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A Log and Core Analysis of the Marmaton Group, Granite Wash Fan Delta in the Anadarko Basin, Washita County, Oklahoma

Cole A. Hatchel
Stephen F Austin State University, hatchelca@jacks.sfasu.edu

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By

Cole Anthony Hatchel, Bachelor of Science

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Cole Anthony Hatchel, Bachelor of Science

APPROVED:

Dr. Julie Bloxson, Thesis Director

Dr. Russel Nielson, Committee Member

Dr. Kevin Stafford, Committee Member

Dr. Robert Friedfeld, Committee Member

Dr. Pauline M. Sampson

Dean of Research and Graduate Studies

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ABSTRACT

The Pennsylvanian Marmaton Group located in the southern Anadarko Basin is a fan delta system that consists of stacked arkosic sandstones, conglomerates, and shale, and within Washita County, Oklahoma, are known to be a prolific hydrocarbon producer. The Marmaton Group in Washita County, though, has a variable and largely unestablished stratigraphic framework and sudden changes in lithology throughout the region, both horizontally and laterally. This combined with a lack of core or outcrop data has created confusion in the subsurface, and the Marmaton Group has remained largely unstudied in southern Washita County, OK.

This study examined two sets of core, correlated over 90 wells logs, and examined thin sections to determine the characteristics of the Marmaton Group in Washita County, Oklahoma. Tops were determined for each of the Marmaton Group intervals (A-F), along with the Skinner Shale. These data were used to create thickness and structure maps of the formations. The two sets of core show a series of interbedded conglomerates, and coarse- through fine-grained sands, topped with shales, indicating rising and falling sea level affecting the delta fan, and creating the unique and striking sediment packages typically observed in fan delta systems. These sediments consist of high amounts of arkosic material

sourced just south of the study area from the Amarillo-Wichita Uplift, as confirmed by the thin sections. These arkosic materials give an atypical well log reading due to the potassium and lithic fragment content of the conglomerates and sandstones, creating a higher-than-normal gamma ray reading. This in turned complicates the boundaries between shale, sandstones, and conglomerate zones in the gamma ray well logs. Density porosity logs, Neutron Porosity logs, and Caliper logs were relied upon to accurately determine the interval boundaries.

Overall, the Marmaton Group is highly variably across Washita County because of the high degree of faulting and mixed lithology of the Granite Wash. The net thickness maps of the Marmaton Group show that the Granite Wash is highly variably throughout Washita County. This is due to the Mountain View Fault System running through the county to the south, and the smaller associated faults that were created from the Amarillo-Wichita Uplift throughout the entire county. The structure maps show that the Marmaton Group rapidly drops down into the deep basin axis, which trends southeast to northwest. As the Marmaton Group continues to the north, it comes out of the deep basin axis, shallowing, although at a much less rate than deepening into the basin. The flooding zone shales in Washita County play a role in deposition of the Granite Wash intervals. The flooding zone shales are thicker in the northern portion of the county, and thin towards the south and the Mountain View Fault. The Granite Wash sediments were being deposited from the southern Amarillo-Wichita Uplift. During times of transgressive sea levels, it appears the flooding surface shales were being deposited over a Granite Wash interval from the north causing variable thickness of the Marmaton Group throughout the county.

INTRODUCTION

The Pennsylvanian Marmaton Group is a part of the Granite Wash clastic wedge in the southern Anadarko Basin, adjacent to the north flank of the Amarillo-Wichita Uplift (Figure 1). It is an unconventional play due to the tight nature of the reservoir, with a production record of 3.7 trillion cubic feet of gas and 126 million barrels of oil cumulative production from over 4,000 wells (Mitchel, 2012). The reservoirs in the Marmaton Group are primarily the tight arkosic sandstones and conglomerates found within the fan delta systems in Washita County, Oklahoma (Mitchell, 2014) (Figure 2).

The Marmaton Group extends from Iowa to Texas, and across Kansas, Missouri, Oklahoma, and Colorado. Although extensive, it is known primarily from the subsurface using a combination of cores and well logs throughout the region, and has a highly variable lateral lithology. The best-known section of the Marmaton Group is the hydrocarbon-rich Granite Wash intervals in the Anadarko Basin (Mitchell, 2011), yet the Marmaton Group consists of not only deltaic siliciclastics, but also shallow marine carbonates towards the north, areas of deep marine shale deposits, and localized starved basins (Rascoe and Alder, 1983). Most previous research has focused on the Marmaton Group within the Anadarko Basin because of the prolific hydrocarbon accumulations (Mitchell, 2011), but there is potential for other areas of the Marmaton Group across the Mid-Continent to contain economic production (Rascoe and Alder, 1983).

Exploration companies in the Anadarko Basin target the Granite Wash section of the Marmaton Group (Mitchell, 2011). Granite Wash in the Anadarko Basin is a drillers' term that refers to the clastic wedge on the north flank of the Amarillo-Wichita Uplift that covers western Oklahoma and the Texas Panhandle. Granite Wash, in technical geologic terms; it is material eroded from granites and re-deposited locally, forming a sedimentary rock with the same major mineral constituents as the original rock (Mitchell, 2014). In the Marmaton Group, the primary parent material is the granite present in the Wichita-Amarillo Uplift to the south. It was deposited in the Anadarko Basin by alluvial fan deltas during the Pennsylvanian, consisting of conglomerates, sandstones, and shales, creating the stacked tight sand intervals that are present throughout the area (Mitchell, 2014). The Marmaton Group is divided into six intervals (A-F) based upon these sequences of siliciclastics, each bound by thick shales that were deposited during transgressive sequences (Mitchell, 2011). The Marmaton Group Granite Wash is arkosic in nature throughout Washita County, with high amounts of feldspar and lithic fragments. This highly-variable lithology in the region creates uncertainty and difficulty when mapping the group in the subsurface.

Using a combination of core and well logging, this project studied the Pennsylvanian Marmaton Group within the Anadarko Basin in Washita County, OK to determine thickness variations and controls on deposition. The Marmaton Group is understudied here because of a lack of stratigraphic framework and data in parts of Washita County, Oklahoma. Two cores from wells Mobil-Edler #2 and Clements-Littke #1 archived at the Oklahoma Geological Survey- OPIC were examined to determine the depositional environment and lithology of the facies present, and thin sections were taken from the cores to determine mineralogy. Core data were correlated with well logs. Well logs were used to determine formation boundaries, and to construct maps and cross sections of the Marmaton Group. It is concluded that the Marmaton Group has atypical electrofacies responses due to the highly variable lithology throughout Washita County. Deposition of the Marmaton Group in Washita County was controlled by a combination of the deltaic fan depositing sediment from the south to the north, faulting creating localized areas of topographic highs and lows, and periodic sea level changes that deposited the flooding zone shales observed in the well logs.

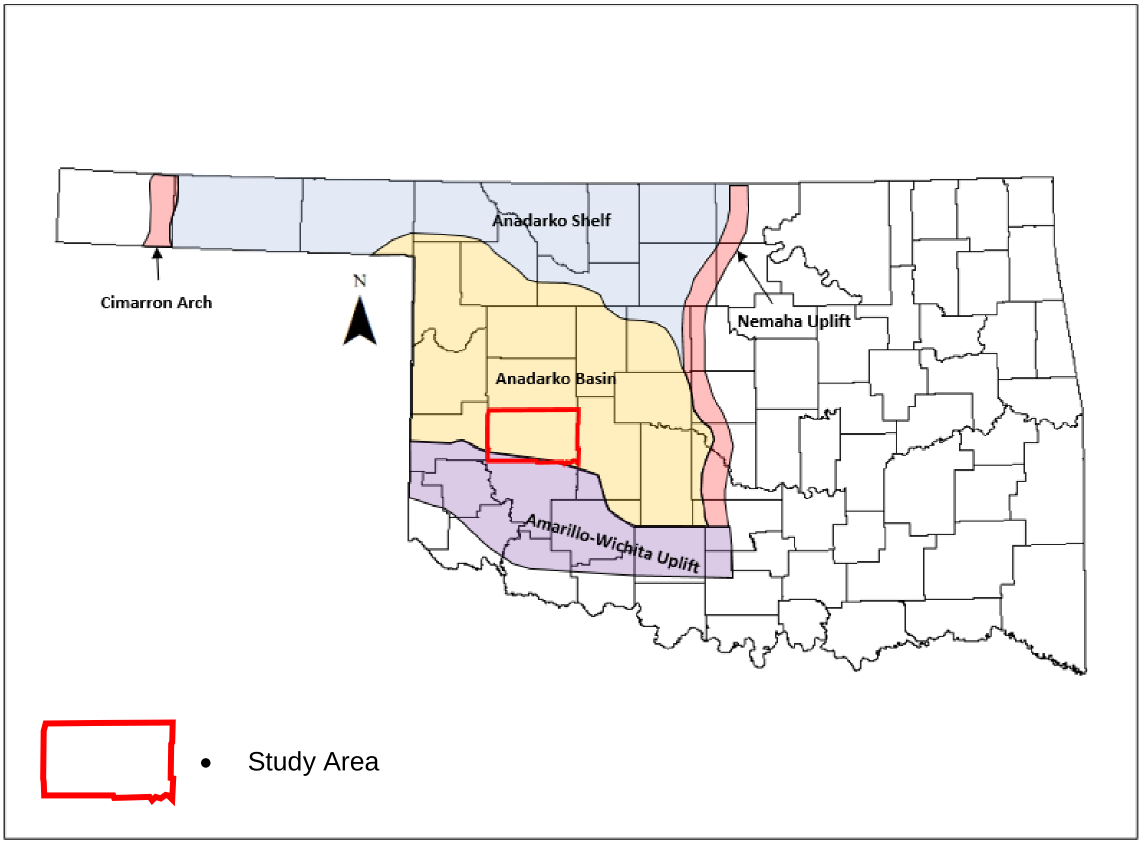

Figure 1: Geological provinces of the Anadarko Basin and basin boundaries. Study area (Washita County, Oklahoma) highlighted in red. Based upon Johnson, 2008.

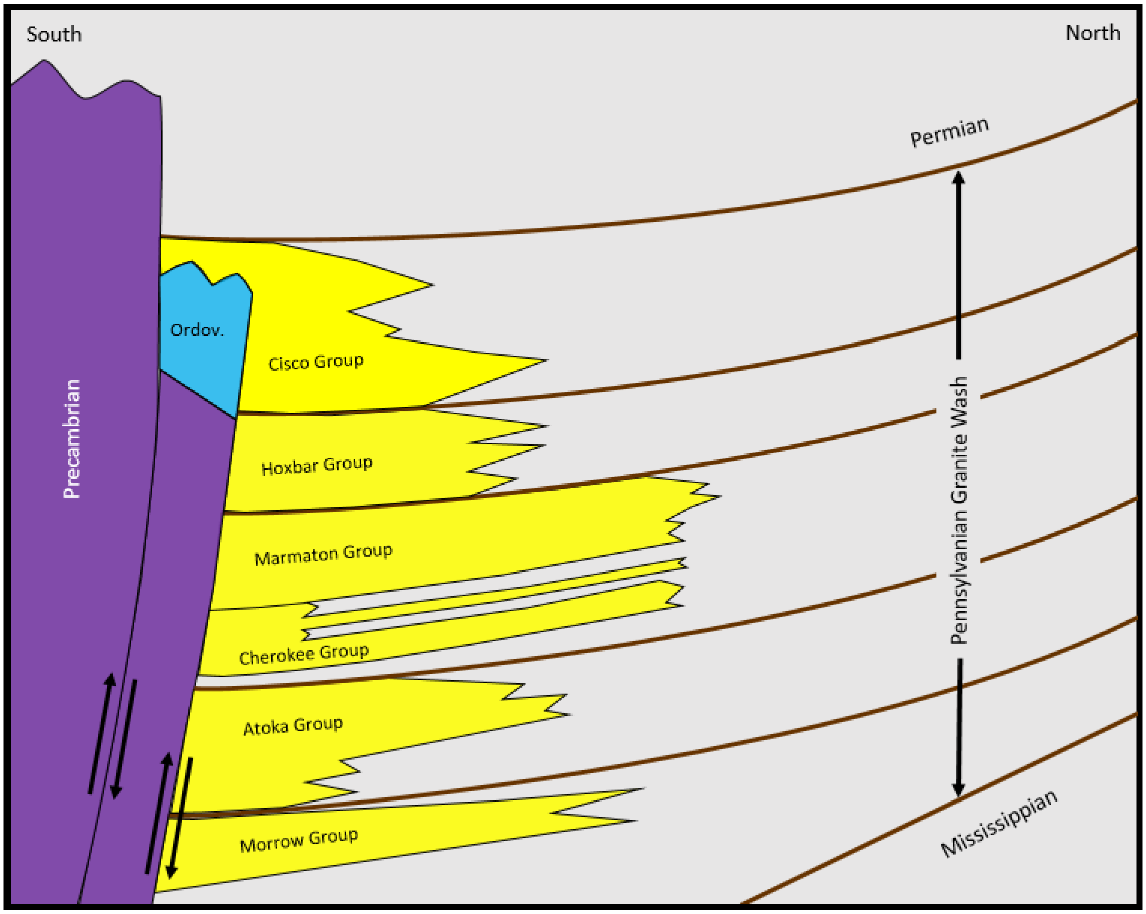

Figure 2: Cross section of the Pennsylvanian Granite Wash in the southern Anadarko Basin. Granite Wash is highlighted in yellow, with the conglomerates thinning towards the north. Based upon Mitchell, 2014.

GEOLOGIC SETTING

The Marmaton Group within the Anadarko Basin was deposited in a SW-NE trending fan-delta system, which is a prograded alluvial fan that originated from an adjacent highland and has moved into a standing body of water (Nemec and Steel, 1988) (Figure 3). In the Anadarko Basin, the Amarillo-Wichita Uplift was the source of the fan-deltas located south of Washita County, producing high-gradient braided streams that carried coarse-grained gravel, sand, and silt into the basin (Ethridge and Wescott, 1984).

The Marmaton Group consists of both proximal and distal fan sections, which vary in thickness and grain size (Figure 3). The proximal fan is the closest section to the point of original deposition deposited by braided streams (Dutton, 1982) (Figure 3), and is the thickest and coarsest portion of the Marmaton Group Granite Wash fan delta sequences towards the south, into southern Washita County (Mitchell, 2011). The proximal area extends to just north of the Mountain View Fault system (Mitchell, 2011) (Figure 3). Overall, grain size and thickness decreases from the uplift in the south towards the center of the basin. Proximal Granite Wash consists of gravel-sized conglomerates, along with coarse-grained sandstone facies (Dutton, 1982; Mitchell, 2011) (Figure 3).

Igneous rock fragments were eroded from the Wichita Igneous Province and deposited arkosic sediments in the fan delta system, creating framework grains of Cambrian igneous rock fragments (Mitchell, 2011). Proximal Granite Wash deposits are typically adjacent to areas of high faulting (Brown, 1979; Nemec and Steel, 1988).

In the distal area (Figure 3), the Marmaton Group Granite Wash clastic wedge contains a finer sand complex compared to the proximal area (Dutton, 1982; Mitchell, 2011). The distal fan is the farthest portion of the fan delta system, and is the most northern extent of the Granite Wash fan delta system (Mitchell, 2011), extending to just beyond the northern boundary of Washita County; beyond Washita County and Custer County to the north, the Granite Wash is essentially non-existent (Mitchell, 2011). The distal fan is composed of gravel- to granule-sized conglomerates, sandstones, siltstones, and shales (Dutton, 1982). These sediments have been affected by both fluvial and wave/tidal processes and will show sediment reworking throughout the section (Dutton, 1982). They include sediments that have been reworked by marine processes to create a delta-front and marine barrier bars consisting of sand and gravel from the proximal sediment; along strike the sediments were reworked by tidal and wave processes if the energy is high enough in the system (Dutton, 1982; Mitchell, 2011).

The Marmaton Group intervals (A-F) are separated by flooding zone shales in the rock record (Mitchell, 2011). These flooding zone shales were deposited during transgressive sea level events. The flooding zone shales were deposited from a basinward deposition as sea level transgressed. The shales were laid down separating the Marmaton Group Granite Wash intervals in the basin. In the study area, the flooding zone shales are at their thickest in the north and begin to thin to the south towards the Amarillo-Wichita Uplift.

The Marmaton Group is conformably bound below by the Upper Skinner Shale (Cherokee Group) and above by the Cleveland Granite Wash (Hoxbar Group) (Figure 2). This shale was laid down extensively in the Anadarko Basin and can reach up to 800 feet thick in Roger Mills County (Mitchell, 2011). Above the Marmaton Group is the Cleveland Wash. The Cleveland Wash is similar in lithology to that of the Marmaton Wash, being highly arkosic conglomerates and sandstones. The Cleveland Wash and the Marmaton A Wash are separated by a dark marine shale (Mitchell, 2011).

The Pennsylvanian Marmaton Group in Washita County lies within the southern portion of the Anadarko Basin in southwestern Oklahoma. The Anadarko Basin is a foreland basin formed during the early Pennsylvanian due to the collision of the South American and African plates with the southern margin of the North American craton (Thomas, 1991). It is elongate, and follows a west-northwest trend, extending across most of western Oklahoma, the Texas Panhandle, southwestern Kansas, and a small portion of southeastern Colorado, covering roughly 35,000 square miles (Al-Shaieb, 1994). This basin is also one of the deepest known sedimentary and structural basins in the United States (Johnson, 1989), with over 40,000 ft of Paleozoic sediments overlying the Cambrian-Precambrian igneous basement along the basin axis (Johnson, 1989).

The Anadarko Basin is bound on all four sides by arches (Figure 1); to the south, the basin is bounded by the Amarillo-Wichita uplift, to the east the Nemaha Ridge, and to the west by the Cimarron Arch (Johnson, 1989). A broad shelf is found on the north side and extends across the western portion of Kansas, often referred to as the Hugoton Embayment (Johnson, 1989).

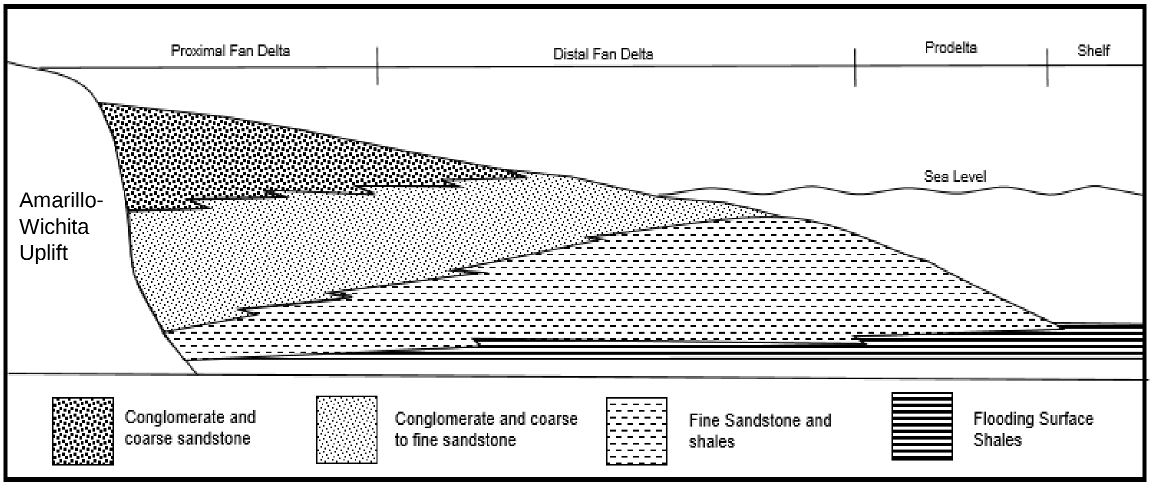

Figure 3: Generalized cross section of a Marmaton Group Fan Delta in the Southern Anadarko Basin. Based upon Ethridge and Wescott 1984.

METHODS

Core Analysis

Two cores archived at the Oklahoma Petroleum Information Center – Core and Well Cutting Research Facility were examined to better understand the correlation between the well log readings and the facies present in the cores. The two cores and their corresponding well logs are from in Washita County from wells Mobil-Edler #2 (API 3514920475) and the Clements-Littke #1 (API 3514920485) (Figure 4). Mobil-Edler #2 (API 3514920475) is located in Township and Range 11N19W and consists of two sections: (1) measured depth of 12,703-12,721 feet; (2) measured depth of 12,974-12,980 feet. Clements-Littke #1 (API: 3514920485) is located in Township and Range 11N16W, and consists of the measured depth interval of 12,473-12,517 feet. The lithology of each facies, the color, grain size, sorting, rounding, mineral composition, laminations present, and other aspects of the facies that might be present were all described (Appendix A). The facies were divided based upon the sudden lithology changes between intervals.

Thin sections were created, from Mobil-Edler #2 and Clements-Littke #1, in order to obtain mineralogy of the observed facies. Thin sections were examined using a Labomed petrographic microscope.

Well Logging

Over 90 well logs were collected within Washita County and the northeast corner of Beckham County, OK (Figure 4). These well logs were obtained from Drillinginfo.com and Oklahoma Petroleum Information Center (OPIC), typically consisting of gamma ray, caliper, neutron porosity, and bulk density. The well logs were uploaded into Petra, and formation boundaries were determined for Upper Skinner Shale, and Marmaton A interval, the Marmaton B interval, the Marmaton C interval, the Marmaton D interval, the Marmaton E interval, and the Marmaton F inteval, based upon a type log of the Marmaton Group located northwest Washita County, Oklahoma (Figure 5). Using the gamma ray, neutron porosity, density logs, and caliper logs; flooding surface shales were used as the boundaries between the Marmaton Group Granite Wash intervals, and allowed for the six intervals to be identified.

The sandstones/conglomerates present have a gamma ray reading of a lower API than that of the flooding surface shales which have a gamma ray reading of up over 150 API. The Granite Wash facies have a gamma ray reading ranging between 75 API and 175 API, density porosity 2 – 4%, neutron porosity 4 – 8 %, and show either a mudcake or no caliper log change. The flooding zone shales have a gamma ray of over 200 API, density porosity 10 – 20%, neutron porosity 24 – 30 %, and show a washout in the caliper log. Five cross sections were then created in Petra to show the facies and thickness changes across the county. Tops were correlated by using the well log responses known from the type log.

