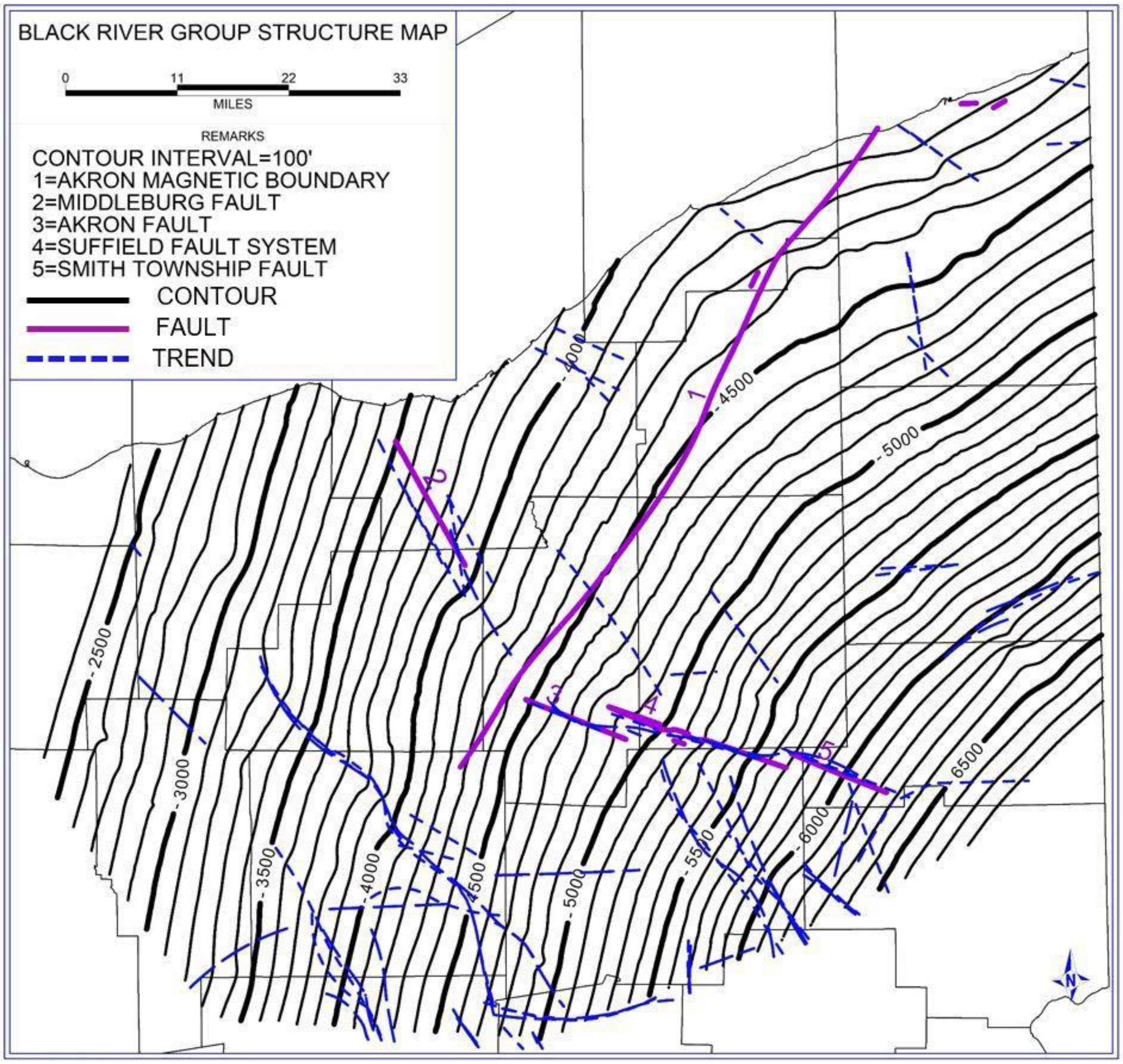

Figure 7: Black River Group structure map with faults and trends, 100' contour interval.

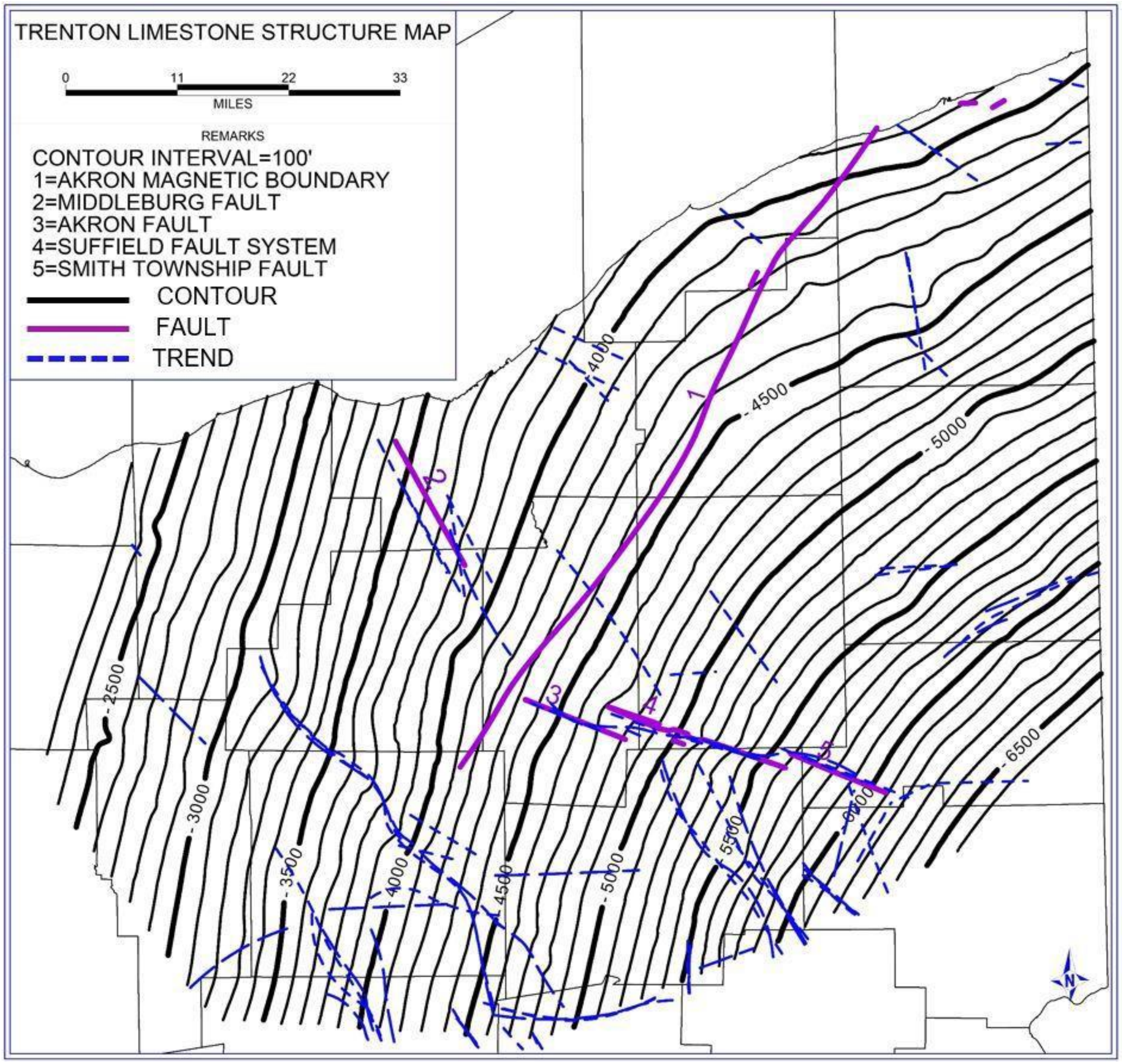

Figure 8: Trenton Limestone structure map with faults and trends, 100' contour interval.

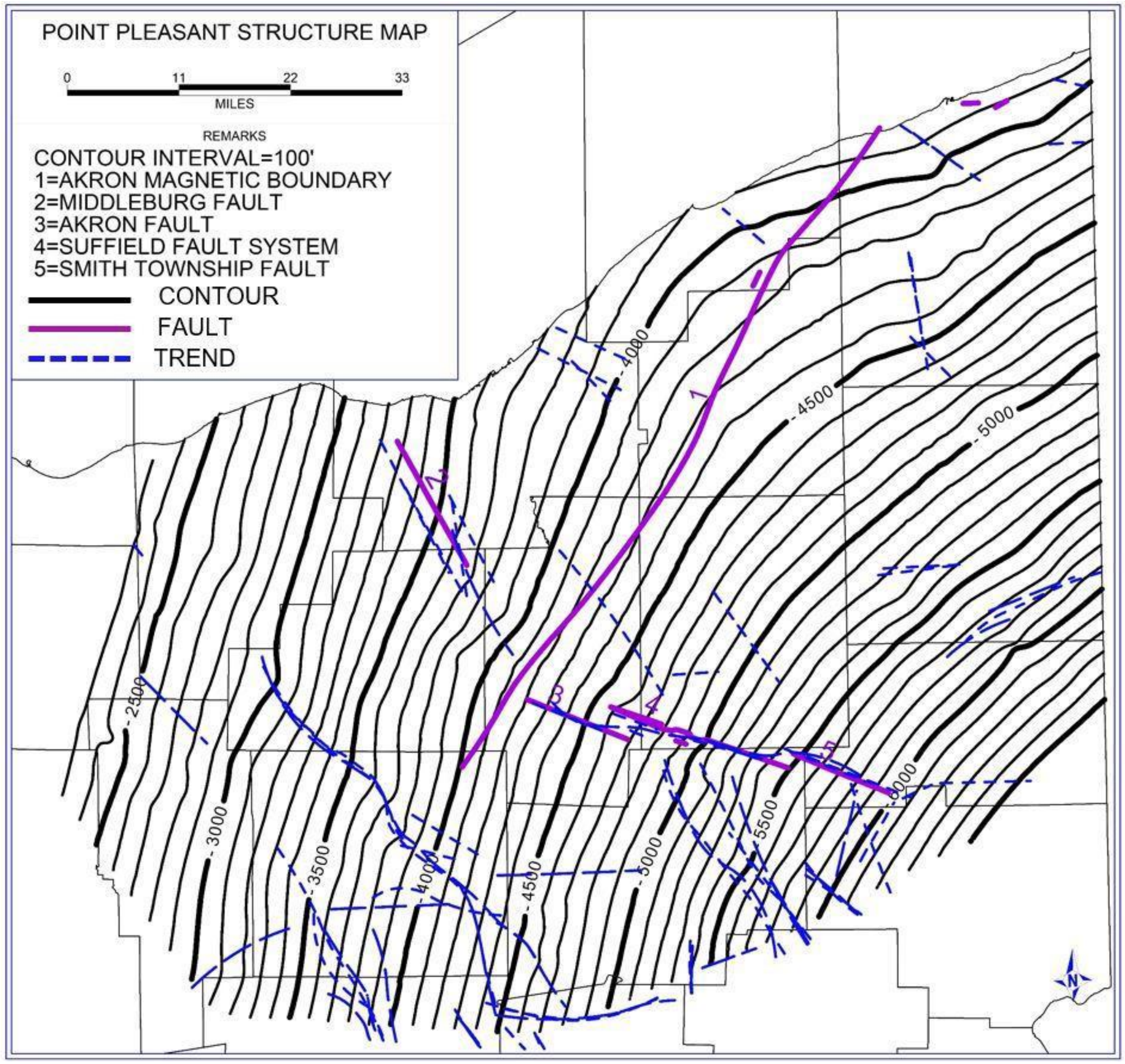

Figure 9: Point Pleasant Formation structure map with faults and trends, 100' contour interval.

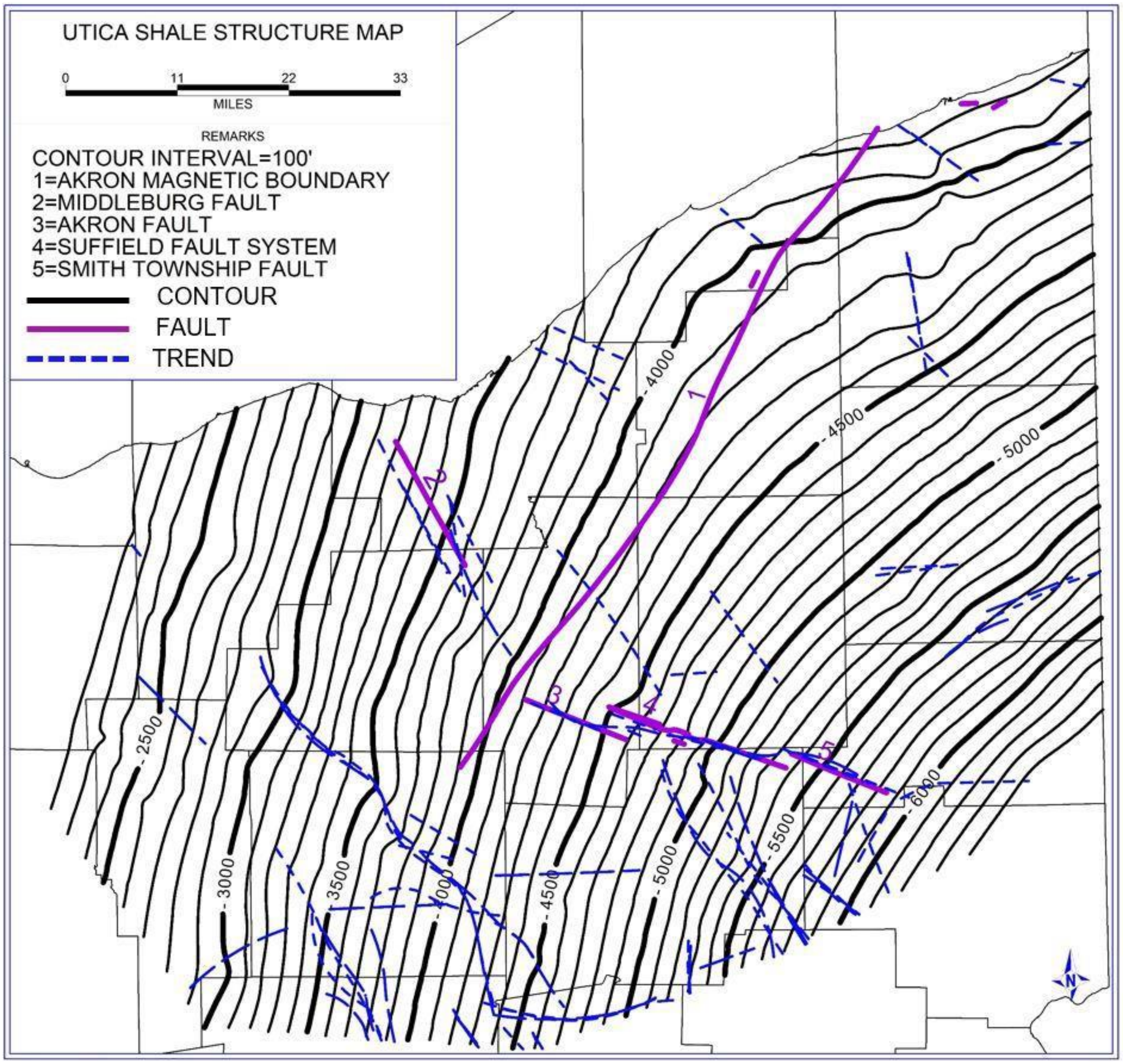

Figure 10: Utica Shale structure map with faults and trends, 100' contour interval.

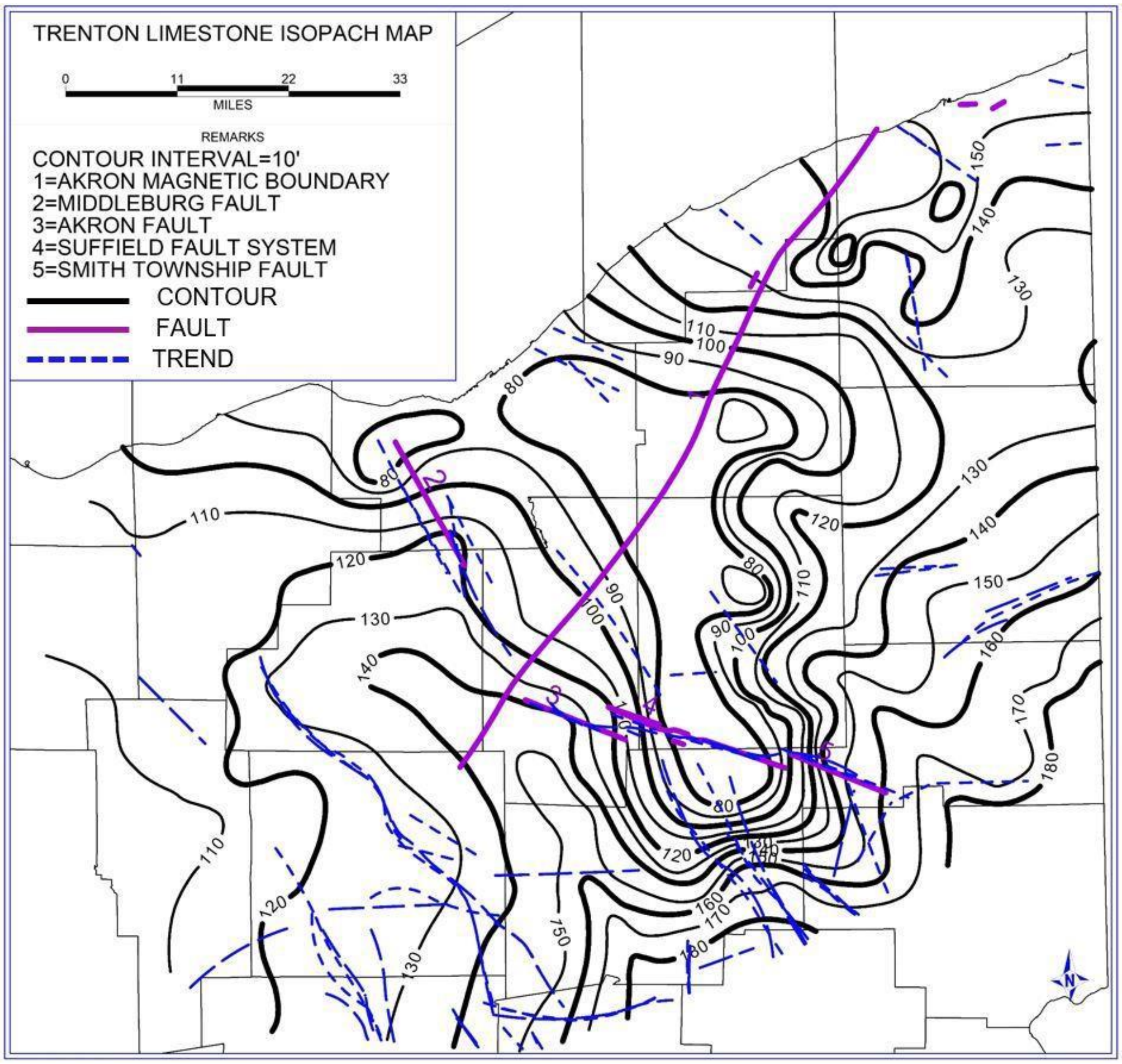

Figure 11: Trenton Limestone isopach map with faults and trends, 10' contour interval.

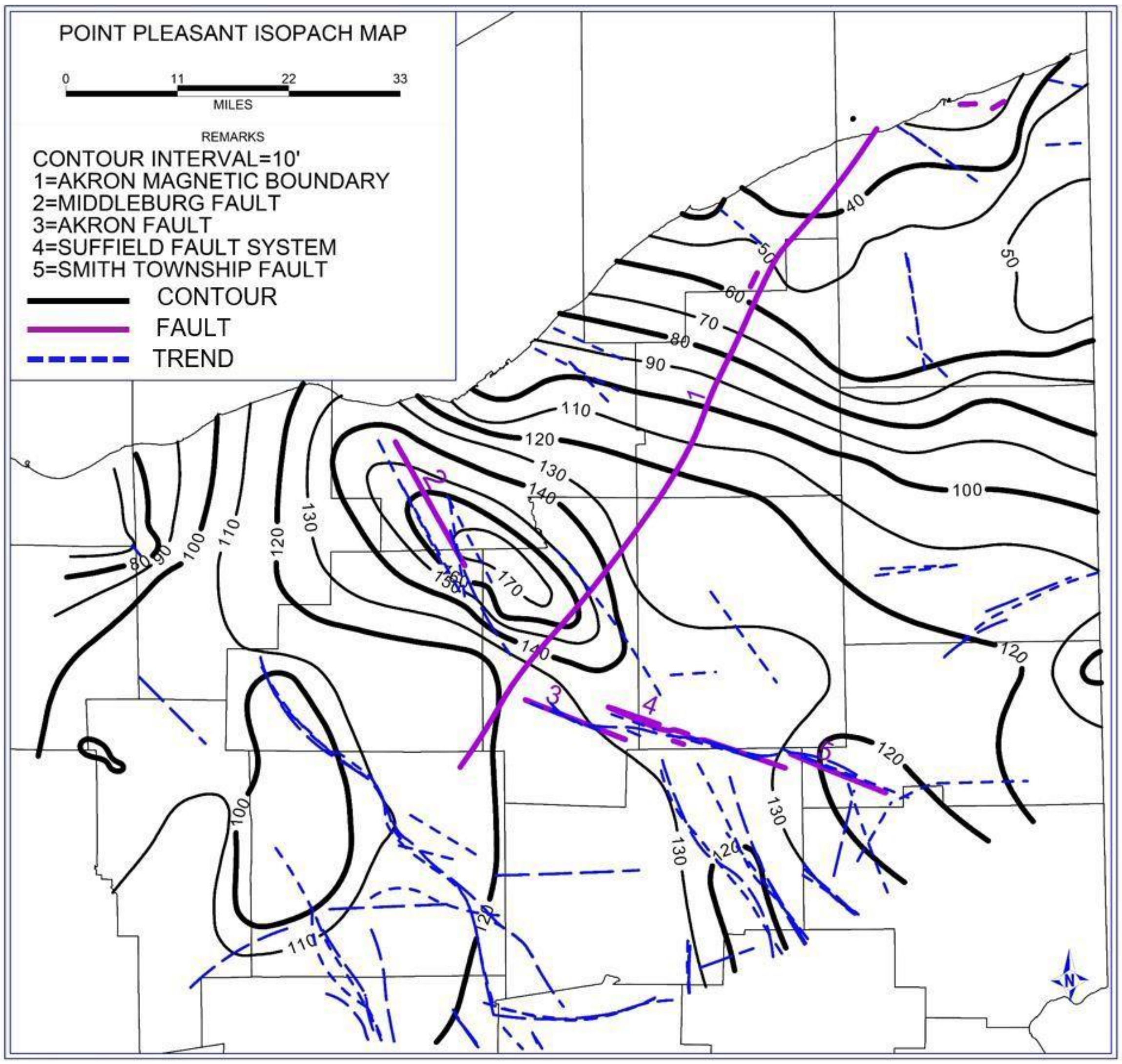

Figure 12: Point Pleasant Formation isopach map with faults and trends, 10' contour interval.