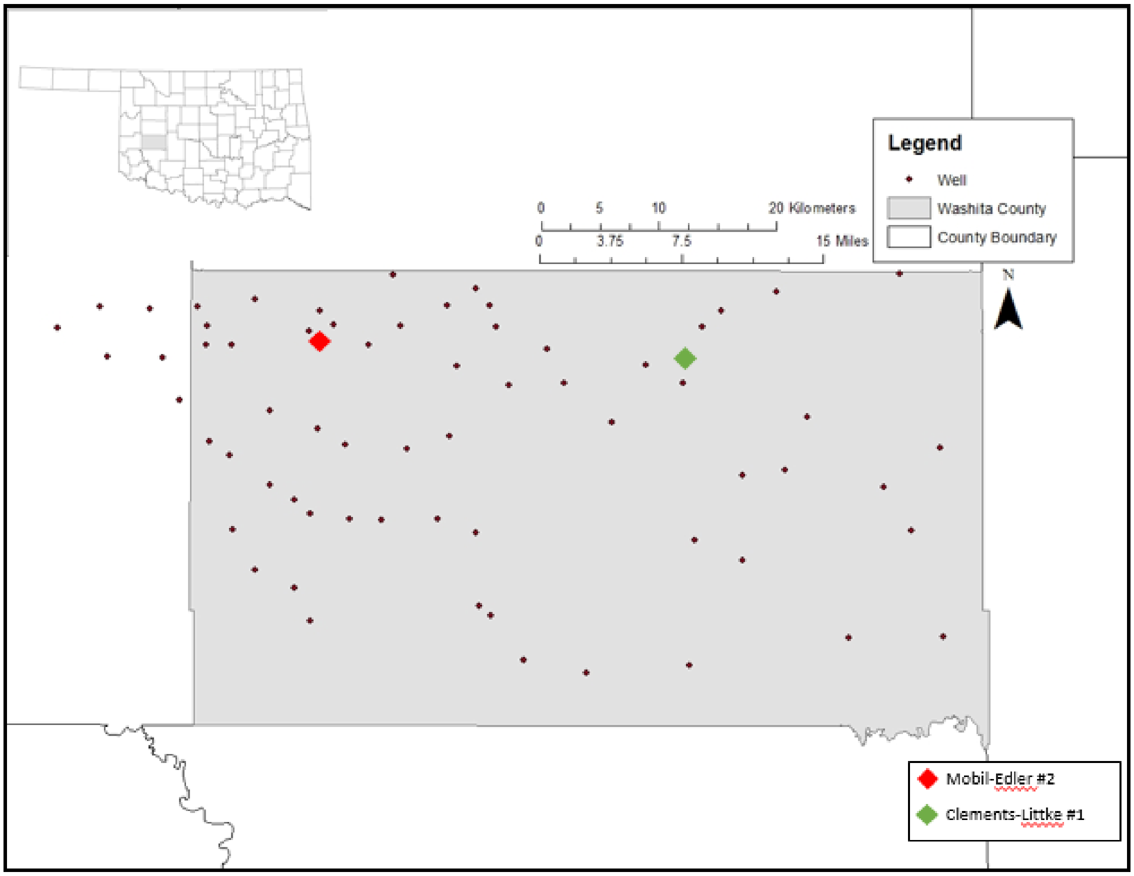

Figure 4: Well location map in Washita and Beckham County, OK

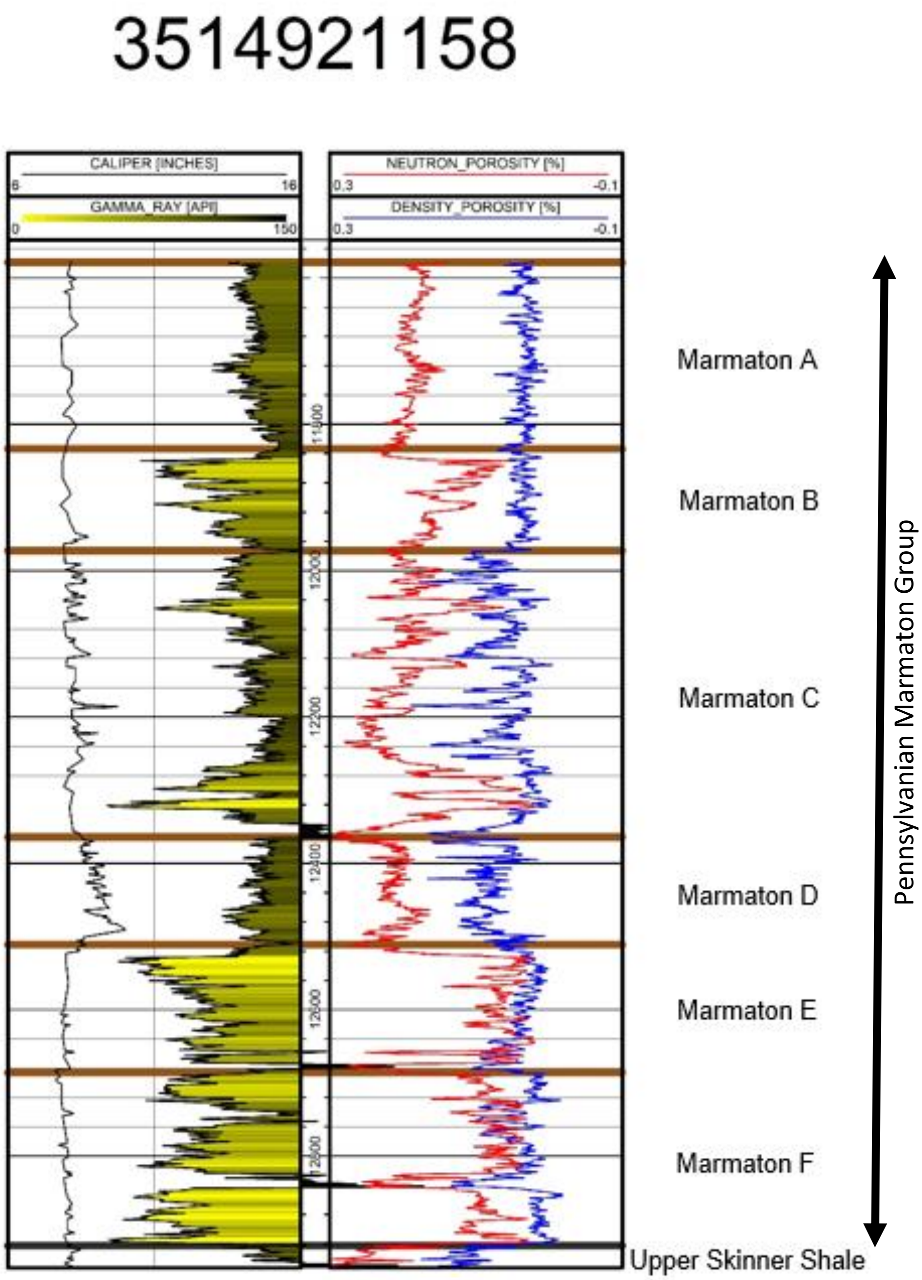

Figure 5: Type log, Riviera-Merz 1-10, northwest Washita County, Oklahoma, located in the distal lobe.

Mapping

ArcGIS was used to create structure and total thickness maps of the study area. The tops data were exported from Petra into ArcGIS. Net thickness maps were hand contoured for each of the Marmaton F through A intervals within the Marmaton Group. The individual thickness raster files were then summed in ArcGIS to create a net thickness map for the Marmaton Group. A subsea level structure map was created for the Upper Skinner Shale (the base formation of the formations of interests), and was hand contoured. A structure map for the Marmaton A (the upper boundary of the Marmaton Group) was created by using raster math in ArcGIS. The Marmaton Group net thickness map was added to the subsea Upper Skinner Shale structure map to create a volumetrically correct upper surface of the Marmaton Group. This method was used because the Marmaton A interval was difficult to follow throughout portions of the county due to the lack of the upper flooding surface towards the east.

SEDIMENTOLOGY

Core and Thin Section Analysis

The Mobil-Edler #2 and Clements-Littke #1 cores archived by the Oklahoma Petroleum Information Center (OPIC) at the Oklahoma Geological Survey are comprised of interbedded conglomerates, sandstones, siltstones, and shales (Figure 6). The Mobil-Edler #2 cored section is composed of the Marmaton E interval from 12,703 – 12,721 feet, and the Upper Skinner Shale from 12,974 – 12,980 feet. The Clements-Littke #1 core consists depths 12,473 – 12,517 feet, and is also the Marmaton F Interval and top boundary of the Upper Skinner Shale.

The Marmaton Group in these cores consists of five facies (Figure 7, 8, and 9 A-E), ranging from orthoconglomerates to paraconglomerates, arkosic to subarkose arenite sandstones to arkosic wackestone. Across these facies, there are varied colors, ranging from gray, tan, and black, grains sizes that varied from pebble through fine-grained sand to siltstone laminations, angular through subrounded, poorly-sorted grains through well-sorted, and mineralogy that generally, consists of quartz, feldspar, and lithic fragments. Creating a highly arkosic stacked conglomerate and sandstone section. There are two distinct conglomerates within the cores. Overall, the conglomerates had grain sizes that range from ¼" to 2 ¼" of an inch in diameter in the grains are pebble to granule clasts. Although not shown in core, the Marmaton Group is known to have boulder sized rock fragments (Mitchell, 2011). The orthoconglomerate (ex: Mobil-Edler #2 depth 12,712 – 12,713 ft) consists of light-medium grey plutonic clasts varying in size from ¼" to 2 ¼" of an inch in diameter (Figure 9-A). It is clast supported, surrounded by coarse to fine sand. The paraconglomerates (ex: Mobil-Edler #2 depth 12, 721 – 12,722 ft) consists of light-medium grey clasts contained within a dark grey mud-rich matrix. The minerals that are present in the both conglomerate facies are quartz, plagioclase, and orthoclase, and are primarily found within volcanic and plutonic clasts rather than the matrix**.** This mineral assemblage creates conglomerates which are arkosic (Figure 9-B).

The arkosic arenite sandstone units that are found within both cores show a variety of grain sizes and color throughout. Most intervals examined are arkosic arenite sandstone, although some sections do contain higher quartz contents, and are subarkose arenite sandstone. The color of the sandstones ranges from tan to grey. The grain size ranges from coarse sand to fine sand, with both fining upward sequences and coarsening upward sequences present. The grains range from moderately-sorted to well-sorted, and sub-angular to sub-rounded. The sandstone intervals show silt/mud flaser, lenticular, and wavy bedding throughout the interval. An example of this can be seen in three thin sections examined: CL1A depth 12,473 ft, CL1B depth 12,492 ft, and MB2A depth 12,709 ft. All three of the thin sections show an arkosic arenite that has high feldspar and lithic fragment content (Figure 9-C and Figure 10).

Arkosic wackestones consist of coarse sandstone intervals with silt flaser laminations and lenses throughout the core and are found at various depths throughout both cores (ex., 12,713 – 12,718 feet in Mobil-Edler #2 and 12,483 – 12,487 feet in Clements-Littke #1). These intervals consist of quartz, plagioclase, and orthoclase silt grains (Figure 9-D).

Shale is found at the bottom of both cored intervals at depths of 12,503 – 12,517 feet in Clements-Littke #1 (Figure 9-E), and in Mobil-Edler #2 at the depths of 12,976 to 12,980 feet. The shale in both cores is the upper most portion of the Upper Skinner Shale unit in the Cherokee Group. The Upper Skinner Shale in these wells is a massive, dark black to grey shale with planar laminations throughout the entire section. The black with gray laminations suggests that it is a shallow to deep marine environment in a distal lobe setting. After examination of thin section CL1C (depth 12,512 ft), it is determined that the interval is a mudstone (Figure 14). The mudstone contains some minor inclusions of plagioclase grains, along with calcite inclusions.

These facies show similar stratigraphic patterns throughout the cored intervals (Figure 7 and Figure 8). There are patterns present such as orthoconglomerates that are vertically succeeded by paraconglomerates that then change facies into shale or siltstone, or orthoconglomerates that are transitioning into coarse sandstone. Both of these sequences represent fining upwards sequences. The packages consists of stacked orthoconglomerate, paraconglomerate, then fining to shale or siltstone, indicating a depositional environment that rapidly deposited sediment with a high mud/fine grain matrix, such as mass wasting flows (Mitchell, 2011) When orthoconglomerate is stacked vertically by sandstone, this indicates that there was a rise in sea level depositing finer sediments on top of the orthoconglomerates. There are instances of coarsening upward sequences that are characterized by coarse sandstone with laminated silt lenses that transitions into orthoconglomerate at the top (ex. Mobil-Edler #2: 12,712 – 12,718 feet). Contacts between facies changes can be either abrupt or gradational.

Southern Anadarko Basin Pennsylvanian Granite Wash Stratigraphy

Series	Group
Virgilian	Cisco Group
Missourian	Hoxbar Group
Desmoinesian	Marmaton Group (Marmaton A, Marmaton B, Marmaton C, Marmaton D, Marmaton E, Marmaton F)
Desmoinesian	Cherokee Group
Atokan	Atoka Group
Morrowan	Morrow Group

Figure 6: Southern Anadarko Basin Stratigraphy relative to Washita County, Oklahoma. Based upon Mitchell, 2011.

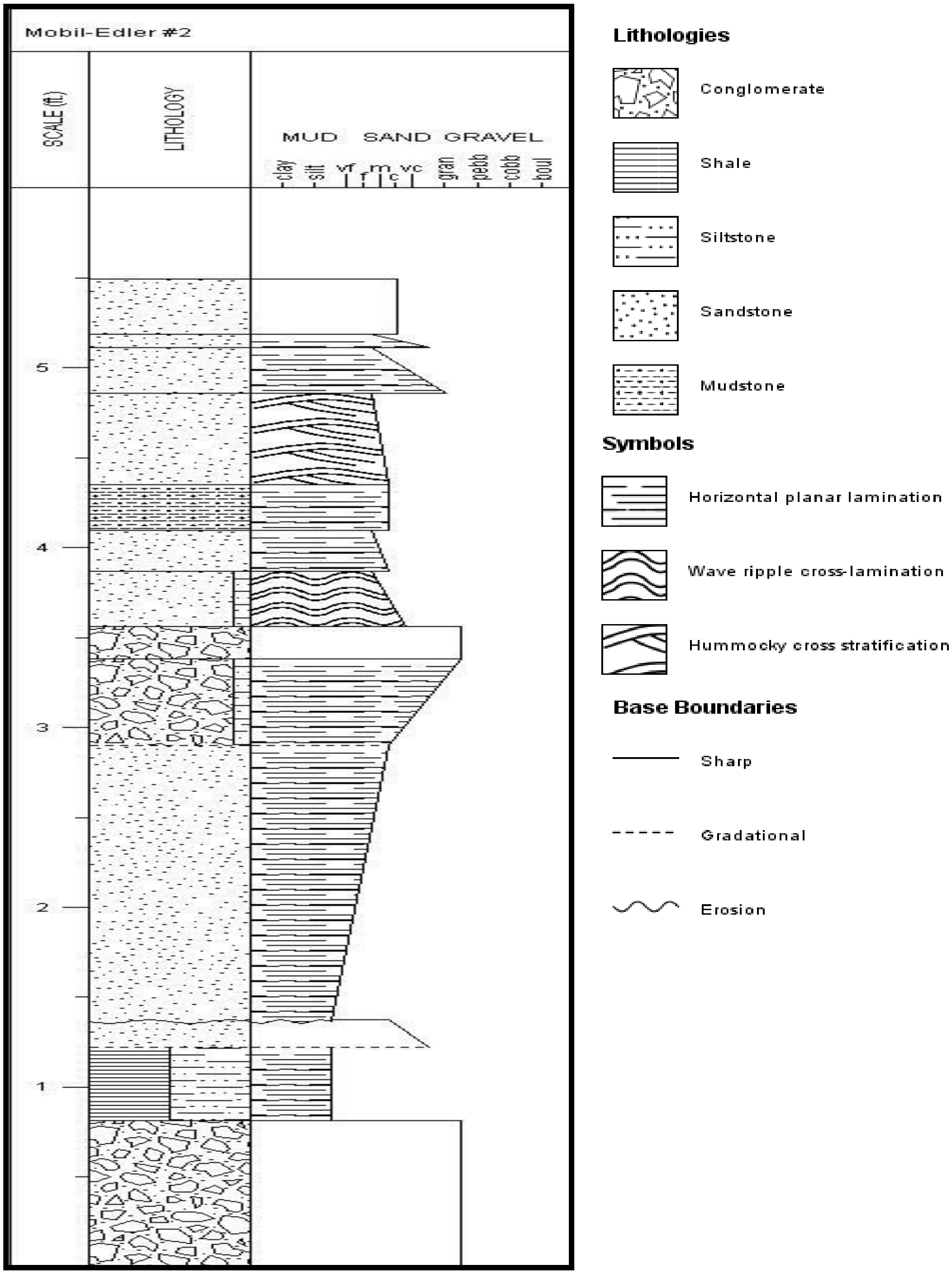

Figure 7: SedLog of Mobil-Edler #2 core, located in the distal lobe in Washita County. Depth: 12,703 12,721 feet, and 12,974 – 12,980 feet.

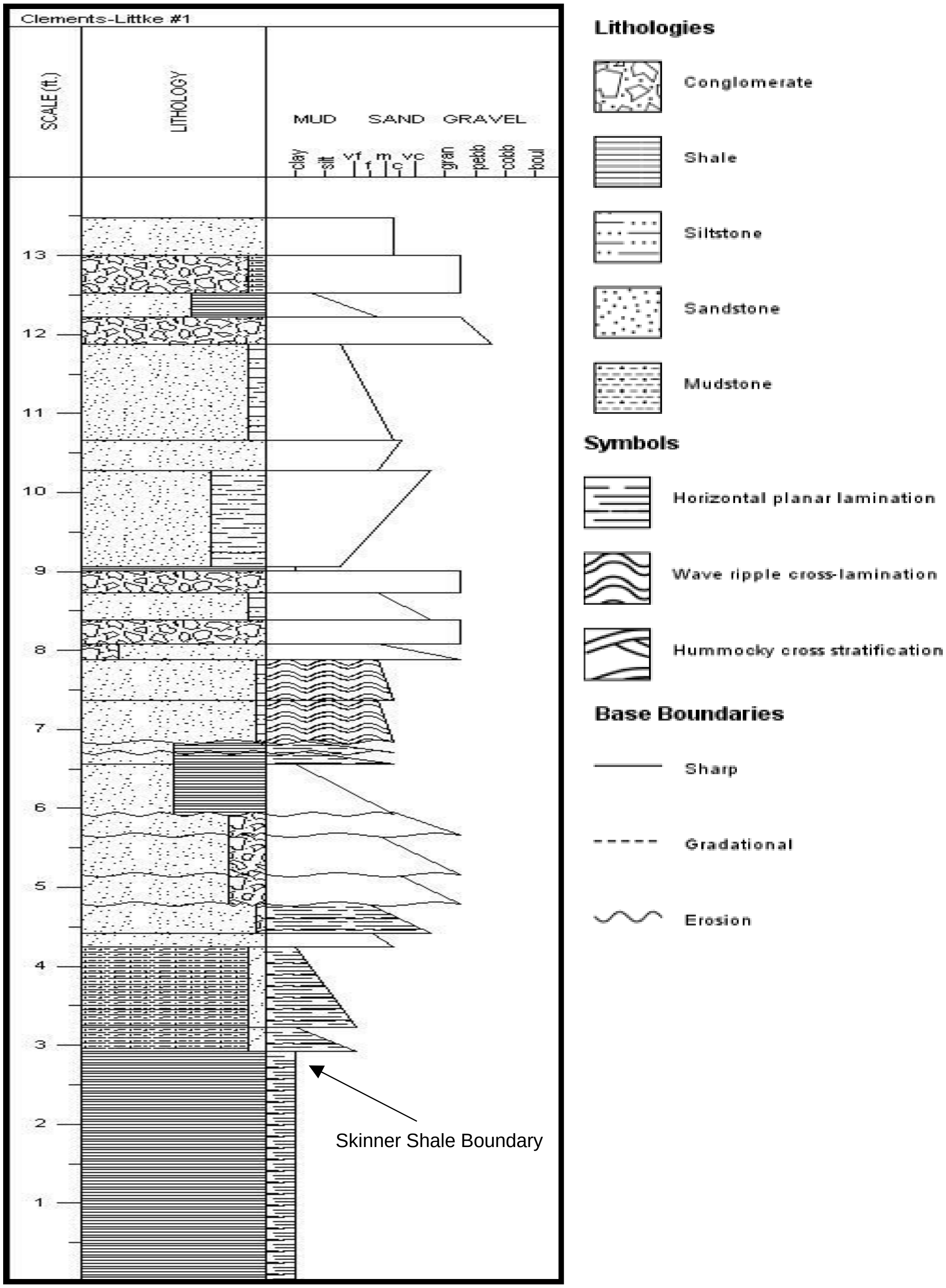

Figure 8: SedLog of Clements-Littke #1 core, located in the distal lobe in Washita County. Depth: 12,473 – 12,517 feet.

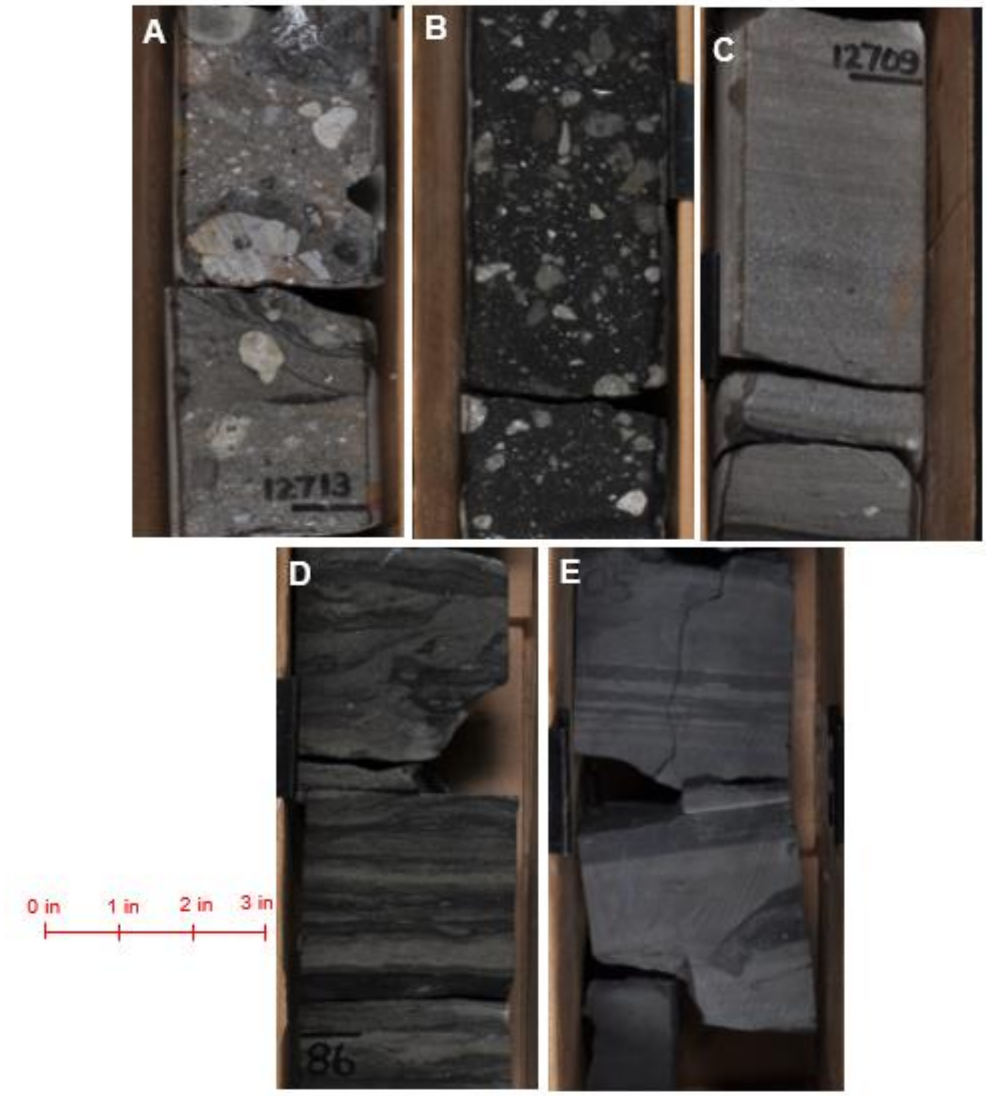

Figure 9: A through E: (A) Orthoconglomerates consisting of gravel sized lithic fragments, (B) Paraconglomerate containing lithic fragments in a mud matrix, (C) Coarse grained sandstone, (D) Sandstone with silt flaser laminations, (E) laminated shale.

Thin Section Analysis

Clements-Littke #1 Thin Section A (CL1A)

Thin section CL1A is from a coarse sandstone interval in Clements-Littke #1 at a depth of 12,473 feet (Figure 10). The largest grain size is coarse sand, the smallest grain size is medium sand. The sandstone interval is moderately sorted and subrounded. The color is light gray in color which suggests that it is a shallow marine environment. After examination of thin section CL1A it is determined that the sandstone interval is arkosic (Figure 11). The predominant minerals in the interval are feldspar and some minor amount of quartz. Which are primarily found in feldspar intergrowths. Another major component are lithic fragments: volcanic rock fragments and plutonic rock fragments (Figure 11). The volcanic rock fragments are fine grained, lighter colored lithic fragments that have little to no quartz content. The plutonic rock fragments have a coarse grained composition that show lighter colored lithic fragments with a higher quartz content. The interval contains calcite cement which suggest that marine deposition occurred of the sediment. Mechanical compaction is present in the thin section, which suggest overburden diagenesis of the interval. With high temperatures occurring during deposition to create the feldspar intergrowths.

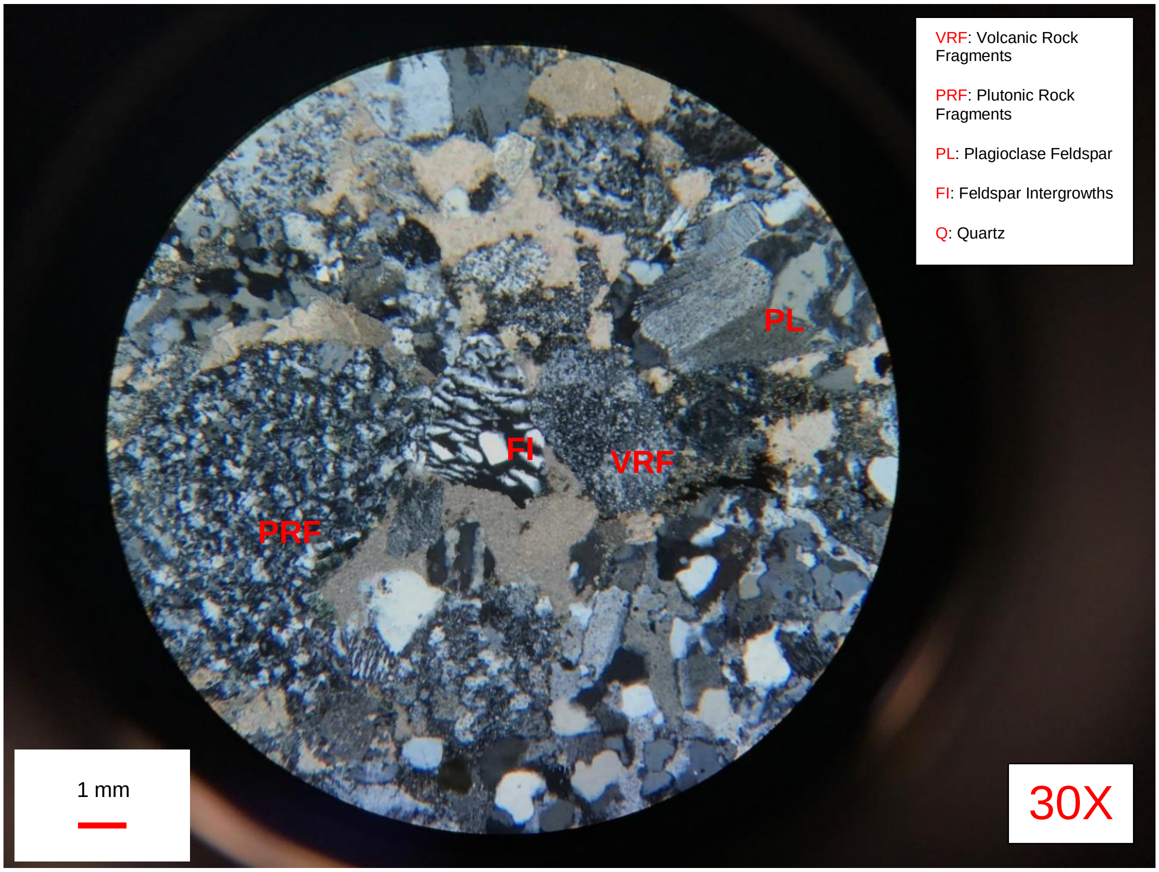

Figure 10: Thin Section CL1A, coarse sandstone interval in Clements-Littke #1 at a depth of 12,473 feet.

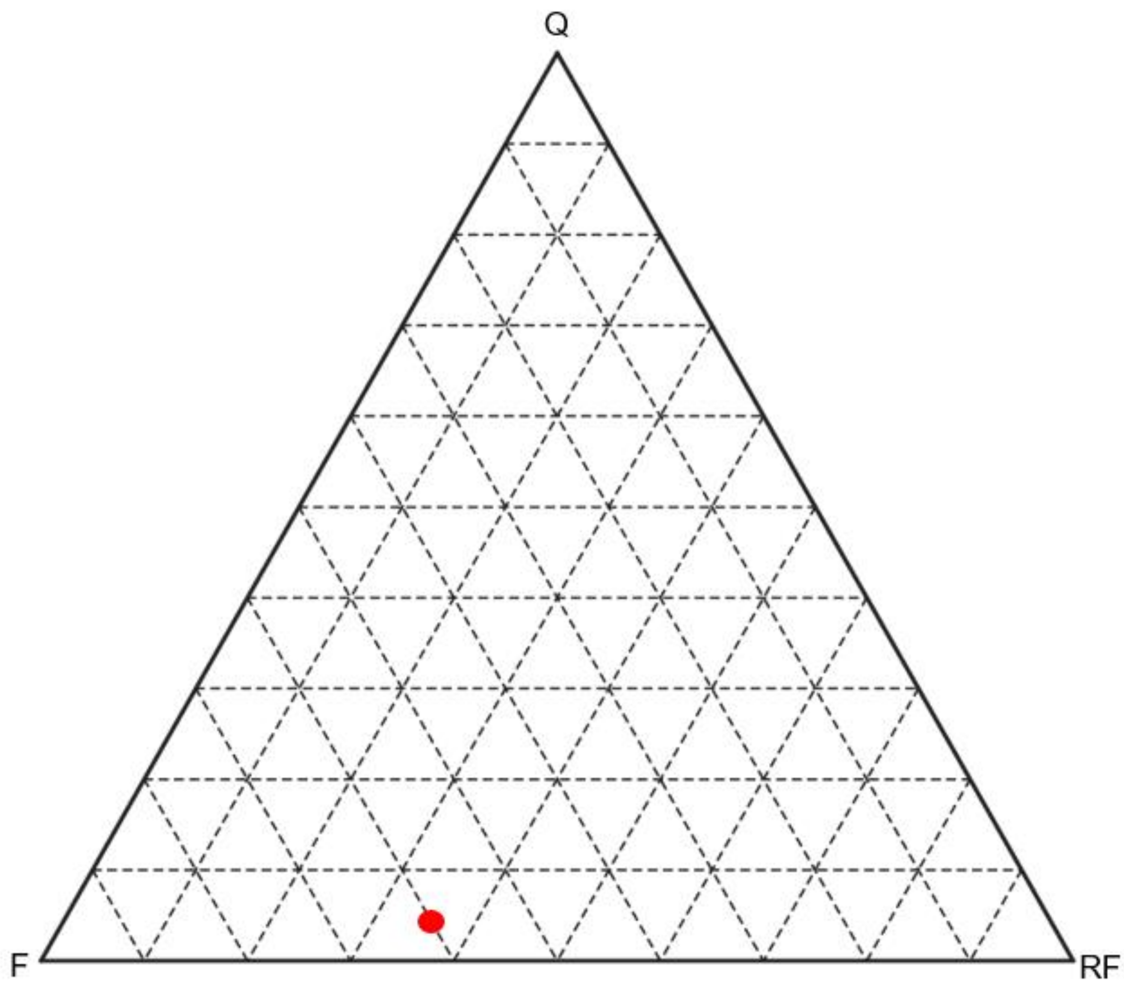

Figure 11: QFR Diagram of thin section CL1A; Q = 4, F = 60, RF = 36

Clements-Littke #1 Thin Section B (CL1B)

Thin Section CL1B is from a fining upward sequence of coarse- to fine-grained sandstone interval in Clements-Littke #1 at a depth of 12,492 feet (Figure 12). The largest grain size is coarse sand, the smallest grain size is fine sand within the sample. The sandstone interval is moderately sorted and subangular. The color is light tan in color which suggests that it is a transitional to shallow marine environment. After examination of thin section CL1B it is determined that the sandstone interval is arkosic (Figure 13). The predominant minerals in the interval are feldspar and minor amounts of quartz. Which are primarily found in feldspar intergrowths. Another major component are lithic fragments: volcanic rock fragments and plutonic rock fragments (Figure 13). The volcanic rock fragments are fine grained lighter colored lithic fragments that have little to no quartz content. The plutonic rock fragments have a coarse grained composition that show lighter colored lithic fragments that are composed of feldspar and quartz. The interval has calcite cement which suggest shallow marine deposition. Mechanical compact is present in the thin section, suggesting large overburden during diagenesis of the interval. With high temperatures occurring during deposition to create the feldspar intergrowths

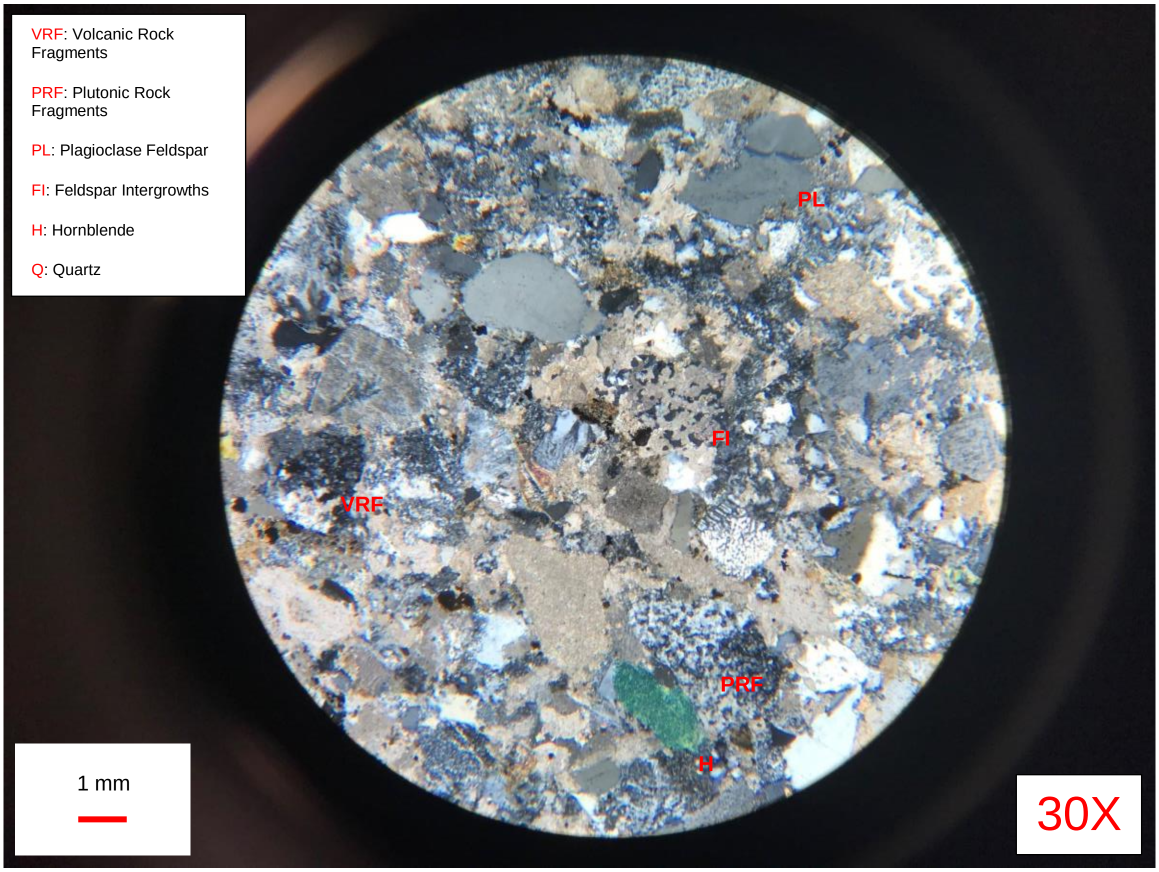

Figure 12: Thin Section CL1B, fining upward sequence of coarse- to fine-grained sandstone interval in Clements-Littke #1 at a depth of 12,492 feet.

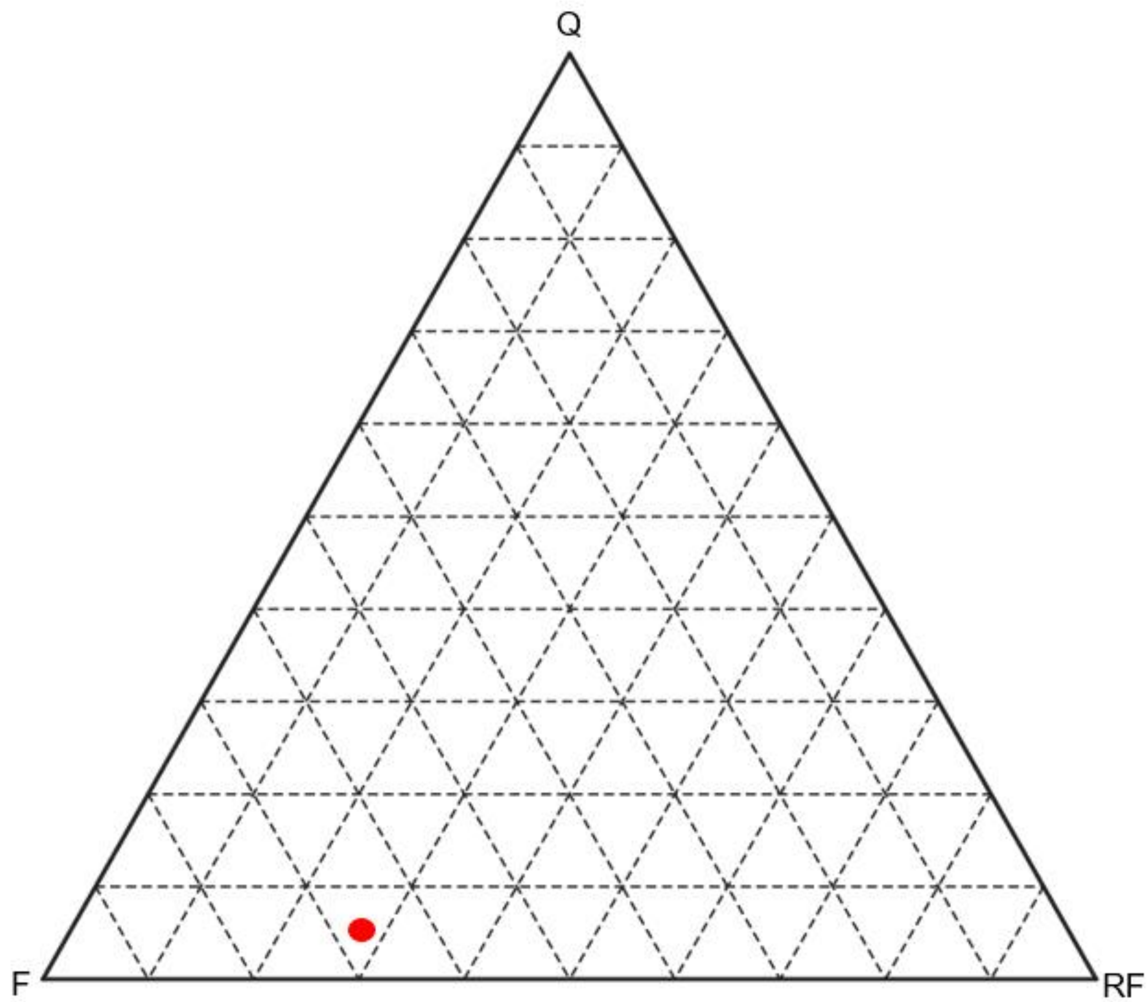

Figure 13: QFR diagram of thin section CL1B; Q = 5, F = 67, RF = 28.

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Clements-Littke #1 Thin Section C (CL1C)

Thin Section CL1C comes from a laminated black shale interval in Clements-Littke #1 at a depth of 12,512 feet (Figure 14). This shale is massively bedded with planar laminations within the shale interval. The color is black with gray laminations which suggests that it is a shallow to deep marine environment in a distal lobe setting. After examination of thin section CL1C it is determined that the interval is a mudstone. The mudstone contains some minor inclusions of plagioclase grains, along with Calcite inclusions. Mechanical compaction of the shale occurred during diagenesis. Natural fractures are present in the shale, which were created during diagenesis. The natural fractures were filled by calcite, to create calcite veins.