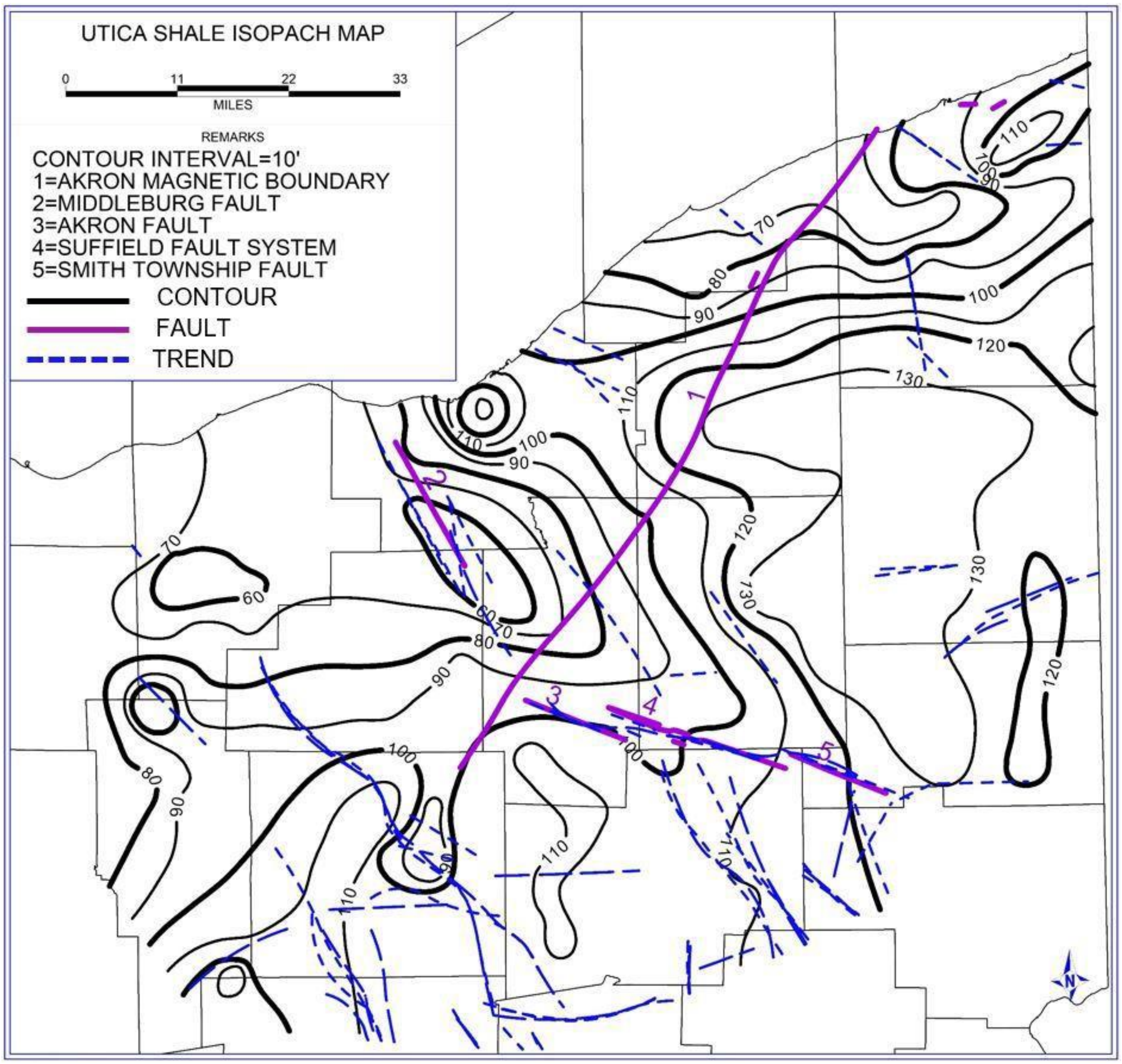

Figure 13: Utica Shale isopach map with faults and trends, 10' contour interval.

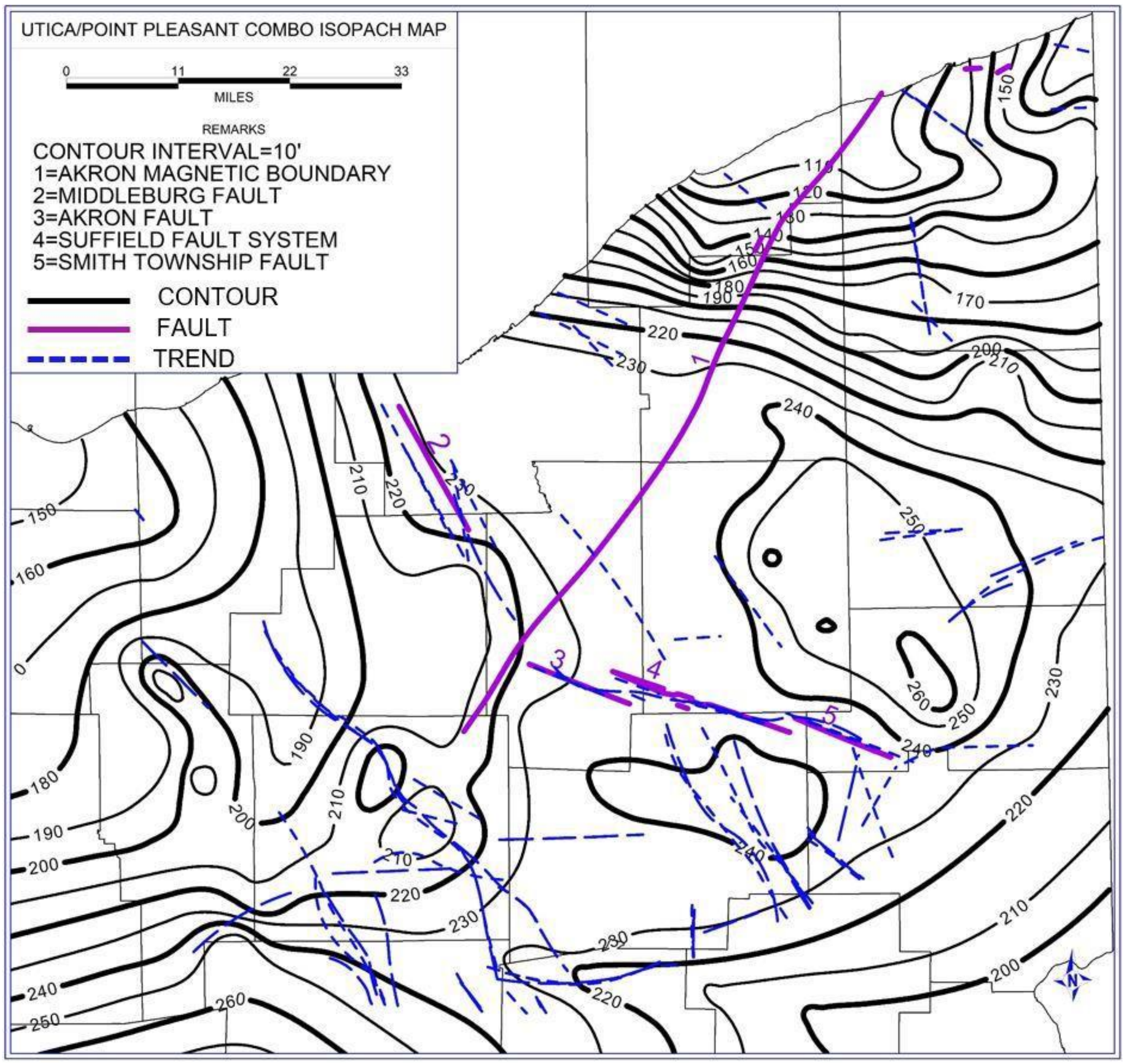

Figure 14: Utica/Point Pleasant Combined isopach map with faults and trends, 10' contour interval.

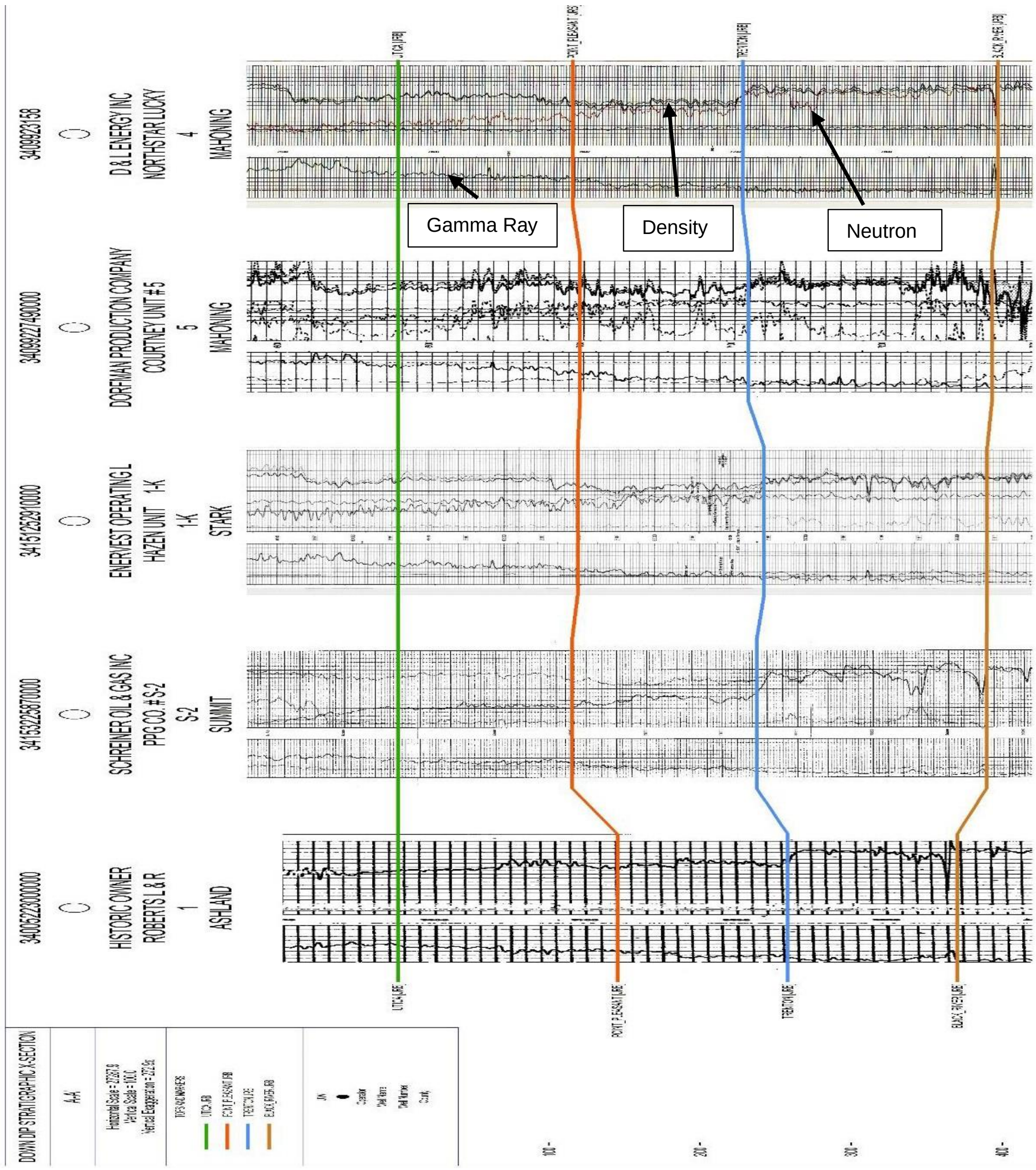

Figure 15: Stratigraphic Cross Section A-A' in the down dip direction running from east (left) to west (right). Green=Utica, Orange=Point Pleasant, Blue=Trenton, Brown=Black River. Hung on top of Utica.