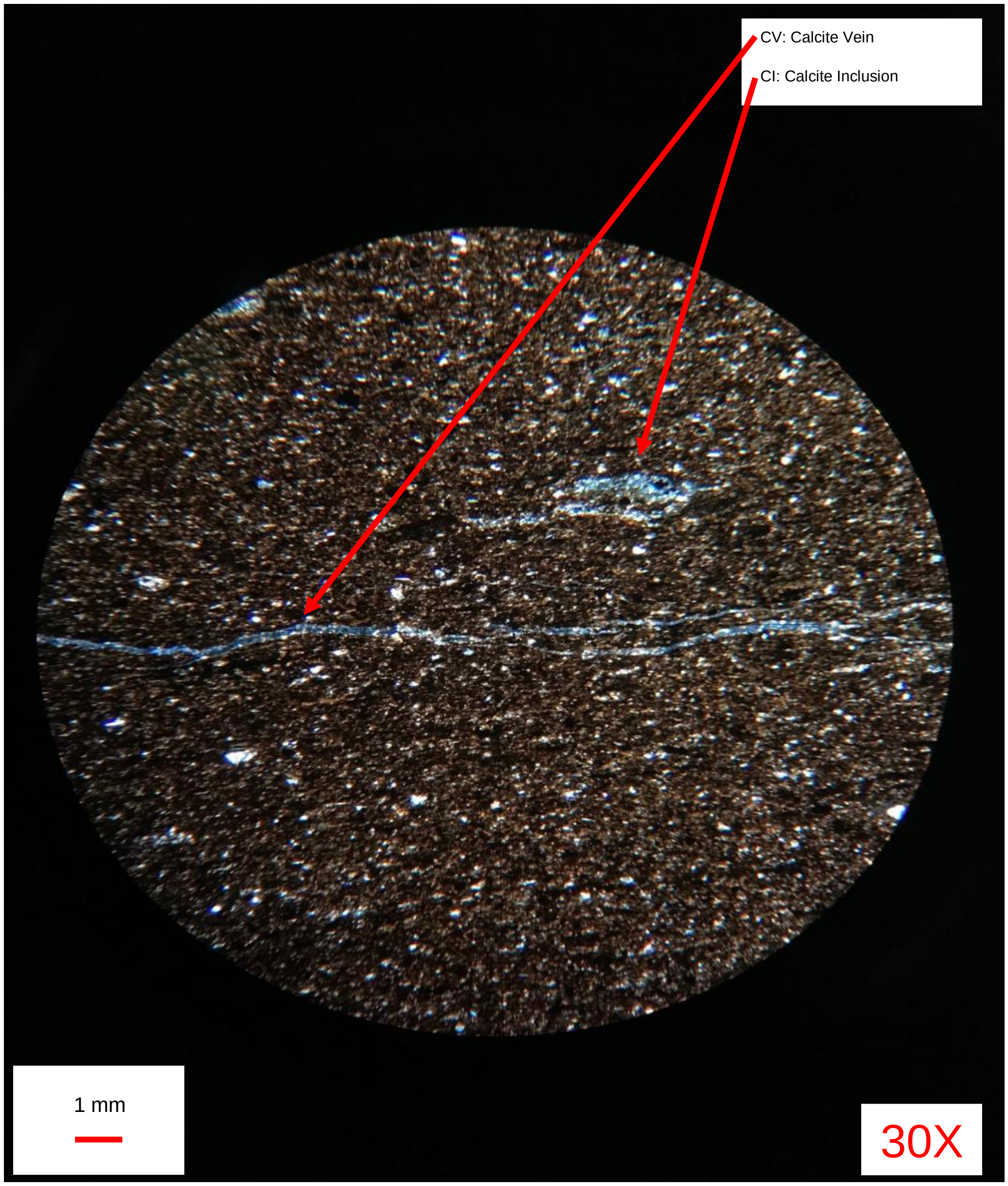

Figure 14: Thin section CL1C, laminated black shale interval in Clements-Littke #1 at a depth of 12,512 feet.

Mobil-Edler #2 Thin Section A (MB2A)

Thin Section MB2A is from a fining upward sequence sandstone interval in Mobil-Edler #2 at a depth of 12,709 feet (Figure 15). The largest grain size is coarse sand, the smallest grain size is fine sand. The sandstone interval is moderately sorted and subrounded to subangular. The color is light gray which suggests that it is a shallow marine environment. After examination of thin section MB2A it is determined that the sandstone interval is arkosic (Figure 16). The predominant minerals in the thin section is feldspar with minor forms of quartz. Which are primarily found in feldspar intergrowths. Another major component are lithic fragments: Volcanic rock fragments and plutonic rock fragments (Figure 16). The volcanic rock fragments are fine grained lighter colored lithic fragments that have little to no quartz content. The plutonic rock fragments have a coarse grained composition that show lighter colored lithic fragments with a higher quartz content. The interval has calcite cement which suggest shallow marine deposition. Mechanical compact is present in the thin section, suggesting large overburden during diagenesis of the interval. With high temperatures occurring during deposition to create the feldspar intergrowths

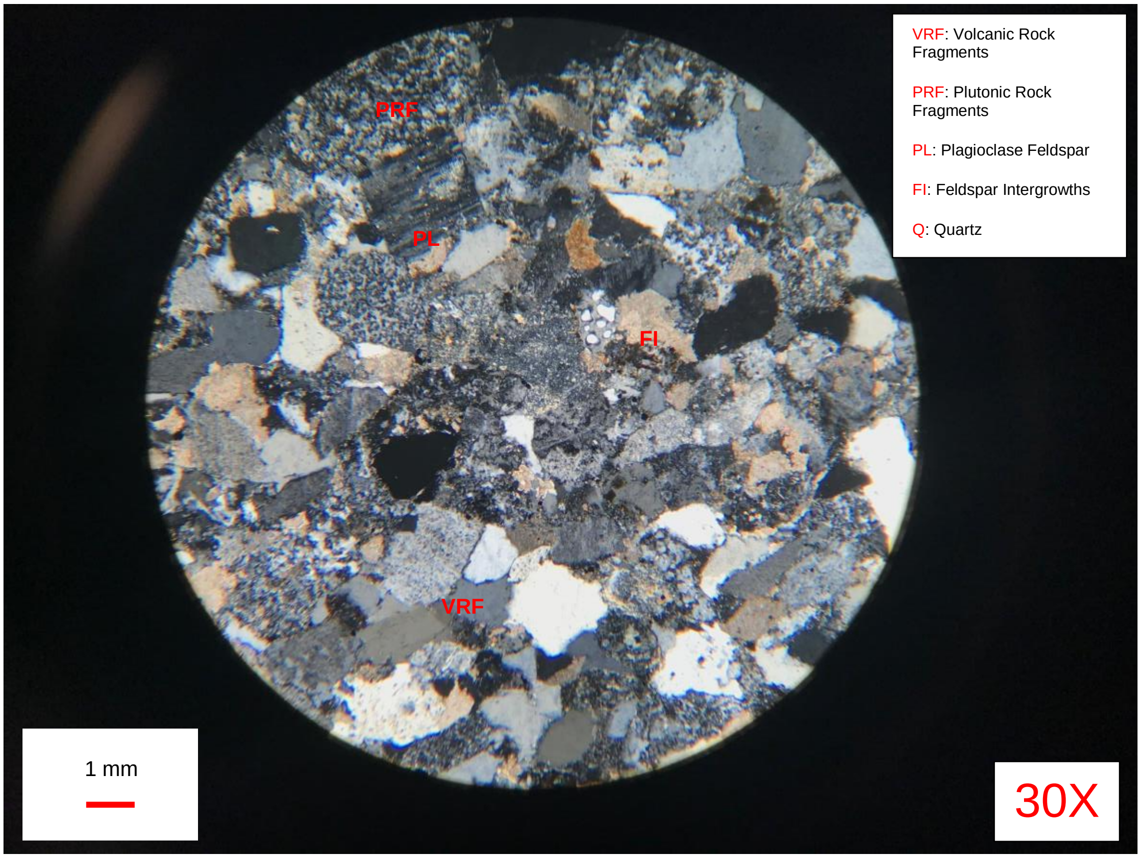

Figure 15: Thin Section ME2A, fining upwards sequence sandstone interval in Mobil-Edler #2 at a depth of 12,709 feet.

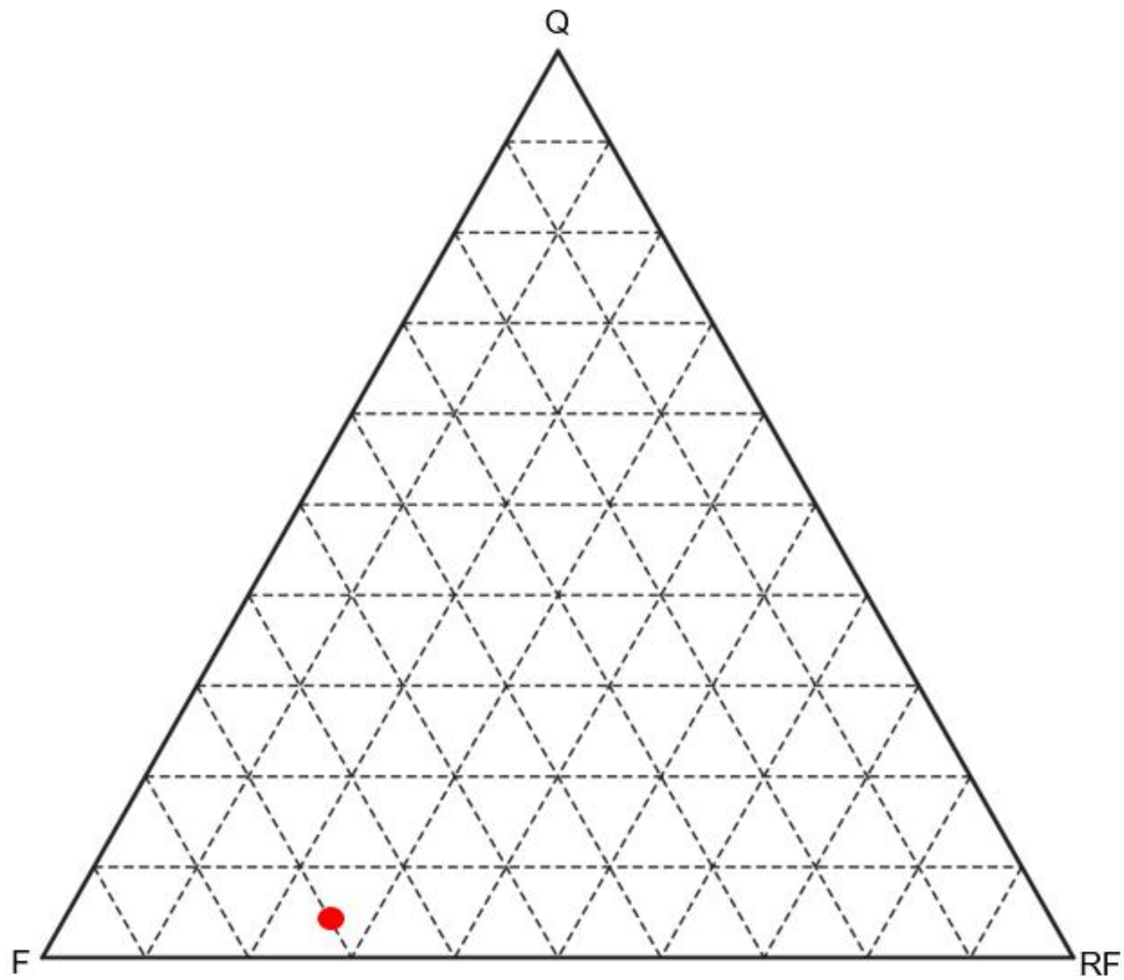

Figure 16: QFR diagram of thin section ME2A; Q = 4, F = 70, RF = 26.

Cored Interval to Well Log Comparison

Well logs measure various physical properties of the rocks, which are then interpreted as specific rock types; they are proxies, rather than direct measurements (Rider and Kennedy, 2011). The four logs used for this study were gamma ray logs, density logs, neutron porosity logs, and caliper logs. A gamma ray log is a record of a formation's radioactivity, recorded in API (Rider and Kennedy, 2011). The radiation that is occurring comes from naturally occurring uranium, thorium, and potassium in the rocks, which in sedimentary rocks, comes primarily from feldspars or are attached to or associated with clay minerals in shales (Rider and Kennedy, 2011). A higher amount of the naturally occurring radioactive minerals causes an increase in the gamma ray reading; gamma ray logs are typically used as shale indicators, with high API readings indicating high amounts of clay minerals. The density log is a continuous record of the formation's bulk density, recorded in g/cm^3 (Rider and Kennedy, 2011). Bulk density is the density of the minerals forming the rock present (matrix) and the volume of free fluids (and gases) which it encloses (porosity) (Rider and Kennedy, 2011). Often times, density porosity is calculated from the bulk density log. It is a conversion of the bulk density log through a mathematical equation to create the converted density porosity log. Finally, the neutron porosity tool bombards the surrounding rock with neutrons to measure the hydrogen index of a formation (Rider and Kennedy, 2011). The hydrogen index is an indication of a formation’s hydrogen content, which in sedimentary rocks are typically found in water or hydrocarbons within the pores (Rider and Kennedy, 2011). The hydrogen index is then related to the porosity of the formation.

Typical sedimentary basins consists of packages of sandstones, shales, and carbonates. Gamma ray is typically used as a shale indicator. The clay minerals found in shale are associated with uranium, potassium, or thorium. Higher amounts of uranium, potassium and thorium will raise the gamma ray reading for the formation. Shale typically has a higher gamma ray reading depending on organic content, with a range from 100 API to 300 API, density porosity 10 – 20%, neutron porosity 24 – 30%, and a washout of the borehole in the caliper log. Shale is primarily composed of clay, which contains higher amounts of radioactive uranium, potassium, and thorium, which will raise the gamma ray reading for shale formations. Sandstones have a lower gamma ray around 20 to 40 API, density porosity 0 – 10 %, neutron porosity 0 – 10%, and either a smaller borehole diameter in the caliper log (washout) caused by a permeable zone or no change. This can vary due to mineralogy and grain size. As grain size decreases the API of sandstone increases, representing tight porosity and permeability. Normally sandstone is quartz dominated with no uranium, potassium, or thorium content. Siltstone has a gamma ray reading around a 60 API, has increasing clay content. Conglomerate can vary in gamma ray readings due to lithology, grain size, and mineral content. When grain size is larger conglomerates typically have a lower gamma ray reading, and when grain size decreases for conglomerates the gamma ray will raise. When examining mineralogy with conglomerates, a higher content of arkosic minerals correspond to high gamma ray readings. When conglomerates are quartz dominated the gamma ray reading will be lower. Typically, conglomerates range from 50 API to over 100 API readings, varying on quartz dominated vs arkosic nature of the conglomerate. (Rider & Kennedy, 2011).

Conglomerates in the Granite Wash intervals have high gamma ray readings for a variety of reasons. Paraconglomerates have a high mud matrix that will increase the API reading, and these mass-wasting events will have lithic fragments in a mud matrix, creating a facies that has a high potassium and lithic fragment interval. The paraconglomerate mud matrix has a high content of uranium, potassium, and thorium that are associated with the clay minerals in the mud matrix. Orthoconglomerates will have a higher gamma ray reading than that of arkosic sandstone because the grains consist of more potassium and lithic fragments that have yet to be weathered due to the short travel distance; this also results in large grain sizes (Rider & Kennedy, 2011).

The Marmaton Group consists of a fan delta system, locally sourced from the Amarillo-Wichita Uplift. The interval consists of conglomerate, sandstone, siltstone, and shale facies throughout the cored sections (Figure 7 and Figure 8). Yet due to their atypical sandstone/conglomerate mineralogy, the well logs do not show a typical deltaic rock package. The facies within the cored intervals are shown from thin section analyses to be arkosic, consisting of increased feldspar content resulting in increased gamma ray readings (Rider and Kennedy, 2011). Potassium present in the Granite Wash intervals increases the gamma ray reading to values well-above normal for sandstone and conglomerate. While a typical sandstone will have a low gamma ray reading of 30 to 50 API readings depending on grain size and lithology, here the gamma ray of the Granite Wash sandstones is around 75 API to over 115 API. The Granite Wash sandstones have a density porosity of 2 – 4%, and a neutron porosity of 4 – 8%. These numbers are indicating that the Granite Wash reservoirs have low permeability and porosity, resulting in a “tight” rock package.

More specifically, when examining Mobil-Edler #2 and Clements-Littke #1 cored intervals through the Marmaton E and Marmaton F interval (Figure 17 and Figure 18), there are several facies changes from arkosic sandstone, paraconglomerate, orthoconglomerate, sandstone with silt lenses, siltstone, and shale that are reflected on the associated well logs. Sandstone is abundantly present throughout the wells. In Mobil-Edler #2 at a depth of 12,704 to 12,706 feet an arkosic sandstone is present with a gamma ray reading of 95 to 100 API reading, neutron porosity 6%, and a density porosity of 2% (Figure 17). This high increase in gamma ray reading is most likely caused by the large amounts of potassium present in the feldspars shown in the thin section (Figure 10). At a measured depth of 12,720 to 12,721 feet the gamma ray increases to a reading of 150 API, neutron porosity 14% and a density porosity of 8%, where there is a paraconglomerate facies. The paraconglomerate contains more clay content which contains more potassium compared to quartz, calcite, and muscovite. Orthoconglomerates are also very prominent throughout the Marmaton Group. An orthoconglomerate is present in Clements-Littke #1 at a depth of 12,474 to 12,476 feet (Figure 18). Here, it has a gamma ray reading of 80 API. This higher gamma ray reading is due to the increased lithic fragments and potassium feldspar, creating an arkosic orthoconglomerate.

Flooding surface shales representing periods of increased sea level are present throughout the Marmaton Group, but are not present in the cored intervals. In Clements-Littke #1, the base of the log shows the Upper Skinner Shale, an analogue for shale readings (Figure 18). The Upper Skinner Shale has a density porosity 22%, and neutron porosity 26 – 30%, and gamma ray 120 API. These readings are similar to the flooding zone shales, except for the gamma ray log, which is typically over 200 API for flooding zone shales. This increase reaches a range of 200 to 300 API in the flooding zone shales due to the increased clay content and associated uranium and thorium content, and creates marker beds for defining the intervals. The density porosity is as high as 20 -

24%, and neutron porosity ranges 24 – 30%, and a washout (decrease) in the caliper log occurs. With a combination of the gamma ray readings stated before, density logs, neutron logs, and caliper logs were relied on to pick tops of the Marmaton Group intervals. This was done by examining the log and looking for the large spikes in gamma ray of over 200 API, flooding zone shales. These spikes would be examined with the corresponding density and neutron log to determine if it was a flooding zone shale or if it is an isolated occurrence of higher potassium, thorium, and uranium content in the zone. If the density log had a lower reading compared to a typical shale and an increase in the neutron log percentage then it is determined to be a flooding zone shale. The density logs showed a reading as low as 2.0 g/cm^3 (30% density porosity) and a neutron porosity reading upwards of 3

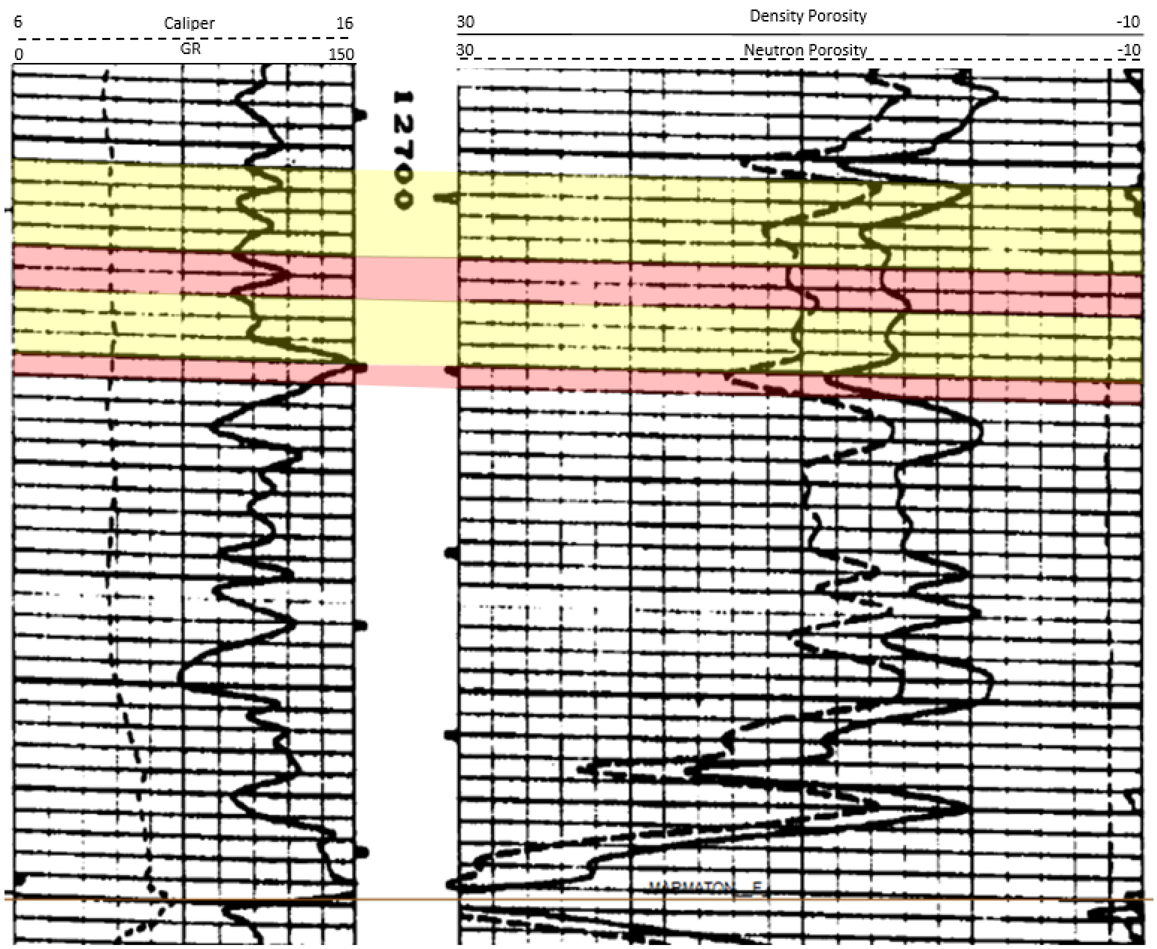

Figure 17: Mobil-Edler #2 well log with associated facies present. Yellow outline is representing sandstone facies, Red outline is representing conglomerate facies.