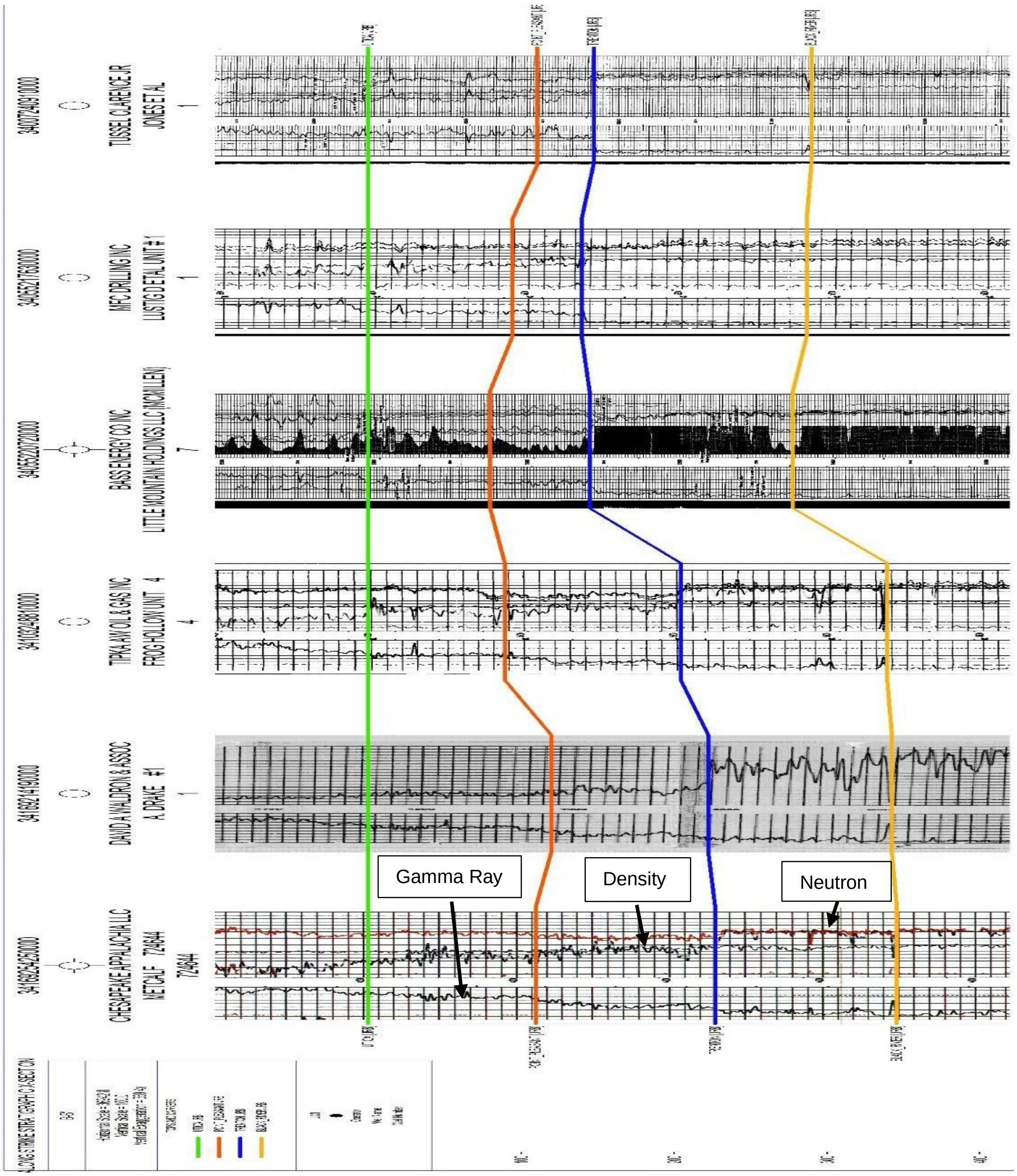

Figure 16: Stratigraphic Cross Section B-B' along strike, running from south (left) to north (right). Green=Utica, Orange=Point Pleasant, Blue=Trenton, Brown=Black River. Hung on top of Utica.

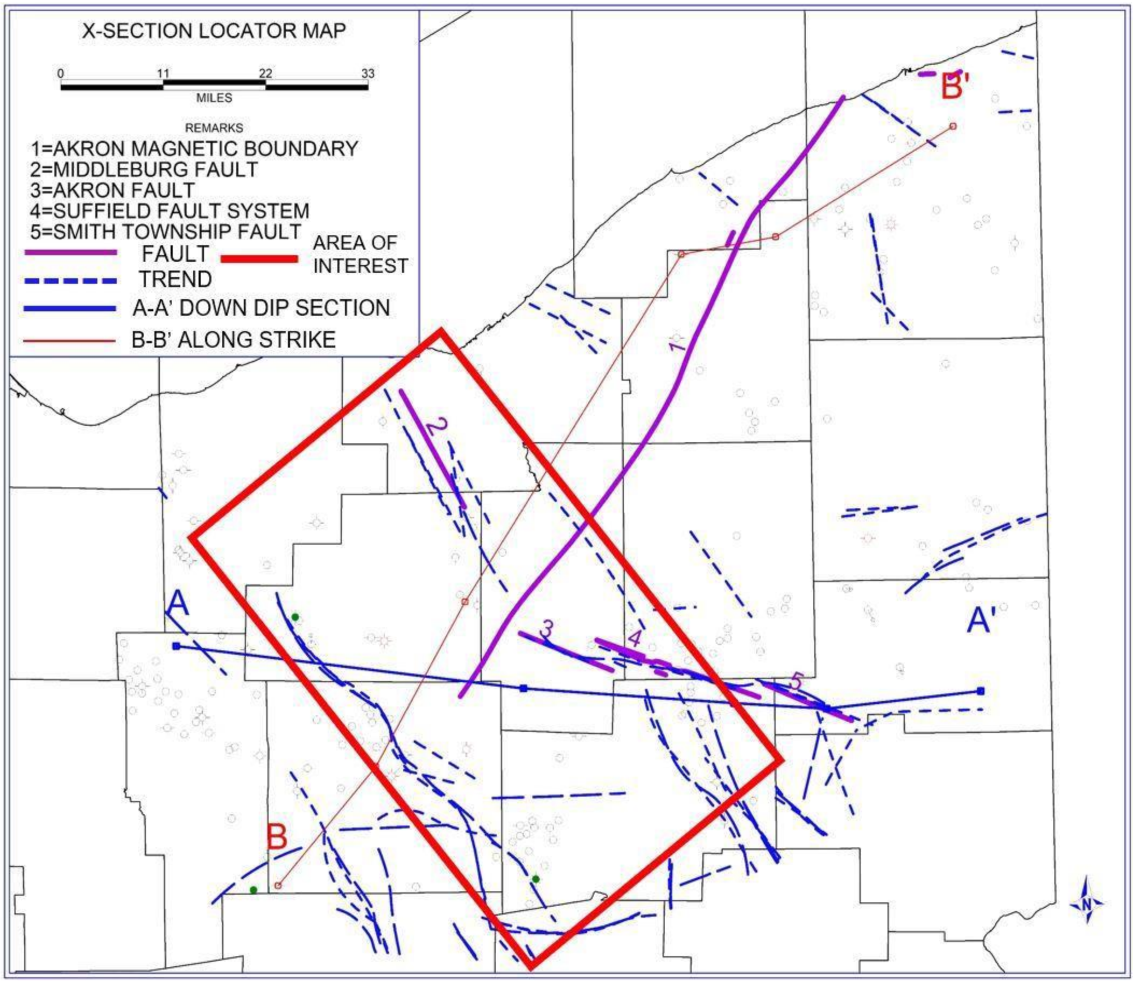

Figure 17: Cross Section Locator Map showing section A-A' in the downdip direction, Section B-B' along strike, faults and trends, and the area of uplift.

6. DISCUSSION

Correlations between the Precambrian basement and the target strata were able to be drawn through study of the generated structure and isopach thickness maps. Though the (assumed) Precambrian aged faults are thought to have largely ceased activity after the large-scale unconformity that formed around Knox time, hypotheses and evidence have emerged suggesting far-field tectonics originating from distanced basin features could have reactivated these faults, causing them to affect the deposition of the target strata (Bloxson, 2017, Solis, 2015, and Janssens, 1994). There are generally two orientations to the faulting that exists in Ohio, a northwest/southeast trending set and a mostly east/west trending set. The known Precambrian faults were determined largely by seismic, which shows that the vast majority originate in the basement and extend into the overlying strata. The lineaments mapped by Solis (2015) through second derivative mapping of slope changes extend into the overlying Devonian strata and are inferred to be Precambrian originated faults that were reactivated through far field tectonics. Several of these lineaments match locations of known Precambrian faults, with some now having suggested extended length. The vast majority of the lineaments do not coincide with known faults or fault systems, yet still match either of the two existing fabrics of faulting across the state. It is assumed that these lineaments, or disruptions of a surface, are most likely faults that extend from the Precambrian basement through the Devonian Berea sandstone at the most recent, suggesting that the target strata of this study should be affected by these lineaments as well. It is important to note that this study was based on 189 wells across a large study area due to data availability and structure was mapped at 100' contour intervals; the effects of lineaments on structure contours would likely be magnified with greater data density and a finer contour resolution. In such relatively thin formations, it is thought that isopach mapping would show influence of structure on strata (Janssens, 1994).

6.1. Lineaments and Structure

Several areas in northeast Ohio appear to have influence from Devonian lineaments (Solis, 2015) on modern-day structure (Figures 18 – 21). Several structural contours appear to bend and pull along strike of the lineaments, Middleburg Fault, and the Akron-Suffield fault system in the Black River Group, Trenton Limestone, Point Pleasant and Utica Shale structure maps. Baranoski (2002) suggests that the Precambrian faults, of which the Devonian lineaments are thought to be representing, began reactivation during early Cambrian time and extended activity through Ordovician and Devonian periods into the Permian period. Isopach maps generated in this study suggest that reactivation of the Precambrian faults occurred pre-deposition or syn-deposition to affect the thickening of target strata, while structure maps generated suggest that reactivation occurred post-deposition of the target strata, giving support to Baranoski's theory.

6.2. Isopach maps and localized uplift

In the four isopach maps, there is an area with apparent thickening and thinning in various strata bounded on three ends by Devonian lineaments (Figures 22-25). The Trenton limestone (Figure 22) appears to experience carbonate thickening in this area of interest. The Point Pleasant isopach shows a depocenter of thickening in the northeastern corner of this area of interest while the remainder of the formation in this area is somewhat static. Conversely, the Utica Shale isopach shows an area of rapid thinning overlying the area of rapid thickening noted in the Point Pleasant isopach, and the remainder of the Utica isopach in the area of interest shows broad gradual thinning. These changes can be better visualized in the B-B' cross section of Figure 16, showing thickening of the Trenton/lower Point Pleasant carbonate package and thinning of the Utica across the described depocenter. It was concluded that the Devonian lineaments bounding this area of interest represent faults, which originated from the Precambrian basement, capable of throwing this "block" area upward or downward, based on the differences in thinning and thickening across this area. The broad carbonate thickening of the Trenton in this area combined with the thinning of Trenton Limestone on either side of the block leads to the conclusion that this block was upthrown as an area of localized uplift. Carbonate formation requires shallower waters above the carbonate compensation depth (CCD) to allow carbonate production, coinciding with the idea that this block was uplifted into shallower waters compared to surrounding areas to allow for this carbonate thickening. The Trenton Limestone is a coarse grained carbonate packstone, suggesting shallower waters and an active depositional environment. Being an uplifted block, overlying siliciclastic deposition should be thin. Yet the Point Pleasant Formation, which is thought to be mostly siliciclastics rather than carbonate, shows a depocenter of rapid thickening (Figure 23). In cross section B-B’ (Figure 16) that goes through the uplifted area of interest, it can be seen that the base of the Point Pleasant Formation appears to have a lower API gamma ray response, indicating presence of carbonate material, compared to the upper portion of the formation which displays a higher API gamma ray response, indicating a higher presence of clay siliciclastic materials. In the 2013 Ohio Department of Natural Resources core study of the target strata from Portage County, Ohio, it was noted that the Point Pleasant Formation can include carbonate beds near the base of the formation, thinning up-section in the formation until it is fully siliciclastic, providing support to the above theory. It is believed that this depocenter of Point Pleasant thickening in the northeastern portion of the area of interest is present because the Point Pleasant Formation contains larger amounts of carbonate at its base in the area, which thickened due to the uplift that was present as Trenton deposition ceased and Point Pleasant deposition began. The Utica Shale isopach (Figure 24) corroborates this theory, with a general thinning across the area of interest and rapid thinning coinciding with the area of rapid Point Pleasant thickening. The thinning in the Utica Shale in this area is also easily viewed in cross section B-B’ (Figure 16). As Point Pleasant deposition ceased and Utica Shale deposition began, it is inferred that this localized uplift was still present, with thick carbonate deposition filling the block. This left area for only a thin layer of Utica Shale to be deposited across the block, with thicker Utica Shale depositing on either side of the uplifted block. The combined Utica Shale/Point Pleasant isopach map (Figure 25) appears to smooth out the inverse depocenters shown in the northeastern corner of the Utica Shale and Point Pleasant isopach maps, along with smoothing out the broad gradual thinning of the Utica and thickening of the Point Pleasant in the remainder of the uplifted area of interest. The remaining portions of the study area display typical behavior expected with general sea level changes stemming from the overall basin orogeny.