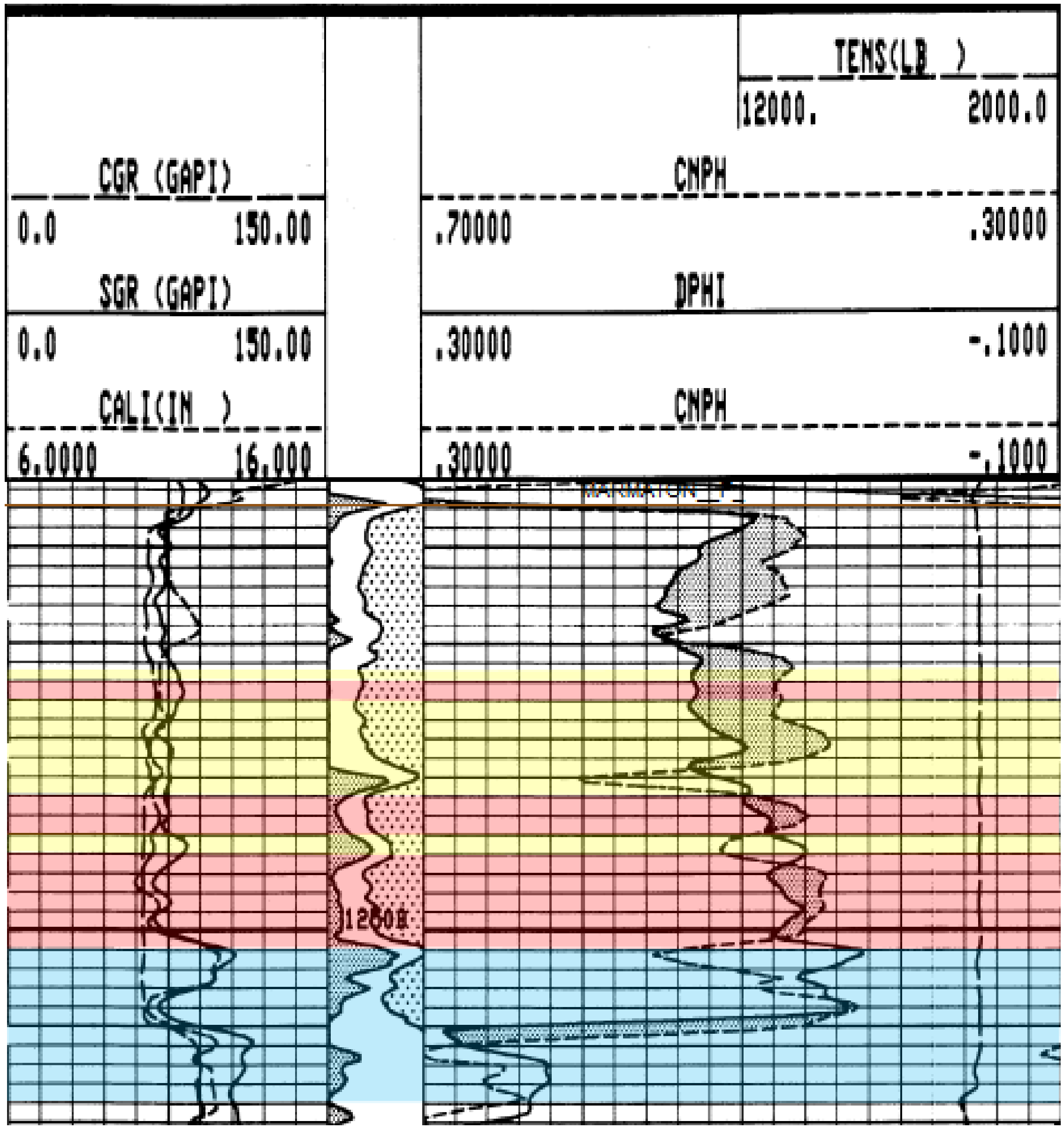

Figure 18: Clements-Littke #1 well log with associated facies present. Yellow outline is representing sandstone facies, Red outline is representing conglomerate facies, Blue outline is representing shale facies.

CROSS SECTION

Several well-to-well cross sections were constructed from the well logs used in the study area (Figure 19). Cross section A – A’ is a stratigraphic cross section of the Marmaton Group running from west to east across the northern distal end of Washita County (Figure 20). The datum for every cross section is the Upper Skinner Shale, this is the base of the Marmaton Group and the first top picked in each well. This stratigraphic cross section is traveling across several faulted areas within Washita County, including two known faulting areas stretching from west to east in the county, the Mountain View Fault and the Cordell Fault in Washita County (Ball et al., 1991). This cross section contains stacked intervals of arkosic sandstones, conglomerates, and shales. These sediments were being deposited in marine deposition settings in the distal lobe. There are six Marmaton intervals: Marmaton A, B, C, D, E, and F. The Marmaton Group experiences several thinning and thickening episodes. These thinning and thickening episodes can be associated with the interval above or below the interval in question, or the interval can act independently due to several reasons, such as more accommodation space that side of a fault for the interval, or the flooding zone shale might be thinner or thicker at the base of the interval. In the western portion of the cross section, the Marmaton Group is at its thickest point at roughly 1,340 feet. In the eastern side of the cross section, the Marmaton Group begins to thin by about 350 feet as it reaches the end of the segment.

The distal lobe, northern end, of the Marmaton Group in Washita County, Oklahoma begins to change in thickness and facies change throughout cross section A – A' (Figure 20). In the distal lobe, two cores were examined which reinforced lithology estimates for the logged intervals. In the cored intervals, a high amount of arkosic sandstone is present with a gamma ray reading of 75 API to 115 API, neutron porosity 8 – 14%, density porosity 0 - 6%. These sandstone intervals are tight porosity and permeability. In the distal lobe conglomerates are still present. The conglomerates have a smaller overall grain size compared to proximal lobe conglomerates. Sandstone is the major facies present in the distal lobe, ranging from coarse to medium sand. In a few wells that are close to the northern Washita County boundary, there is silting out of the arkosic sandstone intervals of the Marmaton Group, beginning to reach the extent of the distal lobe. The mineral assemblage of the distal lobe was examined in thin section, showing a highly arkosic sandstone interval with large amounts of feldspar and lithic fragments. This creates a gamma ray reading for sandstones and conglomerates from 60 – 115 API, neutron porosity 2 – 14 %, and density porosity 0 – 6%. This decrease in gamma ray reading is due to the grain size in the distal lobe becoming smaller and the less potassium content compared to the proximal lobe. The distal lobe API reading can vary. The variance is due to the changing content of paraconglomerates, shale content, and higher potassium content in certain wells that others.

It is known in fan delta systems that sandstone and conglomerate reservoir bodies are limited in horizontal continuity in the subsurface because of the nature of deposition. A turbidite flow or debris flow will not have a wide horizontal extent in the subsurface, which will then relate to little to no correlation of reservoirs between wells. Potential reservoir continuity could be determined for cross section A – A' (Figure 20). Wells API 3514921589 and API 3514921158 are located 3.15 miles apart in northwest Washita County in the distal lobe. It could be determined that continuous reservoirs are contained in the Marmaton F and Marmaton E interval. They show similar log characteristics with both intervals having gamma ray readings between 75 – 90 API for potential clastic reservoirs with density porosity between 0 – 6 %, and neutron porosity 6 – 12% for the Marmaton F and E interval. The Marmaton F interval also contains a shale facies in the middle of the interval, which is present in both wells. Well API 3514921227 located 10 miles to the east of these two wells, none of the correlations are present.

Cross section B – B' is a stratigraphic cross section of the Marmaton Group that travels from west to east in the southern portion of Washita County, Oklahoma and is flattened on the Upper Skinner Shale (Figure 21). Cross section

B – B’ travels along the southern segment of the deep basin axis, and across several known faults. It is located in the more proximal to medial lobe of the fan delta displaying stacked conglomerates, sandstones, and minor shales. The sandstone and conglomerate facies were deposited in a transitional to marine depositional setting. This area of the proximal lobe contains coarser grained sandstones and more conglomerates than that of the distal lobe. Generally, the cross section follows a relatively even thickness for each Marmaton Group interval throughout the cross section, with thickness range between 1,170 to 1,230 feet. This cross section exhibits relatively even thickness of the Marmaton Group intervals from the western portion of the cross section to eastern part of the cross section in southern Washita County, following the general geologic trend of the region, although there are instances of minor thinning and thickening across the segment. The minor thinning and thickening sequences are associated with flooding zone shale thickness changes and minor variations in the Granite Wash interval. The gamma ray reading for cross section B – B’ does not typically become lower than 75 API, neutron porosity 4 – 10%, and density porosity 2 – 4%, representing sandstone facies within the intervals. It does increase in portions to over 130 API in wells, neutron porosity 6 – 10 %, density porosity 4 – 8 % (Figure 21), suggesting higher lithic fragments and potassium content of the proximal lobe, possible conglomerate facies. Throughout the cross section the neutron porosity in the intervals is ranging from 6% - 14 %, and the density porosity ranges from 0% - 10%, indicating tight reservoir quality. These intervals appear to contain more conglomerate zones because it is in the proximal lobe and is closer to the source. There are no observable continuous reservoir bodies between the wells, typical with braided stream systems of the proximal lobe.

Cross Section C – C' is a stratigraphic cross section that extends from north to south in the western part of Washita County (Figure 22). The Upper Skinner Shale is the datum for the stratigraphic cross section C – C'. The cross section travels across the deep basin axis of the Anadarko Basin and crosses several faults. In the northern part of the cross section, the Marmaton Group is at a thickness of 1,350 feet thick, and as it crosses the deep basin axis it begins to thin in all intervals of the group to a thickness of 1,150 feet thick. As the Marmaton Group begins to shallow south of the basin axis, the intervals begin to thicken to 1,320 feet thick as the cross section enters the proximal lobe. In the C end member the cross section shows distal lobe marine depositional environment, and closer the C' end member the Marmaton Group was being deposited in the proximal lobe in a transitional to marine depositional environment.

In the northern portion of the cross section C – C' (Figure 22), the gamma ray reading ranges between 75 – 120 API, neutron porosity 4 – 8%, and density porosity 2 – 6%. This represents tight sandstone and conglomerate intervals in the distal lobe. With no continuous reservoirs between wells in the cross section. As the cross section reaches the proximal lobe located in southern Washita County, the API rises of over 150 API on gamma ray logs for sandstone and conglomerate zones, neutron porosity 4 – 12%, and density porosity 0 – 8%. With varying gamma ray responses in wells, it corresponds to several zones of potassium and lithic-fragment rich conglomerates and coarse arkosic sandstones that is seen in well log responses, as seen by the neutron porosity ranging 10% - 20%, and density porosity 0% - 8% for sandstone and conglomerate intervals. These neutron porosity and density porosity readings coincide with sandstone and conglomerate readings, not shale. In cross section C – C' there are no observed continuous reservoir characteristics between the well logs observed in Washita County.

Cross section D – D' is a stratigraphic cross section that is located in the eastern portion of Washita County and moves in a north to south direction (Figure 23). The stratigraphic cross section's datum is the Upper Skinner Shale. The cross section travels across the deep basin axis of the Anadarko Basin and cross several faulting areas within this segment. In the northern portion of the county, it is at its thinnest within the cross section at 1,000 feet thick. As the cross section travels south towards the basin axis, the Marmaton Group experiences minor thinning and thickening of intervals, from 1,000 feet to 1,350 feet thick. As it reaches the proximal lobe and southern side of the basin axis, the cross section begins to thicken dramatically, to ~1,350 feet thick. The cross section travels across the Cordell Fault, Mountain View Fault Zone, and the basin axis which influences thickening and thinning of the Marmaton Group throughout the cross section. In the D end member the cross section shows distal lobe marine depositional environment, and closer the D’ end member the Marmaton Group was being deposited in the proximal lobe in a transitional to marine depositional environment.

The gamma ray reading in cross section D – D’ is depressed compared to other portions of the county because most of the wells in this area have been fully cased through the Marmaton Group for borehole stability (Figure 23). An open hole log the gamma ray reading follows the typical Marmaton Group readings of 75 – 115 API (ex. well no. 3514921184, Figure 21) within in the southwestern portion of the county. The neutron porosity for this well. The cased wells show the Granite Wash has gamma ray readings of 50 – 75 API (ex. well no. 3514921320, Figure 23). A cased well will damper the gamma ray reading because the radiation travels through a resistant layer, not giving the true reading as an open hole gamma ray log would. The neutron porosity and density porosity logs are the same even though the well is cased. The neutron porosity ranges from 4% - 12%, density porosity ranges from 0% to 8% in cross section D – D’ from the proximal to distal lobe (Figure 23). No known continuous reservoirs are present in the cross section between wells.

Overall, as the fan delta traverses into the basin axis from proximal to distal (Figure 3) the Marmaton Group experience several changes in the electrofacies (Figure 22 and Figure 23). The lithology in the medial lobe consists of tight stacked sandstone, conglomerate, and shales, as indicated by the well logs in the study area. Towards the southern portion of Washita County (proximal lobe), the Marmaton Group is at its thickest and contains more conglomerates and sandstones, and minor shales as determined by the well logs. The proximal lobe has higher grain size due to close deposition of the sediment as it is shed off of the Amarillo-Wichita Uplift. Depositional environment of the proximal lobe is considered to be alluvial fans, braided streams, and debris flows. The lithology in the proximal lobe is highly arkosic with large amounts of potassium since there has been little time for weathering away of the potassium yet, since it is adjacent to the Mountain View Fault System. As determined by thin sections in the distal lobe that contain arkosic sediment.

As the Marmaton Group sediments were deposited north and enter the center of Washita County you leave the proximal lobe and enter the suspected medial lobe (Figure 22 and Figure 23). The medial lobe is still comprised of highly arkosic sandstone and conglomerates, with increases in shale content and more prominent flooding zone shale. The Marmaton Group travels over the Cordell Fault and is subject to thickness changes due to accommodation space. In the medial lobe, the potassium begins to weather away more due to further sediment transport but is still considered highly arkosic sediment. This is seen by the decreasing gamma ray API readings from the southern portion of Washita County towards the central section. The neutron porosity and density porosity stay consistent throughout Washita County. Neutron porosity ranging from 4 – 12%, and density porosity 0 – 8% in the county, representing tight sandstone and conglomerate reservoirs. The mineral assemblage of the medial area has a high potassium content, but less than that of the proximal lobe as noted by the decrease in the gamma ray reading (<130 API). Correlation was determined primarily from the neutron porosity and density porosity. Volcanic and plutonic lithic fragments are still present in conglomerates and sandstones in the medial lobe, and grain size appears in the well log to slightly decrease as the sediment is transported further away from the source.

In northern Washita County the distal lobe of the Marmaton Group Granite Wash is present. In the distal lobe the Marmaton Group consists of tight stacked conglomerates, sandstones, and shales as determined by cores and well logs. The distal lobe was deposited by turbidite and debris flows (Mitchell, 2011). Depositing facies that have a finer grain size than that of the proximal and medial lobe, which consists of coarse sand and conglomerates, as noted in Cross

Section C-C' and D-D' (Figure 22 and Figure 23). As the sediments travel further into the county, the grains will continue the weathering process, decreasing grain size in the distal lobe. The mineral assemblages in the distal lobe are highly arkosic with high amounts of potassium feldspar and lithic fragments in the conglomerates and sandstones of the distal lobe Marmaton Group. This is determined by comparison to the cores examined and the corresponding well logs for the cores. The well logs associated with the cores were able to show that the gamma ray API readings were high in the sandstone and conglomerate intervals, which should be the typical reading for distal lobe rock facies, consisting of gamma ray readings ranging 75 – 120 API for sandstone and conglomerate reservoirs in the distal lobe, with neutron porosity 4 – 8 %, and density porosity 2 – 4%. The neutron porosity and density porosity are consistent for the reservoir bodies between wells, unlike the varying gamma ray.

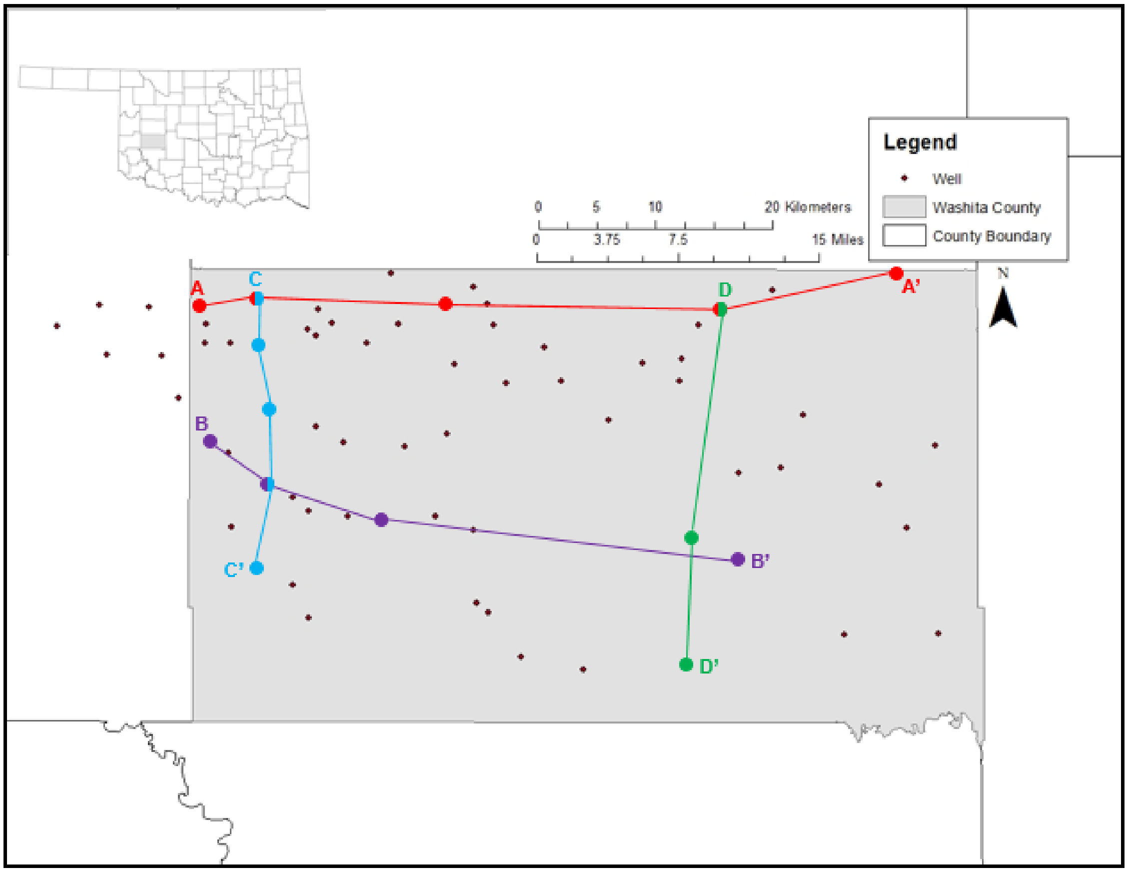

Figure 19: Map of well to well cross sections within Washita County, Oklahoma. Washita County highlighted in grey on state map.

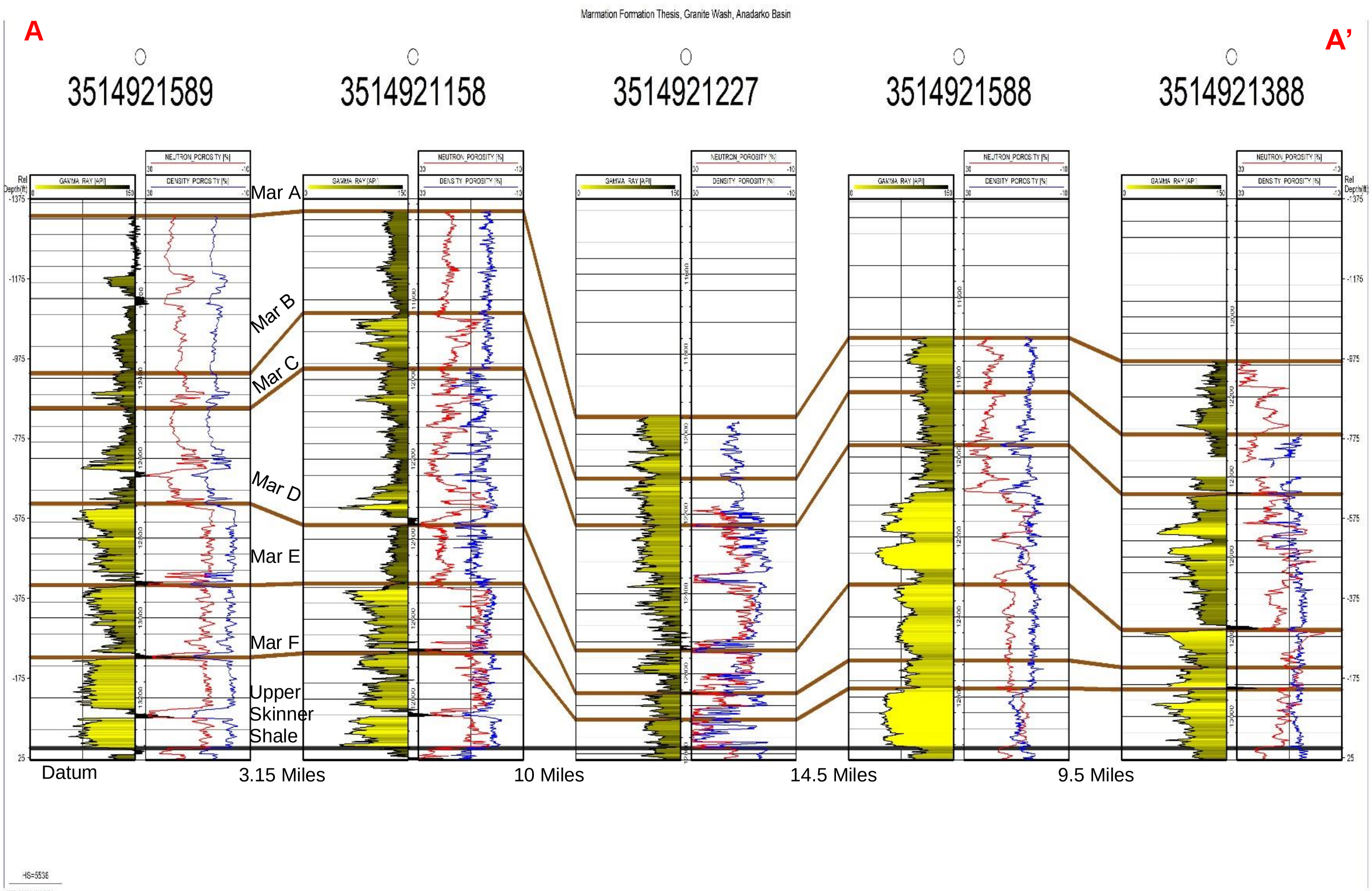

Figure 20: Cross Section A - A'. Stratigraphic cross section of the Marmaton Group, Washita County, Upper Skinner Shale Datum