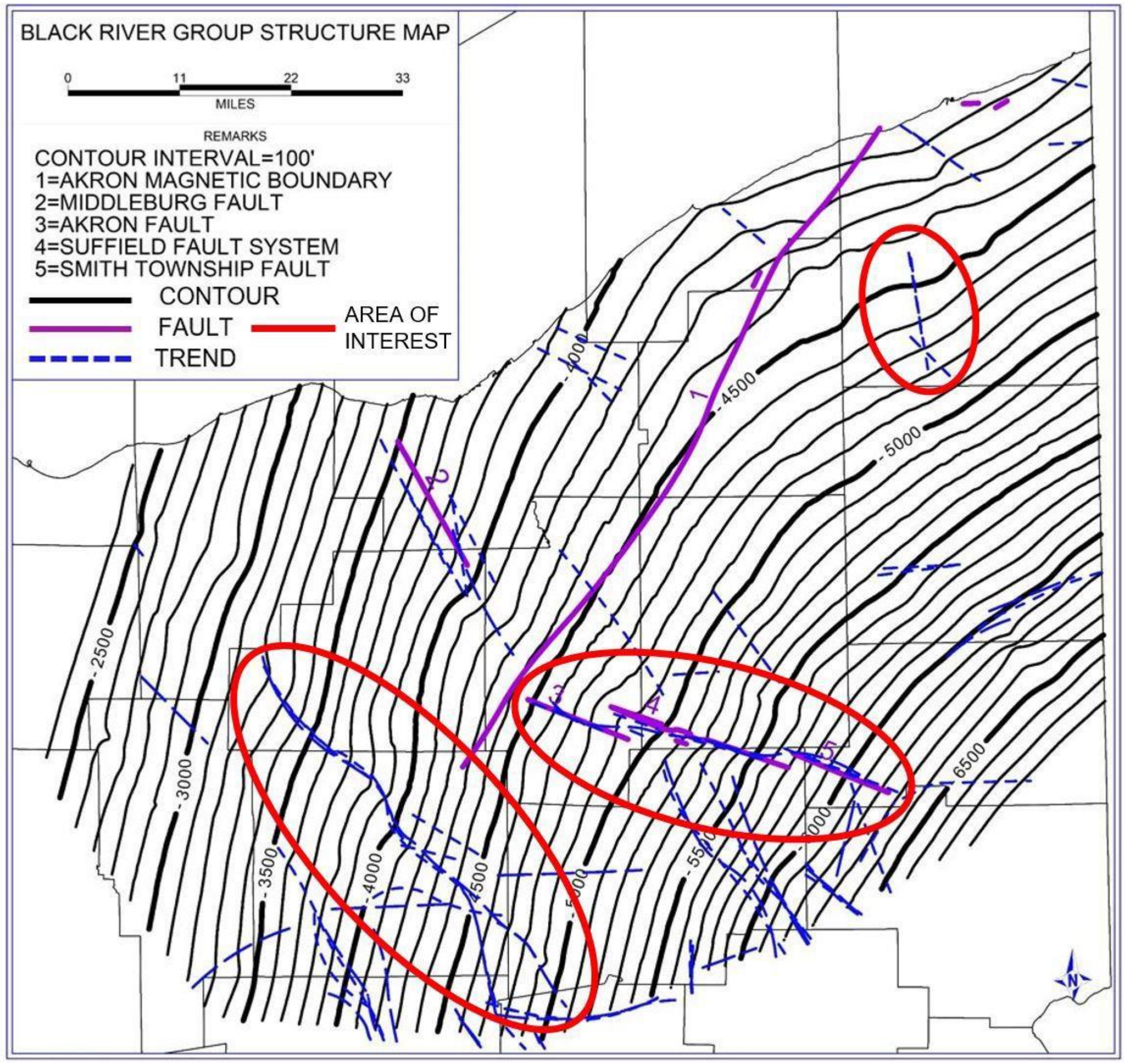

Figure 18: Black River Group Structure Map showing areas of interest where Devonian lineaments affect the structure contours.

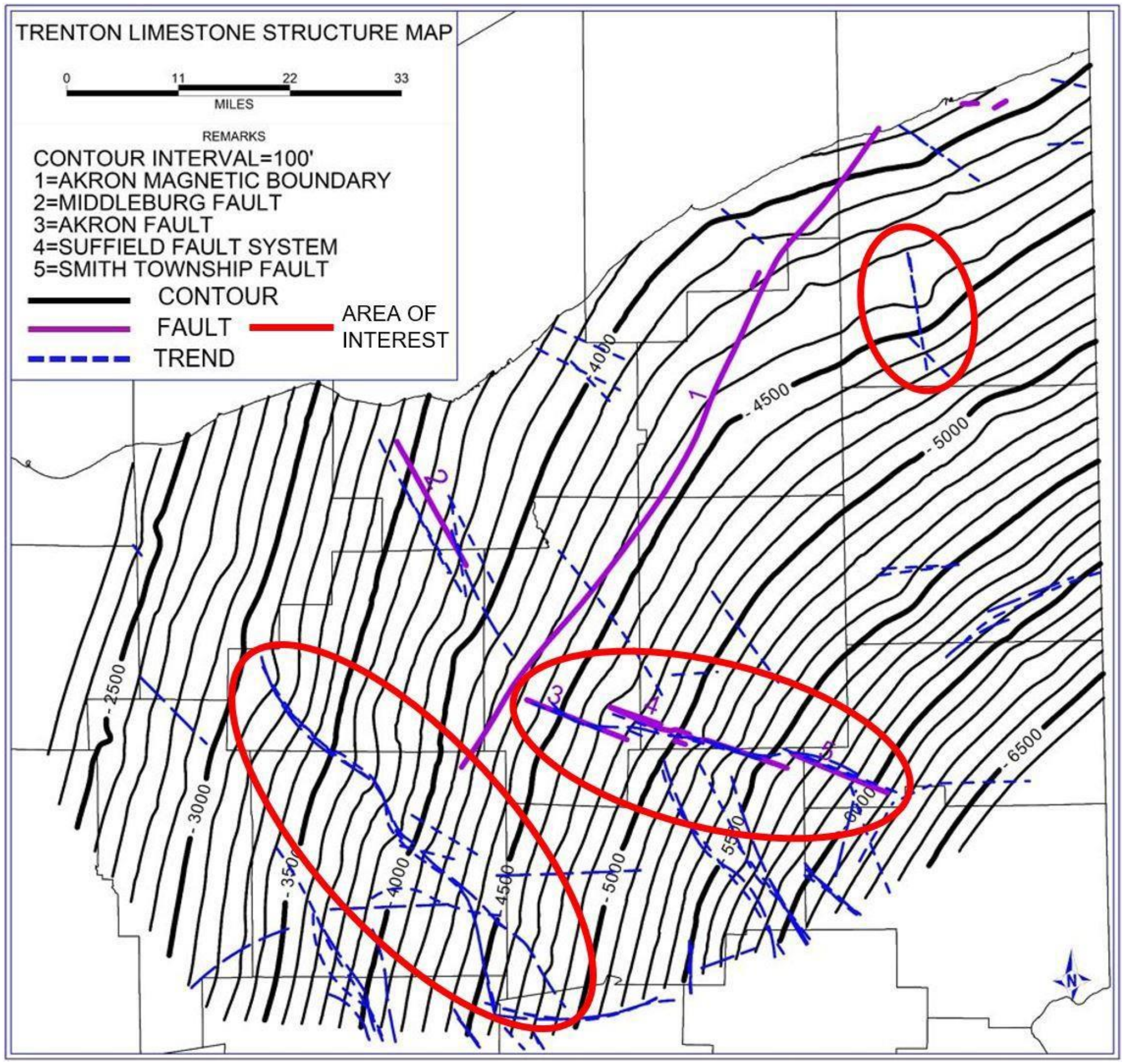

Figure 19: Trenton Limestone Structure Map showing areas of interest where Devonian lineaments affect the structure contours.

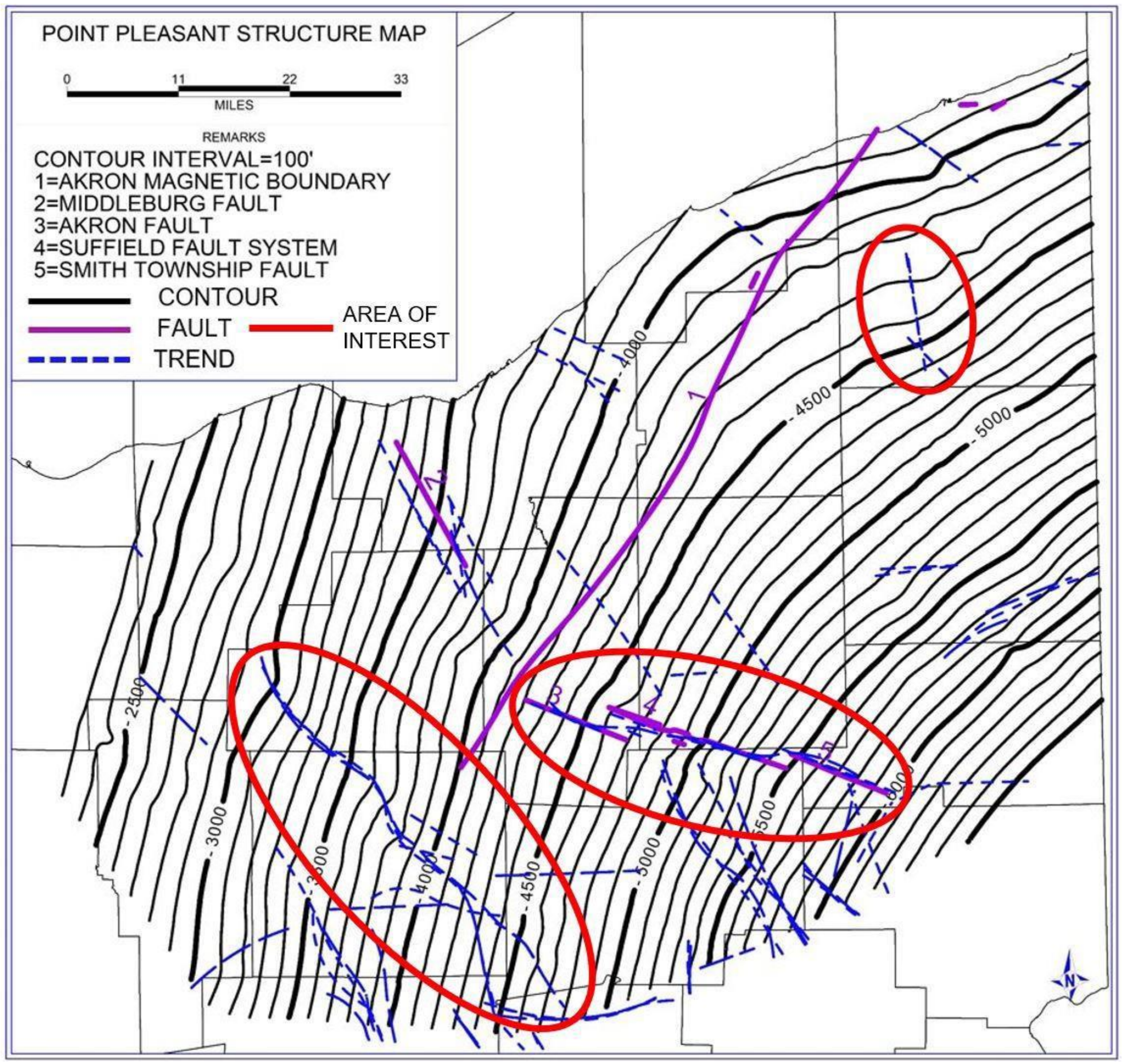

Figure 20: Point Pleasant Structure Map showing areas of interest where Devonian lineaments affect the structure contours.

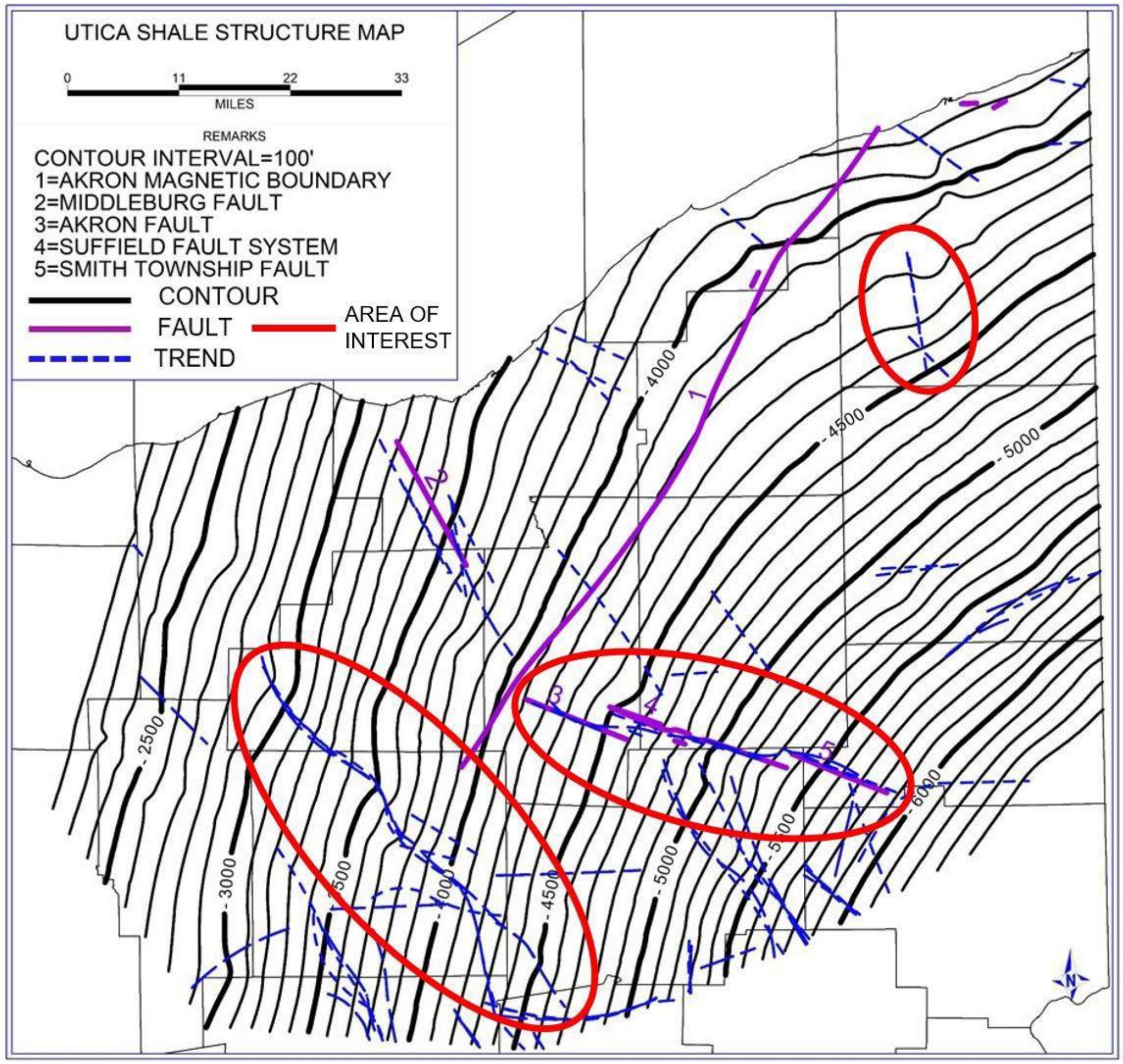

Figure 21: Utica Shale Structure Map showing areas of interest where Devonian lineaments affect the structure contours.

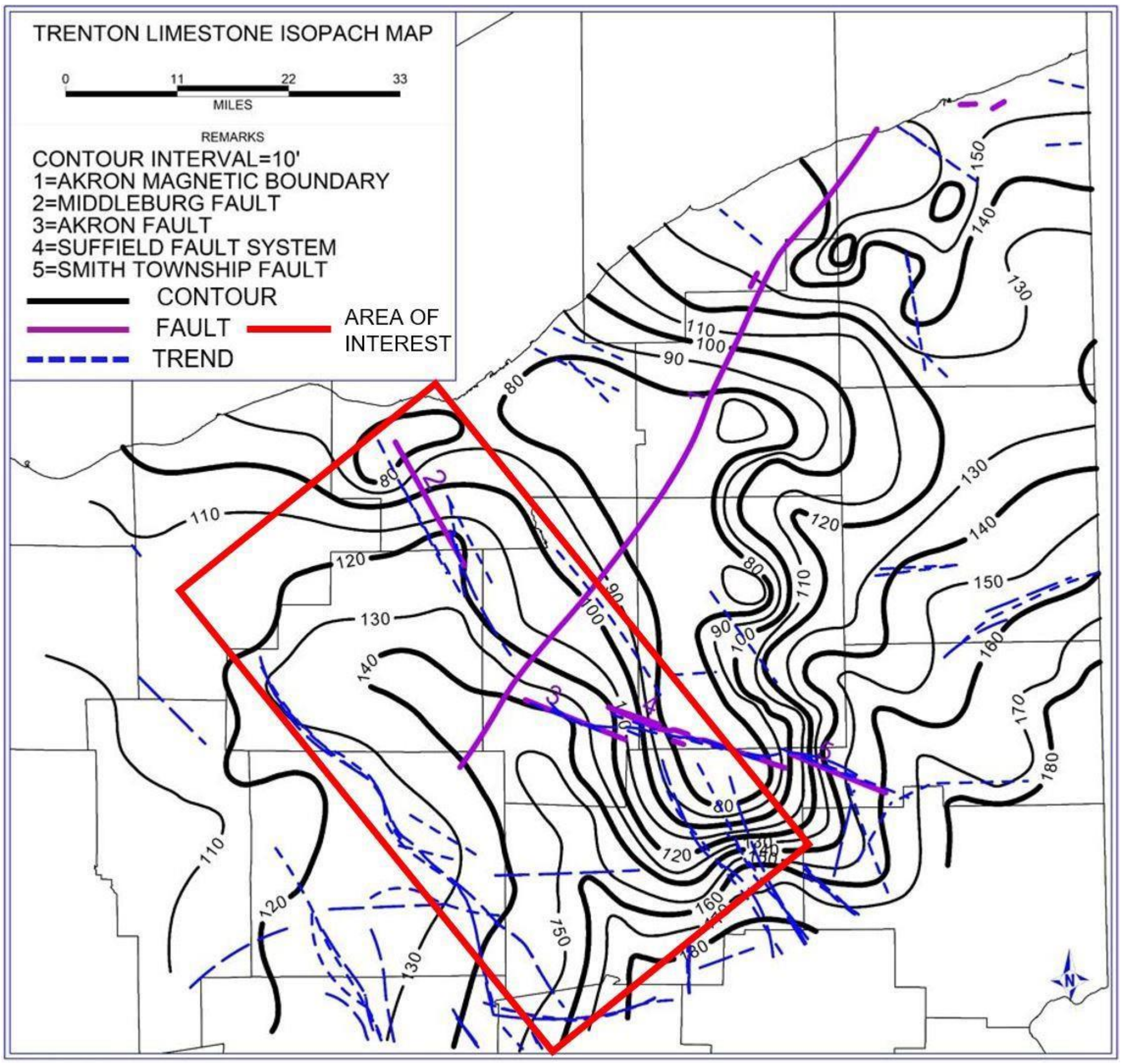

Figure 22: Trenton Limestone Isopach Map showing area of interest where Devonian lineaments bound a localized uplift.

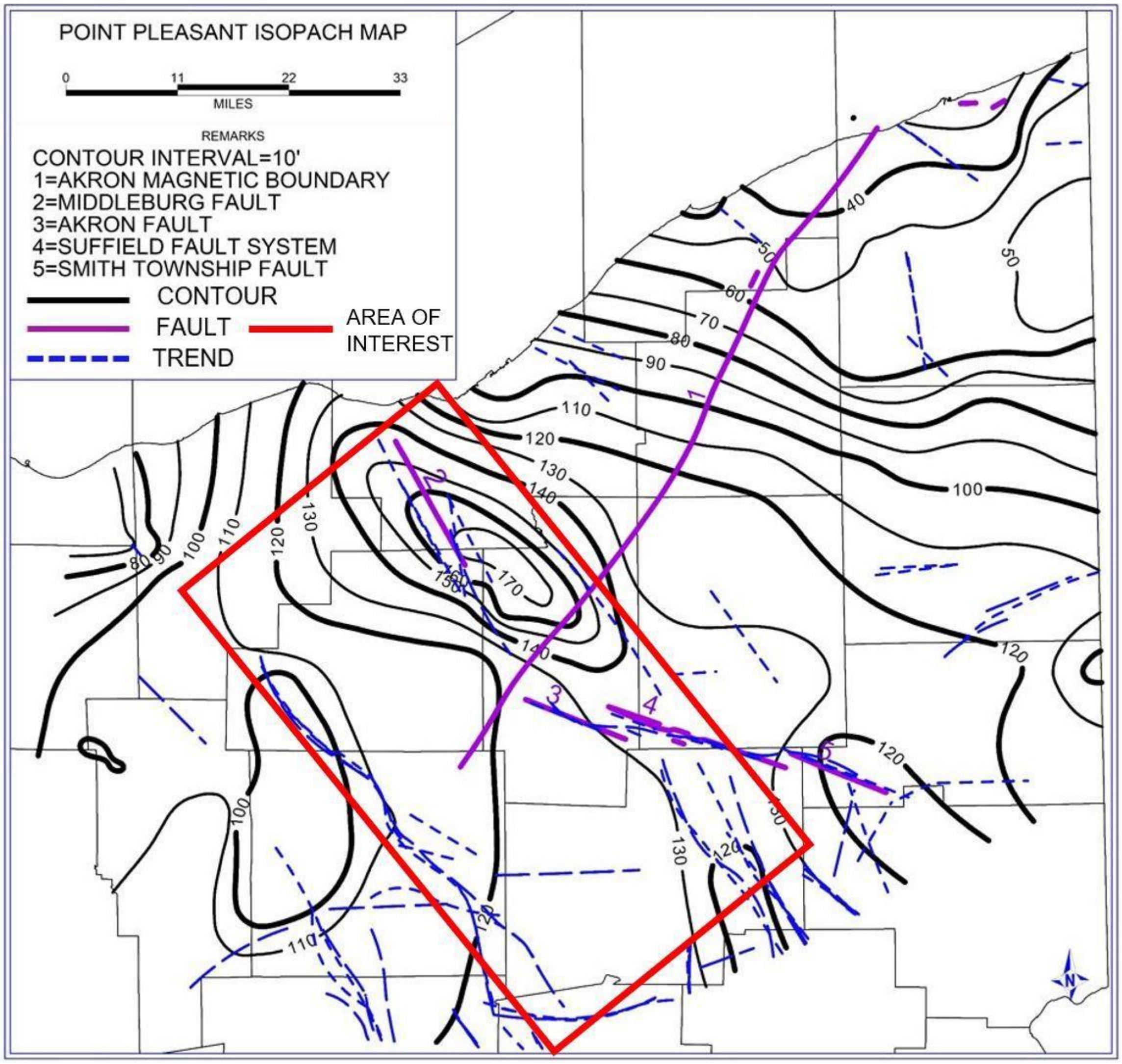

Figure 23: Point Pleasant Isopach Map showing area of interest where Devonian lineaments bound a localized uplift.