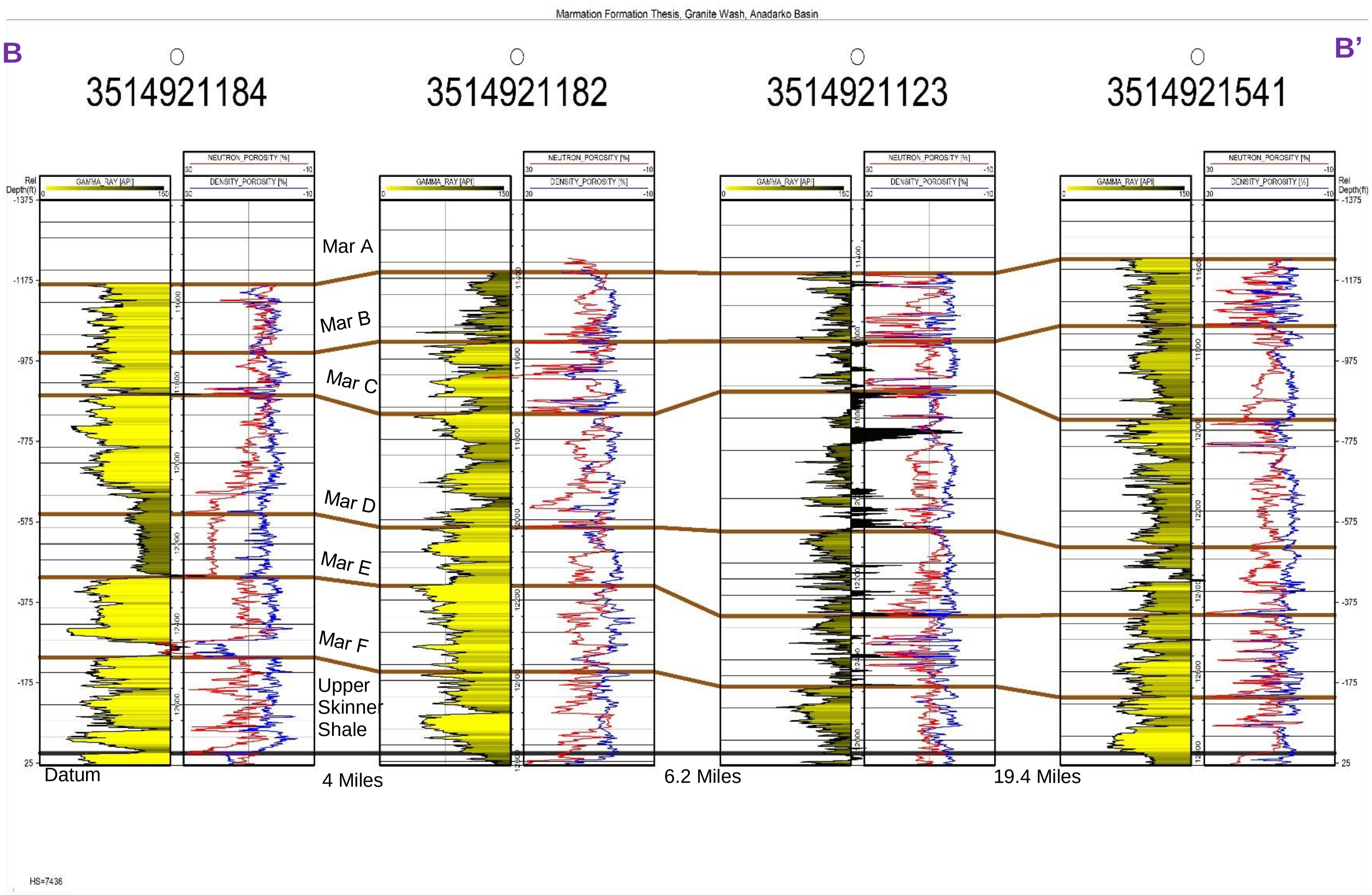

Figure 21: Stratigraphic Cross Section of the Marmaton Group, south Washita County, Upper Skinner Shale Datum.

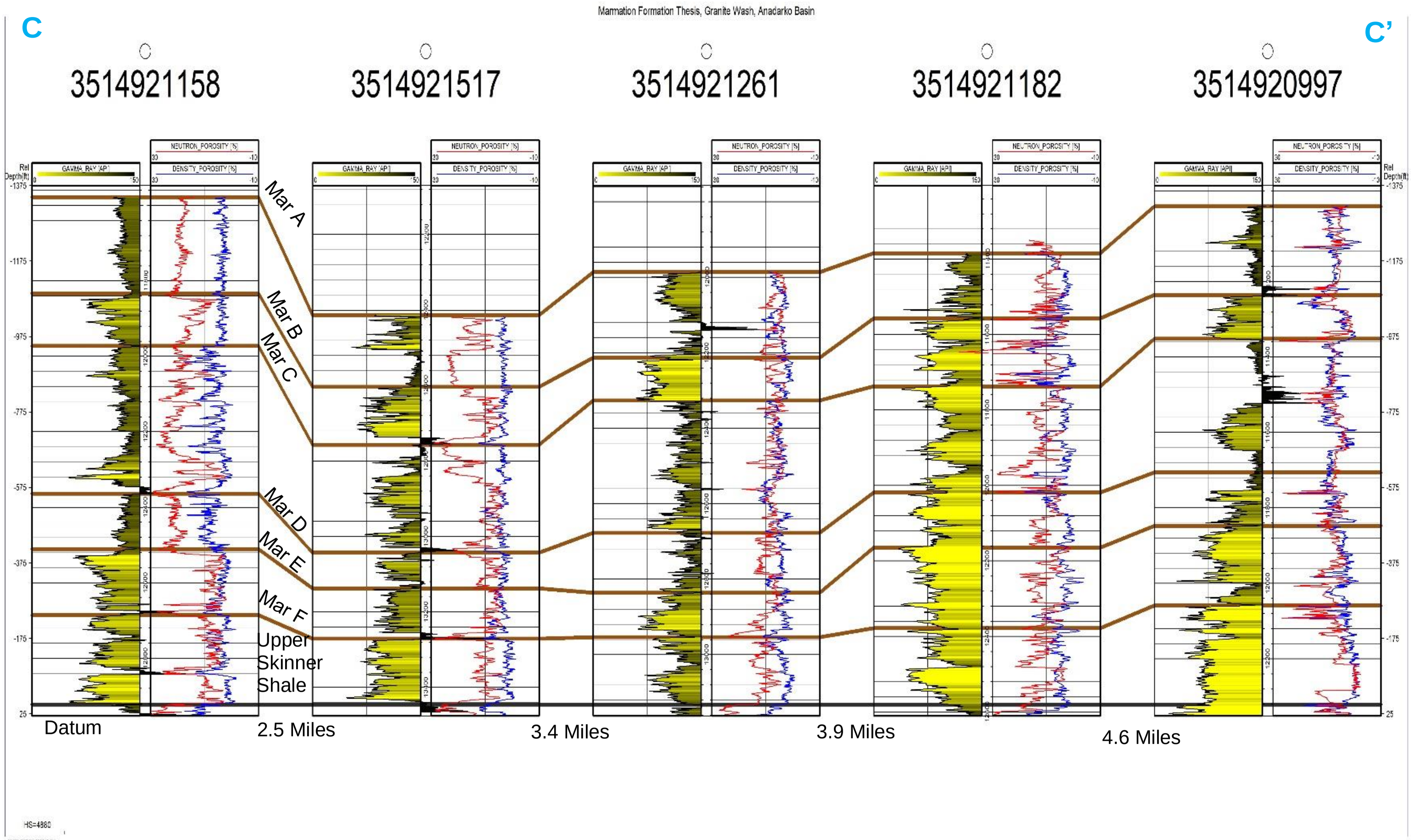

Figure 22: Stratigraphic Cross Section of the Marmaton Group, western Washita County, Upper Skinner Shale Datum.

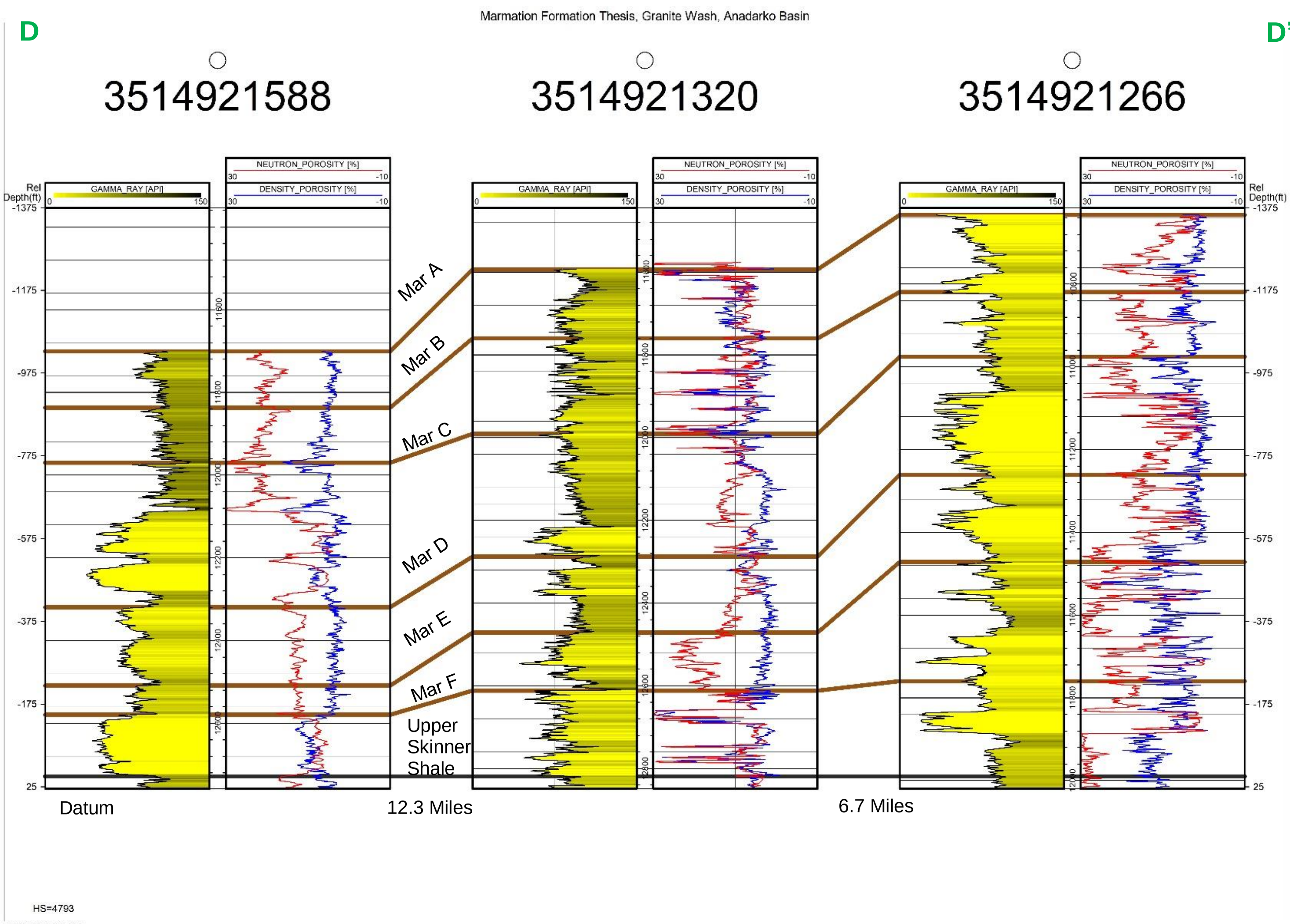

Figure 23: Stratigraphic Cross Section of the Marmaton Group, eastern Washita County, Upper Skinner Shale Datum

APPARENT THICKNESS AND STRUCTURE MAPS

Marmaton F Interval Apparent Thickness Map

The first interval in stratigraphic order within the group is the Marmaton F interval. The Marmaton F interval apparent thickness map was created in ArcGIS to show the thickness of the interval throughout Washita County, Oklahoma (Figure 24).

In the south, the thickness of the Marmaton F interval is the greatest, with its thickest point of 400 feet located adjacent to the Mountain View Fault. From the southern portion of the county heading north (north of the Mountain View Fault), it starts to thin and deepen into the deep axis of the Anadarko Basin in the middle of the county. Before it reaches the basin axis, there is thickening associated with the Cordell Fault, which also aids in subsidence of the basin axis.

Along the basin axis, this southern portion of the Marmaton F forms a lobate structure. The thickness of the Marmaton F interval thins as it enters into the basin axis. It drops from 400 foot thick at its thickest portion, down to 150 foot thick along the basin axis and the center and eastern portions of the county. In the northwest portion of the county it begins to thicken again, particularly adjacent to unnamed fault within the county. In the north central portion of the county, the Marmaton F interval thins to 100 feet in areas.

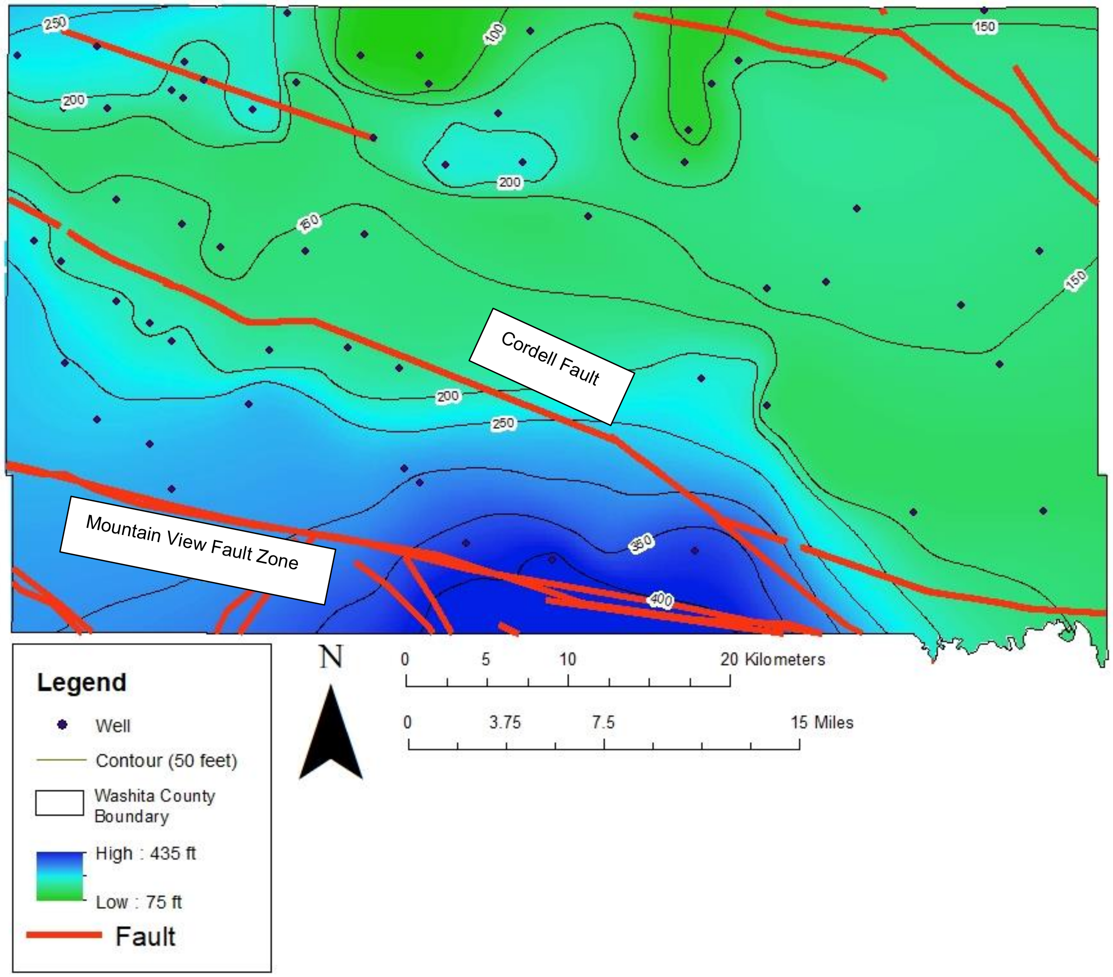

Figure 24: Marmaton F interval apparent thickness map, Washita County, Oklahoma. Faults created from OPIC fault database (2016) and Ball et al (1988).

Marmaton E Interval Apparent Thickness Map

Sitting above the Marmaton F interval is the Marmaton E interval (Figure 25). Adjacent to the Mountain View Fault, the thickest section of the Marmaton E is upwards of 300 foot thick in the southern area of Washita County. From the proximal area of 300 feet it begins to cross over the Cordell Fault and then thins towards the basin axis to 150 ft. The Marmaton E interval follows a lobate fan delta depositional pattern as it drops into the basin axis. North of the basin axis, the primary thickness throughout the upper portion of the county is 150 foot thick. In the center of the northern portion of the county there are instances of the thickness increasing up to 200 foot thick in areas. An isolated thinning area is located in west central Washita County where the Marmaton E interval thins to 100 feet thick. In the northwest portion of Washita County the thickness of the Marmaton E interval rises to 200 foot thick, on the west side of an unnamed fault. Towards the northern end and northeastern boundary of Washita County the Marmaton E interval beings to thin out to 100 foot thick in portions. These thickness packages are variable, and are adjacent to either the basin axis or unnamed fault zones in the county.

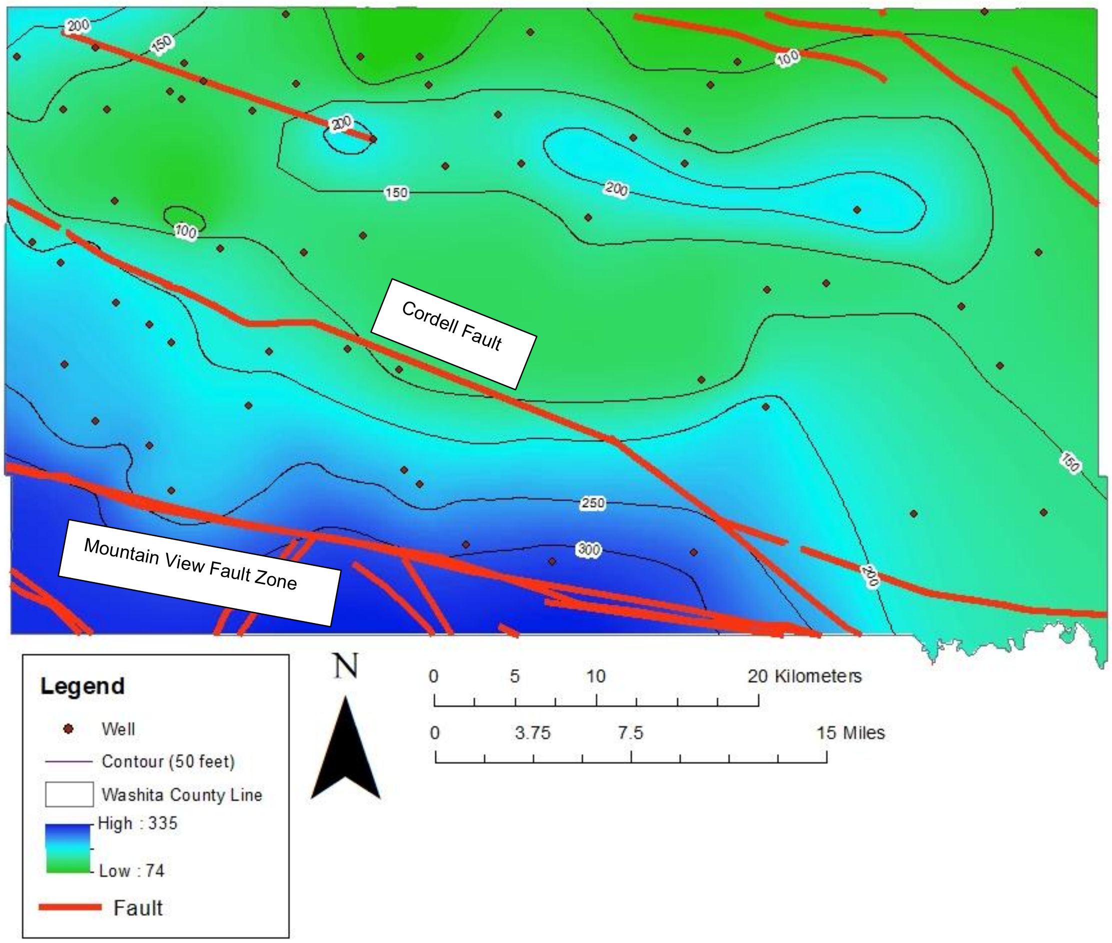

Figure 25: Marmaton E interval apparent thickness map, Washita County, Oklahoma. Faults created from OPIC fault database (2016) and Ball et al (1988).

Marmaton D Interval Apparent Thickness Map

The Marmaton D interval conformably overlies the Marmaton E interval (Figure 26). In the southwestern portion of Washita County the interval is at 250 foot thick adjacent to the Mountain View Fault. Rapidly thinning to 200 foot thick in the proximal lobe throughout the southern portion of Washita County. The proximal lobe thins to 150 foot thick throughout the center of Washita County, south of the Cordell Fault.

At some of the center points of the 200 foot thick portions the max thickness can reach up to 250 foot thick for the Marmaton D interval. These areas of thickening are located near the Cordell Fault. In the northwest and central to north central portions of Washita County the Marmaton D interval thickens from 150 foot to 200 foot thick. North of these thickening, the Marmaton D interval begins to thin. In the northwest section of the county there is a section of thinning to 100 foot thick. In the north central and northeast parts of Washita County the Marmaton D interval begins to thin to 150 feet and thins to its lowest of 100 foot thick at the county boundary. The thinning and thickening of the Marmaton D are typically adjacent to the basin axis, or are associated with unnamed faults within the northern portion of the county.