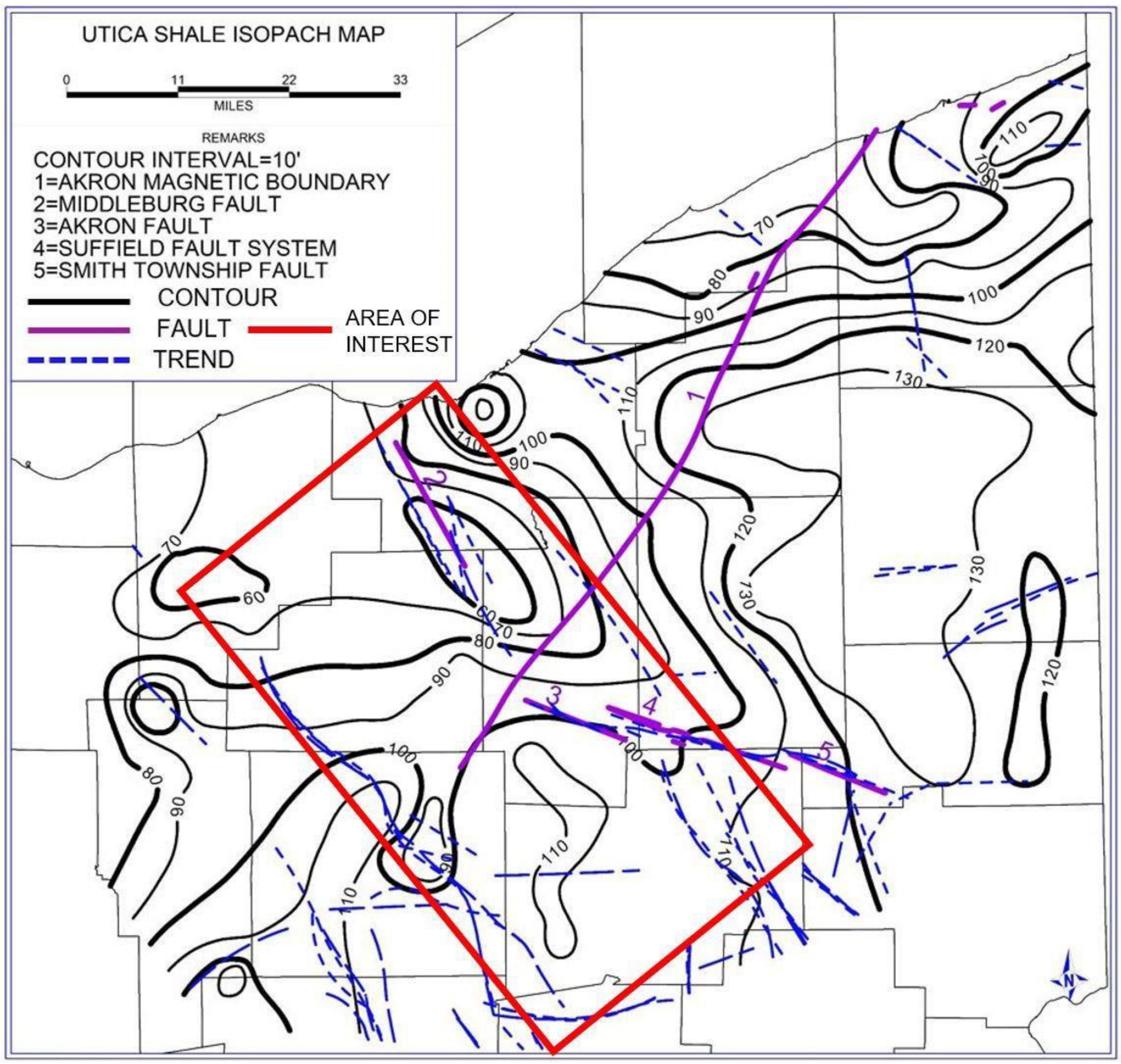

Figure 24: Utica Shale Isopach Map showing area of interest where lineaments produced during Devonian time bound a localized uplift.

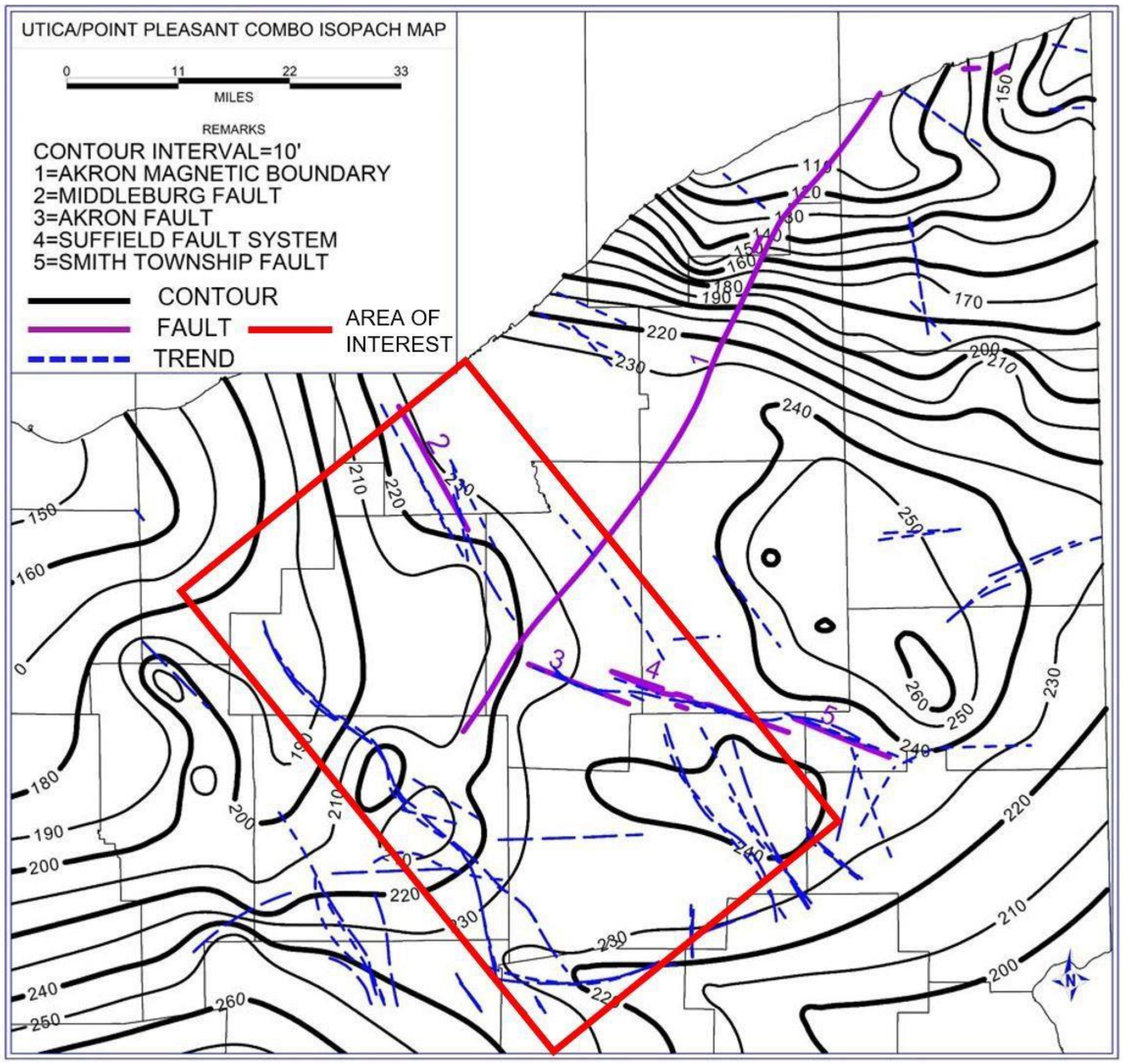

Figure 25: Utica Shale/Point Pleasant Combined Isopach Map showing area of interest where Devonian lineaments bound a localized uplift.

7. CONCLUSIONS

Overall, several Precambrian basement features appear to have an effect on the Ordovician Black River Group, Trenton Limestone, Point Pleasant Formation, and Utica Shale during and after deposition. The primary Precambrian features seen to affect deposition of the Ordovician target strata is the Akron-Suffield Fault system and the Middleburg Fault that were reactivated and originate from the Precambrian basement. Lineaments mapped by Solis (2015) have disrupted structure within the formations as well. These lineaments are inferred to be faults, however that cannot be fully concluded without the use of seismic data, which is not easily accessible in the study area.

A study of the four Ordovician structure maps (Figures 18-21) generated shows the Devonian lineaments having some effect on the contours, though a finer contour resolution would enhance the ability to interpret the affect of these subsurface features. The four isopach maps generated for the Ordovician strata (Figures 22-25) revealed a localized uplift, bounded on three edges by Devonian lineaments, which affected thickness of the target strata. The uplift created a shallow water environment, which led to thicker carbonate production compared to the regions outside of the uplift, specifically in the Trenton Limestone. The Point Pleasant Formation, which is known to have carbonate layers near the base of the formation, experienced a rapid thickening in the northeastern corner of the localized uplift, interpreted to be an area that contains carbonate at the base of the Point Pleasant Formation during favorable carbonate production conditions. Inversely, the overlying Utica Shale experienced a rapid thinning over the area of rapid Point Pleasant Formation thickening, and shows a broad overall thinning of siliciclastic production atop the localized uplift. The combined Point Pleasant/Utica Shale isopach map smooths out the rapid thickening/thinning sequence and the overall broad thickening/ thinning of the two formations along the localized uplift.

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9. APPENDICIES

Appendix 1: Well list table showing well API, latitude, longitude, top of Black River Group, top of Trenton Limestone, top of Point Pleasant Formation, and top of Utica Shale.

API	LATITUDE	LONGITUDE	BLACK_RIVER	TRENTON	POINT_PLEASANT	UTICA
			(SSTVD)	(SSTVD)	(SSTVD)	(SSTVD)
34155240630000	41.46168	-80.72238		-5071	-4967	-4830
34169254250000	40.68014	-82.106613	-3545	-3426	-3309	-3199
34133236840000	41.06888	-81.38334		-4753	-4624	-4522
34133238090000	41.03756	-81.33545	-4990	-4921		
34007243550000	41.55333	-80.99127	-4575	-4471	-4420	-4297
34133244230000	41.20527	-81.15947	-5082	-5024	-4903	-4767
34153229210000	41.042127	-81.460777	-4861	-4708	-4577	-4478
34035208210000	41.46451	-81.685718	-3825	-3742	-3651	-3521
34093208540000	41.187252	-82.305517	-2735	-2618	-2507	-2445
34103218190000	41.039459	-82.166987	-3138	-3019	-2915	-2826
34151210810000	40.953224	-81.262618	-5364	-5293	-5166	-5049
34169214190000	40.860436	-81.905334	-3957	-3837	-3734	-3614
34093208970000	41.305124	-82.341891	-2481	-2376	-2291	-2209
34133237770000	41.003389	-81.284036	-5134	-5063	-4938	-4834
34093208370000	41.191322	-82.308634	-2681	-2563	-2457	-2394
34093208590000	41.231575	-82.024391	-3305	-3185	-3056	-2986
34093209080000	41.337498	-82.307475	-2566	-2459	-2377	-2297
34093209840000	41.235652	-82.276788	-2731	-2615	-2510	-2453
34103212010000	41.177211	-81.739043	-4081	-3862	-3744	-3670
34099231720100	40.993551	-80.824195		-6159	-6031	-5895
34005239820000	41.049584	-82.421214	-2559	-2453	-2343	-2268
34007244870000	41.685725	-80.989556	-4429	-4262	-4218	-4126
34005239570000	40.936386	-82.260641	-2993	-2871	-2770	-2680
34005240110000	40.970409	-82.148615	-3288	-3162	-3058	-2968
34085210940000	41.710034	-81.177526	-4246	-4112	-4061	-3989
34099231270000	41.120132	-80.683004	-6350	-6150	-6030	

API	LATITUDE	LONGITUDE	BLACK_RIVER	TRENTON	POINT_PLEASANT	UTICA
			(SSTVD)	(SSTVD)	(SSTVD)	(SSTVD)
3400523970000	41.061458	-82.220043	-3017	-2901	-2797	-2715
34099231570000	41.089891	-80.612405	-6465	-6297	-6187	-6066
34103248570000	41.083195	-82.060768	-3277	-3145	-3049	-2956
34155240430000	41.136155	-80.688827	-6125	-6020	-5851	-5725
34007242660000	41.603282	-80.854693	-4578	-4426	-4387	-4268
34007242740000	41.863438	-80.609169		-4092	-4035	-3922
34055221360000	41.40878	-81.076464	-4810	-4728	-4623	-4487
34055217630000	41.659356	-81.069851	-4433	-4286	-4241	-4146
34155236740000	41.381297	-80.969191	-4993	-4903	-4797	-4664
34007243380000	41.675107	-80.829825	-4415	-4350	-4234	-4140
34055220720000	41.63484	-81.265552	-4288	-4155	-4090	-4010
34085210500000	41.727289	-81.053342	-4220	-4088	-4041	-3961
34099227490000	40.940461	-80.980226	-6086	-5924	-5813	-5692
34103249010000	41.104426	-81.694652	-4225	-4090	-3977	-3886
34007245250000	41.527244	-80.530431	-5212	-5094	-5022	-4920
34007245420000	41.602245	-80.617002	-4889	-4754	-4718	-4602
34151257740000	40.801884	-81.13347	-6055	-5887	-5755	-5645
34055203390000	41.507815	-81.27764	-4438	-4355	-4258	-4131
34085202800000	41.745878	-81.162288	-4147	-4015	-3970	-3902
34085206610000	41.749224	-81.26689	-4109	-3974	-3935	-3869
34155236700000	41.184746	-80.777184	-5879	-5720	-5611	-5481
34005217620000	40.723555	-82.129113	-3459	-3326	-3225	-3115
34093209480000	41.092632	-82.330907	-2735	-2620		
34103212850000	41.222423	-81.701806	-4024	-3909	-3766	-3708
34103248560000	41.051341	-81.886572	-3851	-3724	-3602	-3517
34151250160000	40.729934	-81.593579	-4827	-4683	-4557	-4449
34151250680000	40.7726	-81.193051	-5927	-5757	-5627	-5519
34169217650000	40.72118	-81.660613	-4685	-4544	-4415	-4307
34035216730000	41.456534	-81.690151	-3829	-3747	-3609	
34055215340000	41.365029	-81.125627	-4870	-4750	-4632	-4510
34005229250000	40.920593	-82.332348	-2892	-2775	-2674	-2594
34007201910000	41.699164	-80.937046	-4416	-4286	-4229	-4158
34007239090000	41.683744	-80.873356	-4471	-4333	-4268	-4187
34007241800000	41.805408	-80.82612	-4166	-4038	-3985	-3875
34007241810000	41.83067	-80.790939	-4188	-4035	-3998	-3914