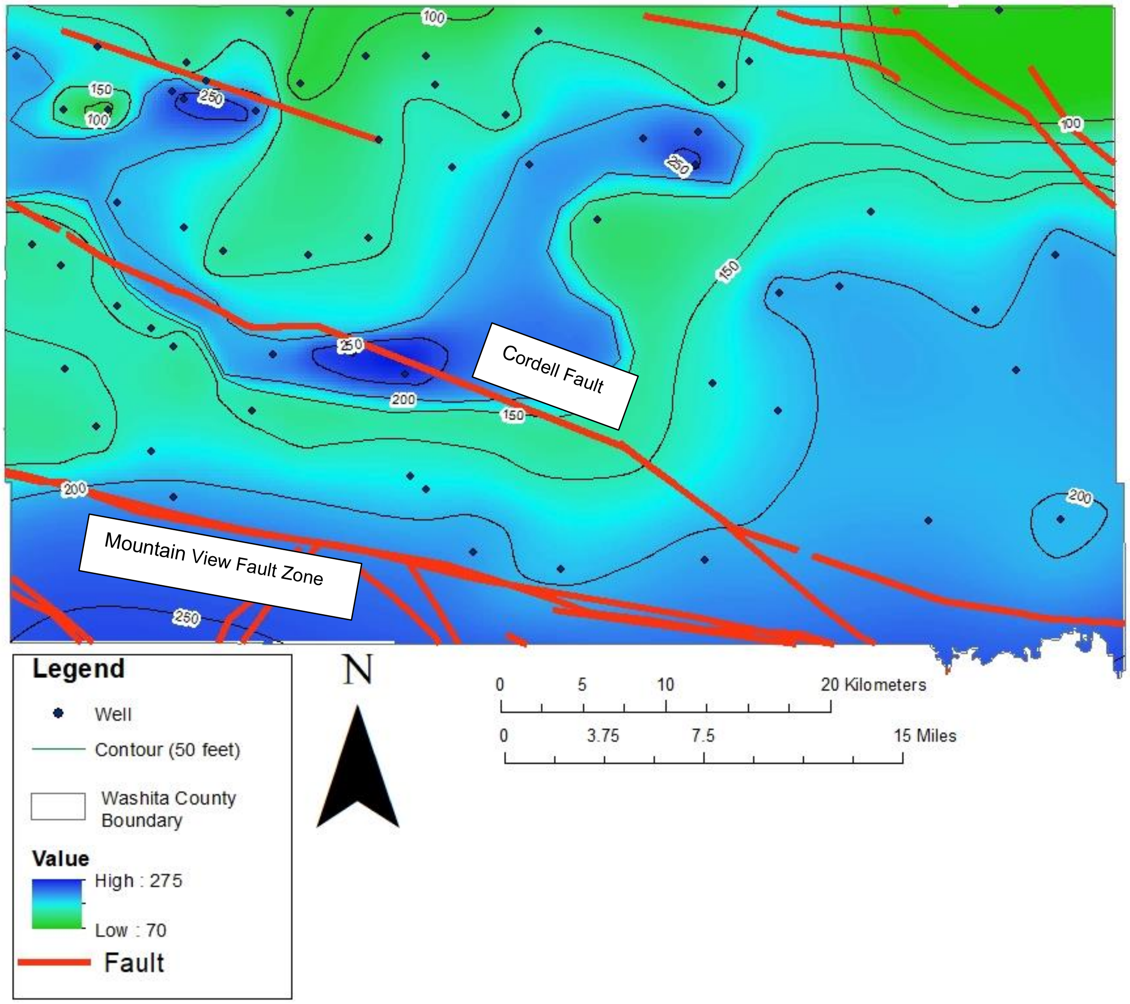

Figure 26: Marmaton D interval apparent thickness map, Washita County, Oklahoma. Faults created from OPIC fault database (2016) and Ball et al (1988).

Marmaton C Interval Apparent Thickness Map

On top of the Marmaton D interval is the Marmaton C (Figure 27). The thickest portion of the Marmaton C is located in the southwestern part of the county, adjacent to the Mountain View Fault. This area has a greatest thickness of 450 feet and begins to thin into the basin towards the north. The Marmaton C thins to a total thickness of 300 foot thick south of the basin axis around the Cordell Fault. It thins from a west to east profile of 450 feet to 300 feet thick. The Marmaton C interval thins to 200 foot thick throughout the center of Washita County.

As the Marmaton C interval comes out of the basin axis and comes structurally up dip, the interval begins to thicken throughout parts of the county. In the northwest portion of the county, the Marmaton C interval thickens from 300 foot thick to 400 foot thick. In the northeastern portion of Washita County the Marmaton C interval thickens to 350 thick from a broad plane of 300 foot thick interval thickness. These thinning and thickening episodes of the northern distal lobe are associated with unnamed faults in the area.

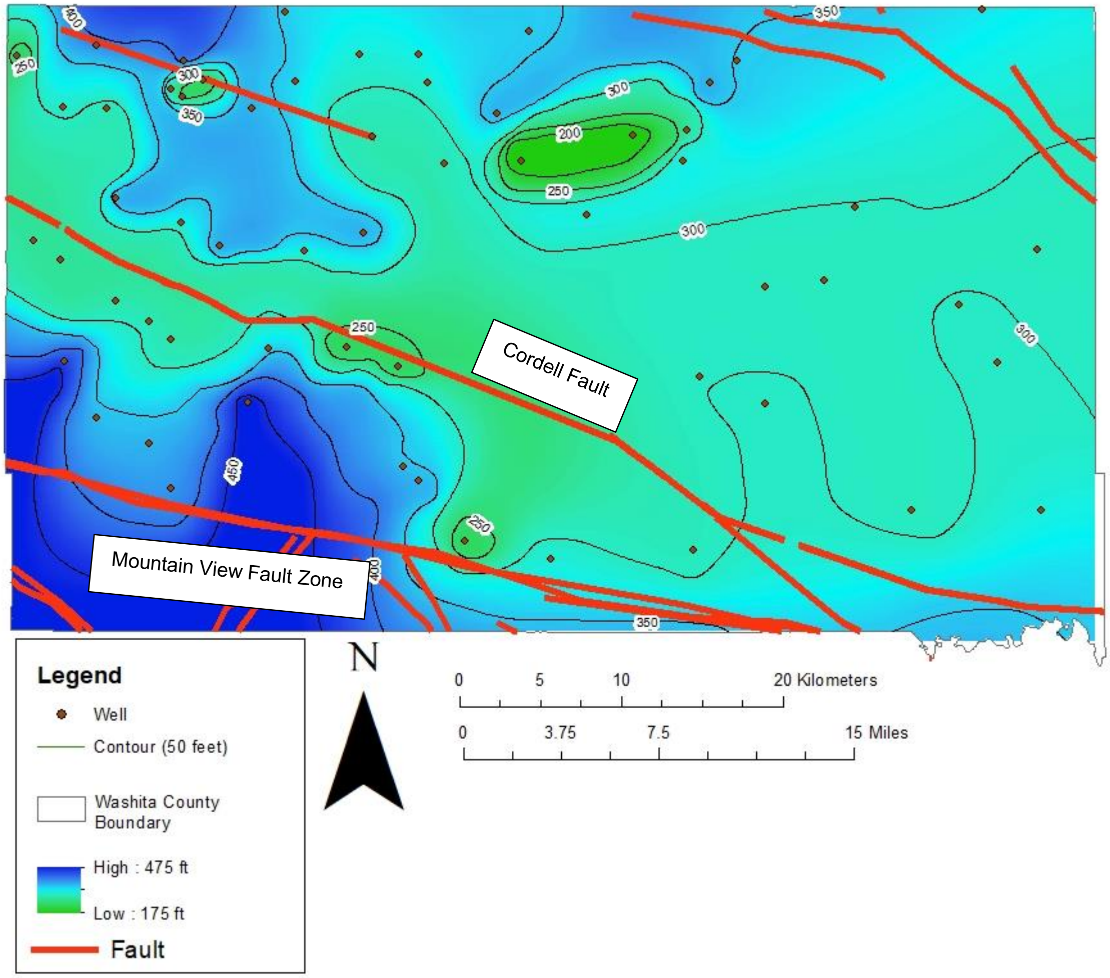

Figure 27: Marmaton C interval apparent thickness map, Washita County, Oklahoma. Faults created from OPIC fault database (2016) and Ball et al (1988).

Marmaton B Interval Apparent Thickness Map

The Marmaton B interval overlies the Marmaton C interval (Figure 28). The thickest portion of the Marmaton B interval in Washita County is located in the south north of the Mountain View Fault. Towards the southeast part of Washita County the Marmaton D has a range thickness form 200 to 250 foot thick. The primary thickness of the proximal lobe is 150 thick throughout the southern portion of the county adjacent to the Cordell Fault.

As the Marmaton B interval comes out of the basin axis it begins to thin in portions of the county. In the northeastern part of the county the Marmaton B thins form 150 foot thick to 100 foot thick. In west central Washita County the Marmaton B thins from 150 feet to 50 feet then north of this thinning, it thickens back to 150 foot thick. In the northwestern portion of Washita County, the Marmaton B experiences several thinning and thickening areas from 150 foot thick to 100 foot thick. These northern thickening and thinning areas are affected by the unnamed faults throughout the distal lobe.

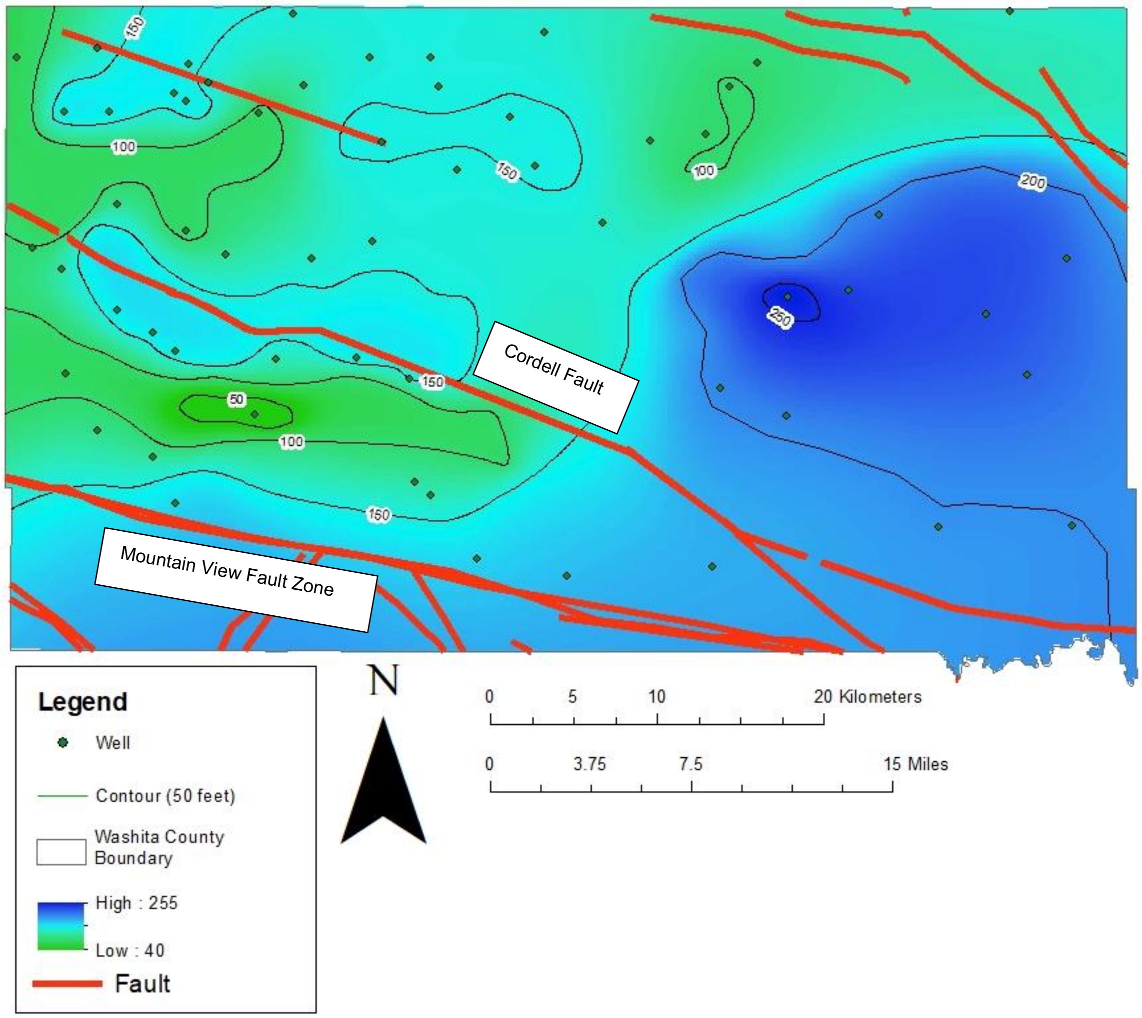

Figure 28: Marmaton B interval apparent thickness map, Washita County, Oklahoma. Faults created from OPIC fault database (2016) and Ball et al (1988).

Marmaton A Interval Apparent Thickness Map

The final interval of the Marmaton Group is the Marmaton A that overlies Marmaton B interval (Figure 29). The thickest segment of the Marmaton A interval is in southern portion of the county, adjacent to the Mountain View Fault. The Marmaton A interval starts to thin towards the basin axis in the center of the county, from 350 foot thick in the south to 200 foot thick rapidly towards the center of the county as it reaches the Cordell Fault. It is then has consistent thickness of 150 throughout the center portion of the county around the Cordell Fault. North of the Cordell Fault there is some thickening of the Marmaton A interval. To the northwest, the Marmaton A interval thickens from 200 foot thick to 350 foot thick in the very far northwestern portion of the county. The Marmaton A just to the east of this thickening segment experiences thinning to 150 foot thick. In the north central part of the county, the Marmaton A thickens from 200 feet to 250 feet. In the northeastern part of the Washita County, the Marmaton A interval thins to 150 foot thick as it starts to contact the county boundary. All of the northern portion thinning and thickening are associated with unnamed faults.

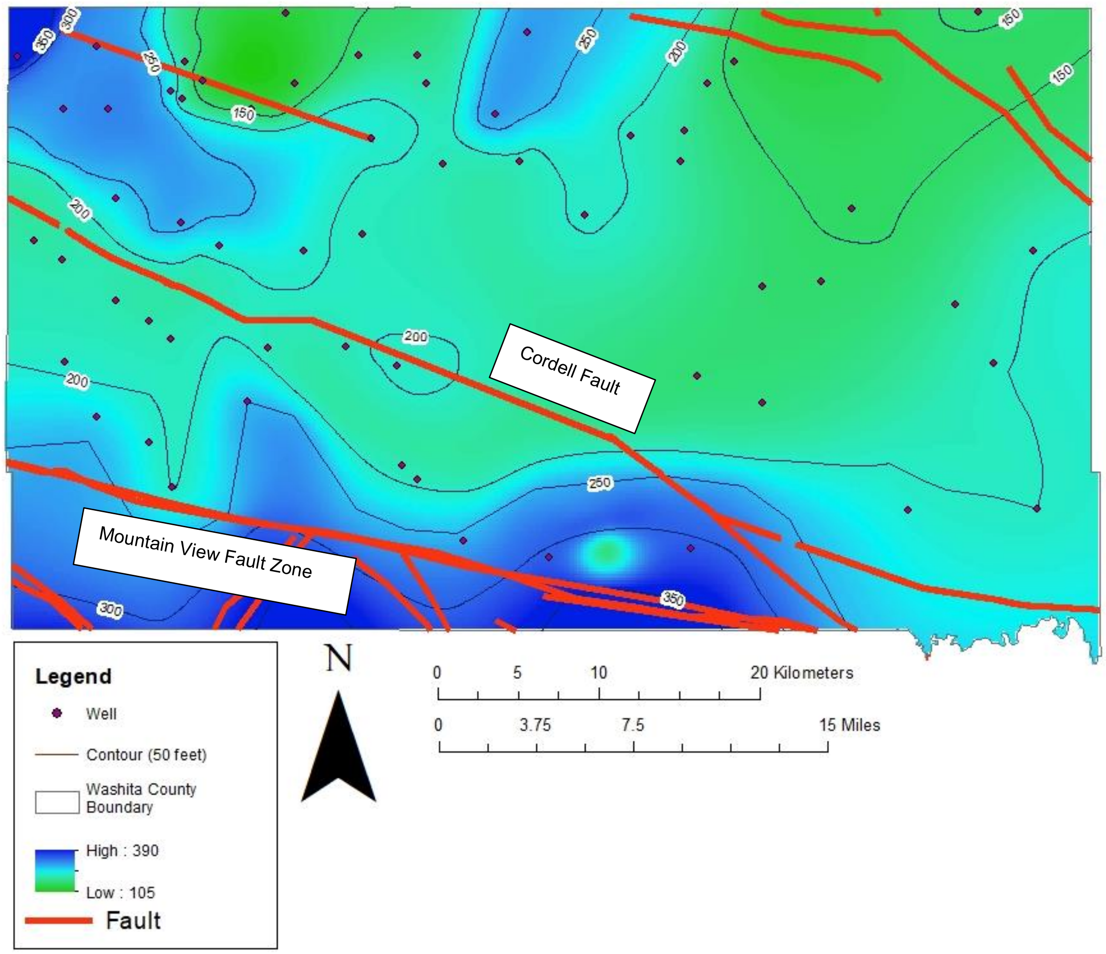

Figure 29: Marmaton A interval apparent thickness map, Washita County, Oklahoma. Faults created from OPIC fault database (2016) and Ball et al (1988).

Total Marmaton Group Apparent Thickness Map

The Marmaton Group is composed of the Marmaton F, E, D, C, B, and A interval (Figure 30). Overall, it follows the trends of the previous apparent thickness maps. The thickest portion of the Marmaton Group is located at the county boundary in the southern portion of Washita County, adjacent to the Mountain View Fault. The greatest thickness is 1,900 foot thick. It begins to thin, from 1,900 foot thick to 1,200 foot thick as it reaches the Cordell Fault.

As it enters the center of the county north of the Cordell Fault, the Marmaton Group thins to an overall thickness of 1,200 feet. With the overall thickness in the center of the county of 1,200 feet, there are some instances of thinning to 1,000 feet. In areas within the center portion of the county the Marmaton Group thins to 1,100 feet of 1,000 feet in thickness. In the northwest part of Washita County towards the county boundary the Marmaton Group thickens to 1,400 foot thick from 1,200 feet. In the north central segment of Washita County the Marmaton Group thins to 900 feet from 1,200 feet. In the northeast part of Washita County, the Marmaton Group thins to 1,000 feet from 1,200 feet as it exits the county.

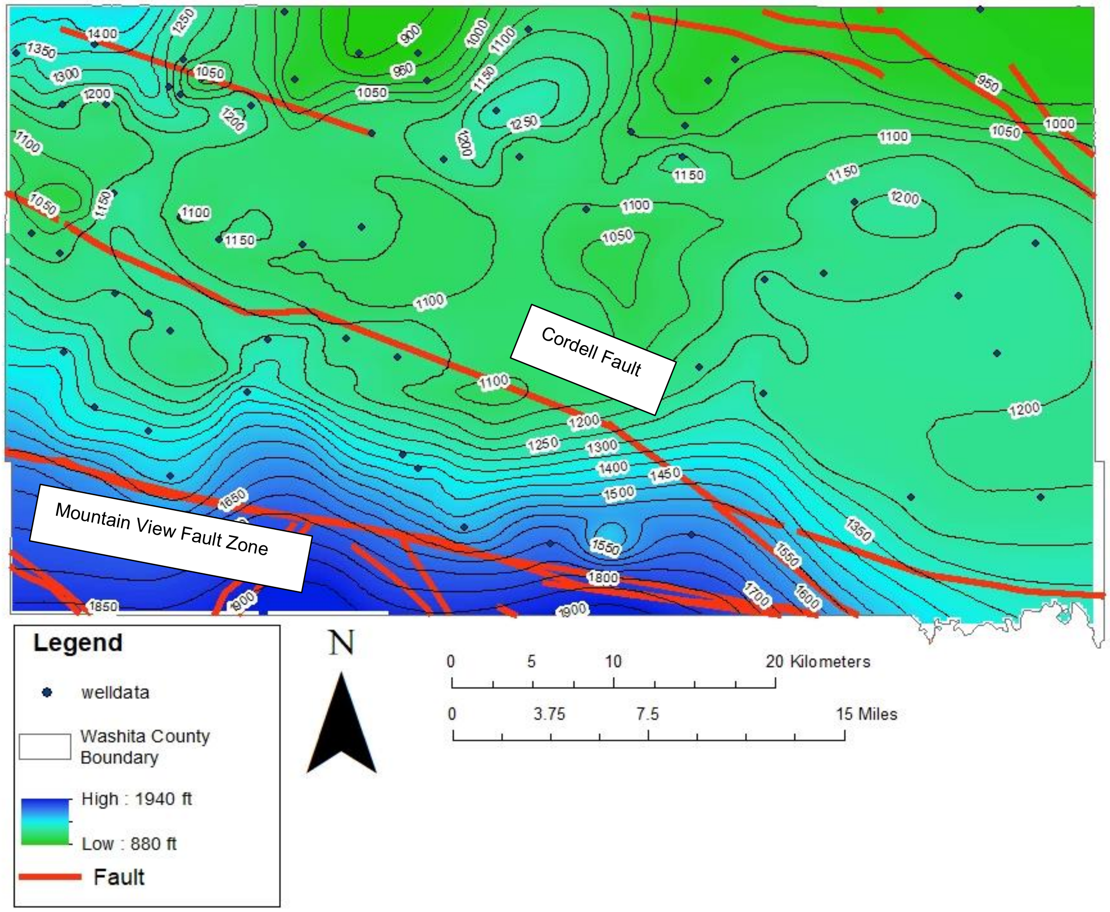

Figure 30: Marmaton Group apparent thickness map, Washita County, Oklahoma. Faults created from OPIC fault database (2016) and Ball et al (1988).

Upper Skinner Shale Structure Map

The formation below the Marmaton Group is the Upper Skinner Shale, creating the base of the Marmaton Group. A structure map was created to show how the base of the Marmaton Group varies in the subsurface (Figure 31). The ancient Amarillo-Wichita Uplift is towards southern portion of Washita County and the Mountain View Fault System runs west to east across the county. Overall, the Upper Skinner Shale surface strikes east-west, and dips towards the center of the county where the Anadarko Basin axis lies, and is up-dip from this center towards the north.