API	LATITUDE	LONGITUDE	BLACK_RIVER	TRENTON	POINT_PLEASANT	UTICA
			(SSTVD)	(SSTVD)	(SSTVD)	(SSTVD)
34007242700000	41.642837	-80.574503	-4829	-4703	-4659	-4535
34007243660000	41.668986	-80.9255	-4459	-4325	-4266	-4182
34035216130000	41.385689	-81.886364	-3456	-3380	-3229	-3159
34055214560000	41.422662	-81.148125	-4679	-4619	-4510	-4378
34055215320000	41.392118	-81.129981	-4804	-4689	-4577	
34055215380000	41.378254	-81.118244	-4853	-4737	-4621	-4497
34099202120000	40.982803	-81.033936	-5868	-5712	-5595	-5476
34103248540000	41.120988	-81.730385	-4172	-4042	-3926	-3834
34103248810000	41.110048	-81.719915	-4178	-4043	-3928	-3839
34151245060000	40.764541	-81.550215	-4936	-4788	-4665	-4553
34151250860000	40.83089	-81.207188	-5733	-5567	-5440	-5325
34151250910000	40.768694	-81.610839	-4771	-4628	-4500	-4396
34151251020000	40.903775	-81.488778	-4931	-4780	-4651	-4537
34151252840000	40.960485	-81.191073	-5523	-5451	-5318	-5212
34151253840000	40.752937	-81.611151	-4780	-4639	-4512	-4403
34153225870000	40.977321	-81.601666	-4625	-4472	-4350	-4235
34155236390000	41.198337	-80.889167	-5585	-5434	-5322	-5196
34169212300000	40.932712	-81.87626	-3873	-3748	-3637	-3524
34169252370000	40.823554	-82.066827	-3594	-3478	-3375	-3272
34005223870000	40.87748	-82.143268	-3341	-3223	-3123	-3028
34005225740000	40.912763	-82.2471	-3063	-2957	-2842	-2747
34093208920000	41.313015	-82.298629	-2633	-2527	-2436	-2363
34103212930000	41.056371	-81.913185	-3768	-3644	-3527	-3439
34103213250000	41.238328	-81.715319	-3971	-3850	-3684	-3629
34169213140000	40.890146	-81.903975	-3921	-3796	-3689	-3572
34169213340000	40.885622	-81.719776	-4387	-4254	-4131	-4028
34169213980000	40.877822	-81.846591	-4023	-3895	-3780	-3678
34169214340000	40.858665	-82.044912	-3597	-3476	-3380	-3276
34169214660000	40.845739	-81.873136	-4059	-3933	-3814	-3719
34093207950000	41.174861	-82.286076	-2801	-2684	-2571	-2506
34151251170000	40.687908	-81.581567	-4892	-4749	-4619	-4512
34103246840000	41.088442	-82.069259	-3248	-3115	-3019	-2928
34005237740000	40.984336	-82.383802	-2646	-2538	-2432	-2352
34005241800000	40.673634	-82.15679	-3392	-3280	-3162	-3027
34093207190000	41.272896	-82.171584	-2860	-2761	-2650	-2560

API	LATITUDE	LONGITUDE	BLACK_RIVER	TRENTON	POINT_PLEASANT	UTICA
			(SSTVD)	(SSTVD)	(SSTVD)	(SSTVD)
34103250370100	41.0605	-82.037449	-3387	-3256	-3159	-3074
34007245230000	41.820088	-80.544338	-4449	-4300	-4245	-4153
34093207940000	41.28935	-82.32074	-2568	-2419	-2365	-2290
34099231580000	40.962797	-80.66342	-6748	-6579	-6466	-6350
34151245190000	40.746467	-81.543868	-4966	-4815	-4687	-4581
34151246660000	40.649334	-81.593795	-4913	-4764	-4641	-4536
34151246980000	40.670911	-81.584217	-4933	-4787		
34151248170000	40.931687	-81.205506	-5517	-5443		
34151250070000	40.77558	-81.586256	-4850	-4703	-4582	-4471
34151250110000	40.755801	-81.598243	-4815	-4669		
34151250130000	40.765664	-81.58197	-4874	-4726	-4605	
34151250150000	40.743779	-81.626847	-4734	-4588	-4466	-4361
34151250260000	40.933235	-81.276767	-5328	-5251	-5079	-4991
34151251140000	40.706965	-81.56204	-4955	-4808	-4682	-4569
34151255460000	40.713491	-81.612833	-4815	-4668	-4542	-4434
34151256300000	40.936094	-81.269956	-5341	-5265	-5090	-5000
34151256600000	40.776001	-81.532104	-4990	-4838	-4722	-4620
34151257000000	40.922177	-81.23731	-5433	-5360	-5230	-5113
34151257620000	40.977482	-81.258416	-5334	-5261	-5132	-5031
34151258560000	40.968192	-81.258678	-5343	-5271	-5142	-5025
34153228990000	41.184734	-81.642068	-4176	-4076	-3912	-3856
34155240780000	41.238327	-80.641315	-5896	-5746	-5630	-5511
34155240790000	41.249266	-80.664774	-5825	-5678	-5560	-5440
34155240910000	41.220356	-80.560187	-6158	-6001	-5889	-5767
34169213070000	40.900513	-81.885633	-3941	-3818	-3708	-3594
34169213270000	40.885481	-81.86537	-3982	-3856	-3752	-3638
34169229910000	40.840251	-81.801238	-4218	-4109	-3967	-3883
34169248880000	40.927723	-81.912329	-3846	-3722		
34169249250000	40.67718	-81.825129	-4329	-4199		
34169249790000	40.860474	-81.83709	-4082	-3951		
34169250300000	40.899573	-81.936908	-3824	-3704		
34169250570000	40.921957	-81.953817	-3751	-3629		
34169251930000	40.939612	-81.915844	-3761	-3635		
34169252300000	40.932159	-82.02594	-3583	-3468		
34169254400000	40.950128	-81.925624	-3763	-3638		

API	LATITUDE	LONGITUDE	BLACK_RIVER	TRENTON	POINT_PLEASANT	UTICA
			(SSTVD)	(SSTVD)	(SSTVD)	(SSTVD)
34169254530000	40.893928	-81.973582	-3734	-3617		
34169255950000	40.827627	-81.977108	-3764	-3643	-3547	-3433
34005217840000	41.021944	-82.355605		-2638	-2534	-2450
34005222750000	40.96124	-82.351356	-2782	-2677	-2561	-2483
34005222890000	40.942788	-82.317921	-2875	-2763	-2651	-2576
34005222900000	40.975762	-82.40499	-2676	-2567	-2456	-2369
34005223000000	41.045111	-82.314315	-2822	-2710	-2597	-2452
34005223090000	41.024637	-82.430859	-2566	-2460	-2360	-2277
34005223480000	40.911049	-82.297989	-2915	-2811		
34005223510000	40.973338	-82.384039	-2654	-2543	-2449	
34005228650000	40.994179	-82.411078	-2621	-2513	-2422	
34005239990000	40.929468	-82.273623	-2953	-2847		
34005240230000	40.782329	-82.201107	-3259	-3143		
34005240480000	41.00853	-82.39321	-2605	-2496	-2386	-2310
34005240610000	40.947789	-82.266392	-2976	-2869	-2758	-2674
34005241600000	40.946706	-82.403366	-2664	-2559	-2448	-2372
34005241720000	40.891054	-82.194254	-3225	-3118	-2997	-2910
34005241760000	40.88685	-82.205167	-3195	-3090	-2972	-2879
34005241860000	40.975962	-82.240539	-3042	-2933	-2827	-2733
34007240090000	41.671626	-80.650228	-4674	-4546	-4495	-4396
34007240710000	41.680627	-80.632511	-4673	-4549	-4504	-4405
34007240900000	41.712181	-80.671793	-4533	-4408	-4358	-4282
34007241450000	41.770654	-80.794452	-4379	-4216	-4173	-4125
34007241460000	41.739694	-80.816186	-4425	-4264	-4215	-4147
34007241920000	41.79836	-80.784987	-4269	-4110	-4050	-3967
34007242530000	41.622246	-80.846358	-4522	-4379	-4327	-4224
34007243110000	41.695852	-80.735327	-4486	-4355	-4301	-4219
34007243390000	41.569458	-80.989762	-4526	-4424	-4365	-4243
34007243830000	41.543692	-80.972559	-4628	-4523	-4474	-4344
34035221990000	41.298202	-81.735828	-3892	-3773	-3603	-3547
34055212810000	41.457743	-81.230866	-4539	-4479	-4379	-4244
34093215040000	41.168103	-82.126695	-3144	-3031	-2908	-2841
34099231350000	41.12128	-80.927058	-5739	-5609	-5478	-5347
34099231710000	41.091167	-80.547705	-6609	-6430	-6331	-6202
34099231820100	41.07437	-80.882379	-5939	-5802	-5675	-5541

API	LATITUDE	LONGITUDE	BLACK_RIVER	TRENTON	POINT_PLEASANT	UTICA
			(SSTVD)	(SSTVD)	(SSTVD)	(SSTVD)
34133236120000	41.026596	-81.21133	-5310	-5238		
34133238610000	41.042039	-81.255208	-5172	-5099	-4974	
34133238790000	41.042955	-81.276673	-5118	-5048	-4922	-4828
34133238910000	41.030629	-81.240905	-5233	-5164	-5030	-4931
34133239620000	41.097649	-81.283062	-5037	-4967	-4840	-4748
34133239760000	41.016727	-81.262626	-5209	-5137		
34133239960000	40.999942	-81.208951	-5349	-5276		
34133240170000	41.000782	-81.228954	-5304	-5231		
34133240420000	41.050959	-81.122374	-5565	-5417	-5284	-5174
34133240790000	41.049723	-81.180963	-5365	-5291		
34133240870000	41.028485	-81.113961	-5544	-5468		
34133241020000	41.045927	-81.197174	-5324	-5251	-5114	-5014
34133241040000	41.064583	-81.180782	-5390	-5247	-5108	-5006
34133241940000	41.093464	-81.062521	-5608	-5456		
34133244070000	41.107989	-81.05843		-5431	-5301	-5170

10. VITA

Jarrod R. Bridges graduated from Longview High School in Longview, Texas in May 2013 and enrolled at the University of Texas at Austin. He originally majored in biochemistry and followed that major path for two years before deciding to pursue geology. He transferred to Texas Tech University in August of 2016 to finish pursuing geology, and graduated Summa Cum Laude with a Bachelor of Science in Geosciences in August of 2018. After finishing his undergraduate, he enrolled in the geology graduate program at Stephen F. Austin State University in August of 2018 to pursue a Master of Science degree. He interned with R. Lacy Services in Longview, Texas as a geology intern during summer and Christmas breaks from May 2015 through September 2018. He then began to intern with both R. Lacy Services and Buffco Production, both in Longview, Texas, while pursuing his Master of Science degree. In July of 2019, he was offered a full time geologist position at Buffco Production and accepted that role, and has been in that position since while finishing his graduate degree. He will continue his career as a petroleum geologist after the completion of his graduate degree.

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This thesis was typed by Jarrod R. Bridges in accordance with the GSA manual.