In this south, the structural depth of the Upper Skinner Shale starts at 10,500 feet below sea level across southern Washita County. The Upper Skinner Shale then deepens towards the north into the basin axis, reaching a depth of 11,300 ft below sea level. It then gradually decreases towards the north to 11,100 ft below sea level. There are two areas of deepening of the Upper Skinner Shale in structure depth in north central and northeast parts of the county. In the north central part of the county, the structure depths drops to 11,200 feet. In the northeast portion of the county, the structure depth drops to 11,300 feet.

The Upper Skinner Shale structure map shows the general trend of the basin axis. In the southern portion, the Upper Skinner Shale drops into the deep basin axis, this could coincide with the thicker proximal lobe that lies above it. When it reaches its deepest depth in the basin axis, the Marmaton Group is at its thinnest point. North of the basin axis, the Upper Skinner Shale rises in structural depth, which coincides with thickening and thinning episodes of the overlying Marmaton Group.

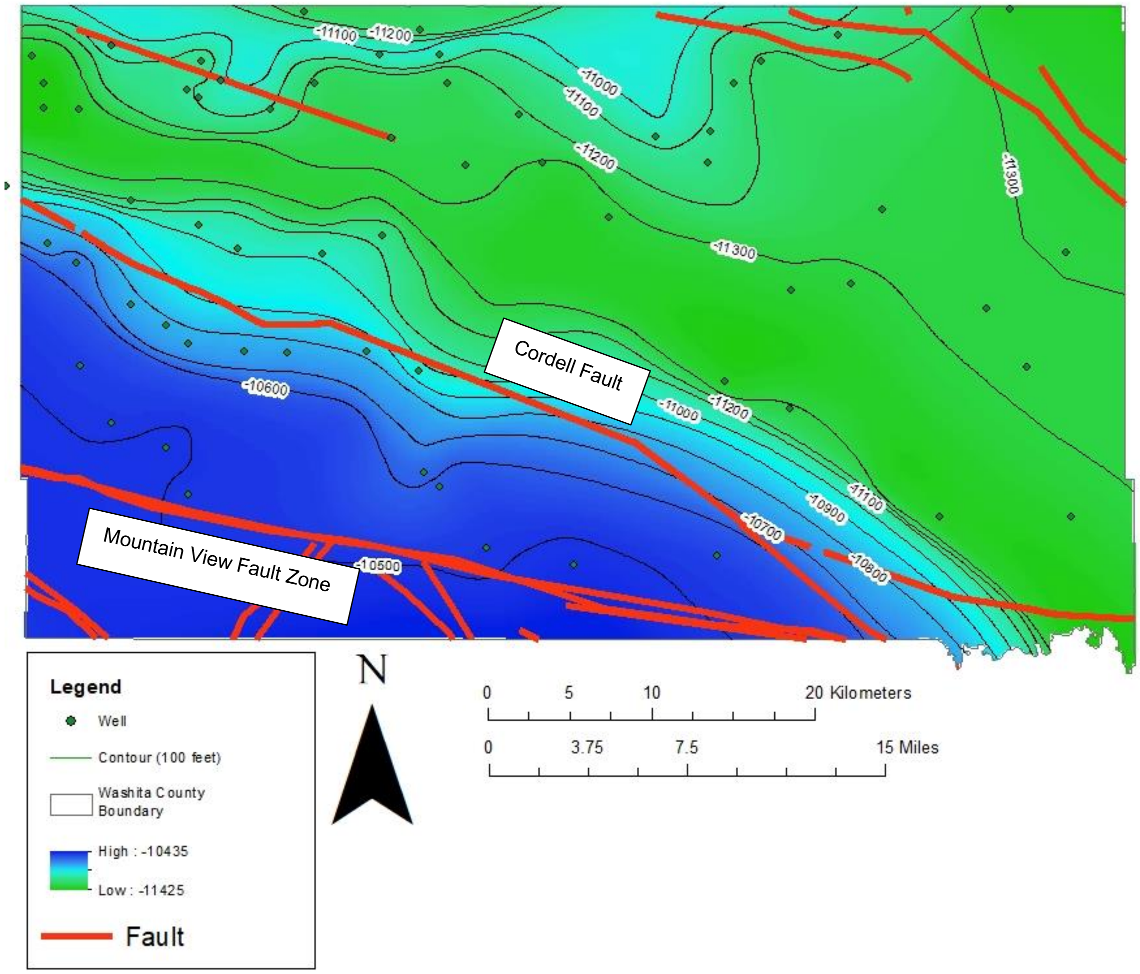

Figure 31: Upper Skinner Shale Structure Map, base of Marmaton Group, Washita County, Oklahoma. Faults created from OPIC fault database (2016) and Ball et al (1988).

Marmaton A Interval Structure Map

A structure map was created of the Marmaton A interval to represent the top structure depth of the Marmaton Group (Figure 32). Towards the southern portion of Washita County is the ancient Amarillo-Wichita Uplift and the Mountain View Fault System running in a west to east direction. The Marmaton A has a strike that runs relatively east-west, and dips towards the north into the center of the Anadarko Basin located in central Washita County. It then shallows towards the north, coming up out of the basin.

Across Washita County, the depth of the Marmaton A starts at 8,600 ft below sea level in the south, stretching across the southern portion of the boundary. The Marmaton A interval then rapidly deepens to 10,300 ft below sea level towards the north, into the basin axis. In the northern portion of Washita County, the structure depth of the Marmaton A interval starts to gradually shallow to 9,600 feet below sea level in the northwest and north central part of the county. In the east central portion of the county the Marmaton A interval shallows to 10,100 feet. North of this rise it drops back to 10,200 feet below sea level. Towards the northeast, the Marmaton A interval again deepens to 10,500 feet below sea level.

The Marmaton Group A Interval structure map follows a similar pattern as the Upper Skinner Shale structure map. The structural depth drops down into the basin axis, which coincides with the thicker Marmaton intervals in the proximal lobe. North of the basin axis, the Marmaton Group A interval begins to rise up the northern flank of the basin axis. An instance of deepening occurs in the northeast corner of Marmaton County, most likely due to faulting in the area from unnamed faults in northern Washita County.

Both of the structure maps show similarities in structural depth changes throughout Washita County, Oklahoma, with deepening into the basin axis in structural depth and then rising out of the basin axis towards the north. As the Marmaton Group enters the north flank (distal lobe) of the basin axis, the structural depth begins to rise as it heads towards the northern side of the Anadarko Basin. The irregularity in the Marmaton A structure map in northeastern Washita County could be due to more rate of subsidence in the Marmaton Group in the area.

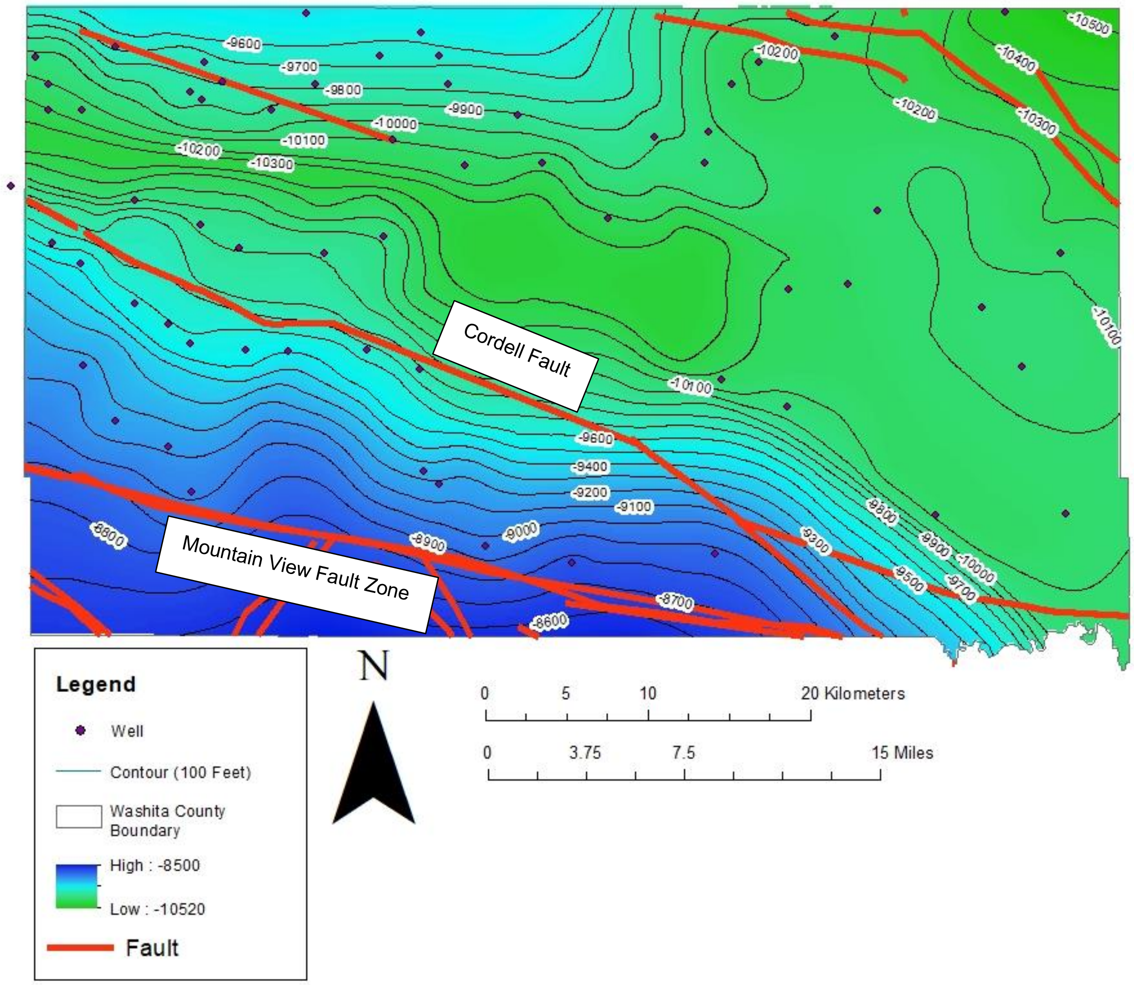

Figure 32: Marmaton A Interval Structure Map, top of Marmaton Group, Washita County, Oklahoma. Faults created from OPIC fault database (2016) and Ball et al (1988).

INTERPRETATION

Depositional Interpretation

The Pennsylvanian Marmaton Group was deposited in a fan delta system (Mitchell, 2014). A fan delta system is complex, consisting of a variety of depositional environments and stratigraphic features, including a proximal lobe of the fan delta being an alluvial fan to transitional environment, a medial lobe consisting of shallow marine deposits, and the distal lobe consisting of deep marine turbidite flows and sands (Figure 3 and Figure 30). From the proximal lobe to the distal lobe, the mineral composition within the Marmaton Group is arkosic overall. This was determined by the well log responses reacting with arkosic nature sandstones and conglomerates, confirmed by the thin section analysis. A variety of facies variations from primarily conglomerate with coarse sandstones and minor shales in the proximal lobe and towards the distal lobe the facies change to less conglomerates with coarse-to-fine grained sandstones with more shale content (Figure 9 A through E). The arkosic sediment is sourced from the Amarillo-Wichita Uplift (Mitchel, 2011). Although these sediments are typically unstable at the surface, they are transported only a short distance into the Anadarko Basin (Figure 1 and Figure 3).

The two types of conglomerates (orthoconglomerates and paraconglomerates) examined in Mobil-Edler #2 and Clements-Littke #1 cores were deposited by turbidite flows and debris flows in the fan delta. The orthoconglomerates are grain-supported, consisting of grains up to 5 inches in diameter, although typically range from ¼ inches to 4 inches (Figure 9 A and B). There are accounts of orthoconglomerates containing up to 1 foot in diameter boulders in the Marmaton Group (Mitchell, 2011). These orthoconglomerates were deposited in a variety of depositional environments including: alluvial, fluvial, transitional, and shallow marine environments. This is due to the higher energy of the proximal systems to carry the larger cobble to boulder size grains in the fan delta system (Mitchell, 2011). When sea level was lower and the shoreline was further north, orthoconglomerates were also deposited into the distal lobe, as the high energy environments were able to transport the gravel sediment further north. In the core, the orthoconglomerates sometimes contained silt flaser bedding, showing distal deposition or marine reworking. The orthoconglomerates are also typically associated with a fining upward sequence (base of the cores) or a coarsening upward sequence (top of the cores). These sequences are related to a change in sea level. Fining upwards sequences display a rise in sea level as where coarsening upward sequences are characteristics of a drop in sea level. When water levels rise, there is a rise in water energy and when water levels fall, there is a decrease in energy.

Several paraconglomerates are present in the cored intervals (Figure 9 A and B). Paraconglomerates in the cores are mud-supported conglomerates with free-floating 1 inch to ¼-inch gravel to coarse sand-sized grains within the matrix. Some coarse sand intervals are associated in the paraconglomerates. These paraconglomerates show an example of mass wasting events in the proximal to distal lobe that rapidly deposited the mud and gravel into the system. Paraconglomerates can be found in debris flows and proximal to distal turbidite flows, which create primarily matrix supported conglomerates with clasts included in the matrix (Prothero and Schwab, 2013).

There are several types of sandstone intervals throughout the two cores. Coarse to medium sand is present throughout (Figure 9 C), along with sand facies that contain silt or mud laminations (Figure 9 D). They can vary in color from tan to gray due to the depositional environment and change in relative sea level. The gray colored sand is associated with shallow to deep marine depositional environment and relative rise in sea level (Mitchell, 2011). The grain size of the massive, structureless, sandstone intervals varies due to the distance of the sediment from the source giving each interval different grain sizes. A shallow marine to deep marine fan sandstone facies are associated with fining grain size from medium to fine sand as the sediment is transported farther from its proximal source as examined in the cored intervals. The sandstone facies were deposited by proximal to distal turbidite flows (Mitchell, 2011).

Several fining upward sequences consisting of conglomerate (base) to medium sand (top) are present in the cored intervals (Figure 9 A). These fining upwards sequences were deposited by a rise in relative sea level, which begins to deposit finer sediment into the system. These fining upward sequences are affected by fluvial processes, along with tidal and wave processes. The tidal and wave processes have reworked the sand that deposited in the delta and creating planar, flaser, and wavy bedding within the cored intervals. Planar bedding is present in several intervals where sand and silt were deposited, indicating a low energy environment of the fan delta. Flaser bedding occurs when silt has been introduced to the fan delta deposition and is a tidal-dominated area. This creates a sand-dominated interval that has associated flaser cross laminations. Wavy bedding occurs when there is an equal flux of sand deposition along with tidal domination, which creates an equal mix of sand and silt/clay bedding. These beddings are present in medial to distal fan deposits, such as those found the cored intervals (Prothero and Schwab, 2013).

In the Clements-Littke #1 cored well, there is a single section of interbedded mudstone and fine-to-medium sandstone at a depth 12,495 – 12,497 feet (Figure 33). This is a distal fan depositional environment that represents a time of low water velocity and calm tidal changes. There is planar bedding that is present in this interval of interbedded mudstone and sandstone.

Overall, these facies seen in the core represent distal lobe deposition. This is determined by the lesser amount of conglomerate and a higher amount of coarse to medium sand present in the core, along with silt being present. Silt flaser laminations and planar laminated bedding is present, showing a marine reworking of finer sediments.

In northern Washita County, the sediments generally fine as they reach farther away from the source of the sediment in the south. As the sediments begin to fine, they lose some of their radioactive minerals that contain or are associated with potassium, uranium, and thorium, which will decrease the gamma ray well log reading. This decrease in the gamma ray log reading is associated with less arkosic mineralogy in the distal lobe compared to its proximal counterpart, as determined by the core to well log comparison. Beyond Washita County, there are instances of the Marmaton Group to begin to “silt out” (Mitchell, 2011), which is out of our mapped area. The Granite Wash begins to lose its arkosic wedge nature and the main lithology present is siltstone. The gamma ray reading will decrease because the arkosic minerals have weathered away and the main mineral composition is quartz. During this time in the center of the basin the primary deposition was shale, siltstone, and sandstone. In this area is where the Marmaton Wash begins to silt out, or lose its arkosic nature due to a different sediment system (Figure 34)

Within Washita County, there are instances in both cores of silt being introduced into the system as flaser or wavy bedding, causing the gamma ray readings to fluctuate from the silt content. There are no instances of “silting out” described above in these cores. In certain well logs, electrofacies begin to change, not from “silting out” precisely, but rather to finer sediments being present in the rock. As the Marmaton transitions to the fan deltas edge, more silt was introduced to the system by marine reworking. North of our study area, the Marmaton Group is known to change lithology to finer-grained siltstone and shale (Mitchell, 2011). In the core, there is evidence of silt being introduced into the system as wavy bedding due to distal fan reworking.

South of the basin axis, little shale is present in the well logs. In the proximal lobe, the source rock is at such a short distance, less than 10 miles, that the primary lithology is conglomerate to coarse sandstone. The sediments do not weather away fast enough in the proximal lobe to deposit fan delta shales, these are typically distal to prodelta shales. In the proximal lobe, the flooding zone shales can be present but are at their thinnest point due to the high structural relief up structure.

The combination of well log and core analyses further support the overall deltaic depositional interpretation. The southern portion of Washita County is considered the proximal lobe of the fan delta, as indicated by a higher gamma ray reading for suspected conglomerates and sandstones, and minor shales noticed throughout the well logs. In the proximal lobe, the Marmaton intervals are at their thickest, most noticeable adjacent to the Mountain View Fault. The proximal lobe extends to around the Cordell Fault and the deep basin axis, where the distal lobe is begins.

In southern proximal lobe, the Marmaton Group is at its thickest. The thickest portion can be upwards of 1,900 foot thick against the Mountain View Fault System. As the fan delta extends into Washita County, the fan delta follows a lobate structure. The facies that are present in the proximal lobe of the Marmaton Group are large conglomerate intervals, coarse arkosic sandstones, and shales (Figure 25). There have been recorded instances of the conglomerate intervals containing boulder sized lithic fragments in the proximal lobe (Mitchell, 2011). In an open hole logged well in the proximal lobe the gamma ray, reading is typically higher than compared to the distal lobe (Figure 25, API 3514921123). The gamma ray reading can be as low as 75 API in an open-hole, but can reach up to 150 API, due to the higher content of plutonic fragments and volcanic fragments located in the proximal lobe (Figure 25 and Figure 26). The proximal lobe will contain a higher potassium content in the mineral assemblage due to less erosion and weathering in the proximal lobe. Other unstable minerals can be present in the proximal lobe due to rapid subsidence and deposition of the Granite Wash sediments as they are infilling the basin (Mitchell, 2011).

The distal lobe covers the center or Washita County to a little past the northern edge of Washita County. The distal lobe consists of conglomerates, sandstones, and shales. In the distal lobe the sandstones and conglomerates have a slightly lower gamma ray than that of the proximal lobe. This is due to the lessening of the potassium and other minerals found in lithic fragments in the distal lobe. This suggests that the system flows from the south towards the north, from the Amarillo-Wichita Uplift towards the Anadarko Basin.

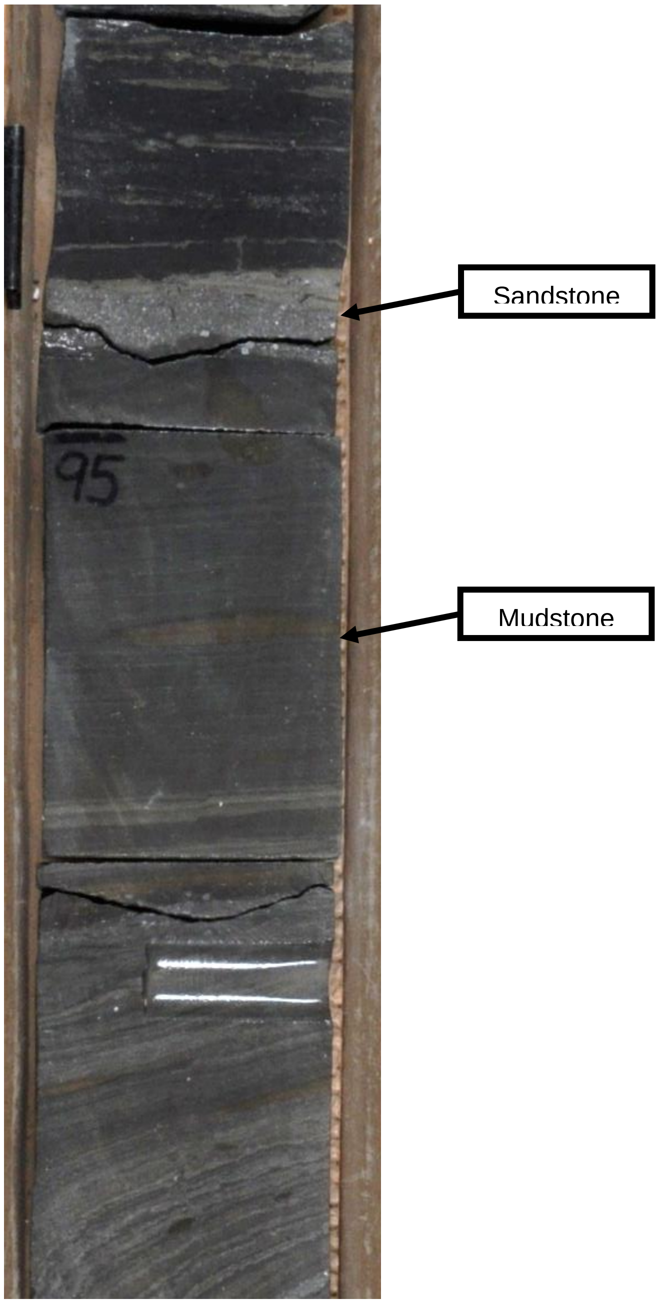

Figure 33: Interbedded mudstone and sandstone, Clements-Littke #1, Depth: 12,495 – 12,496 feet.

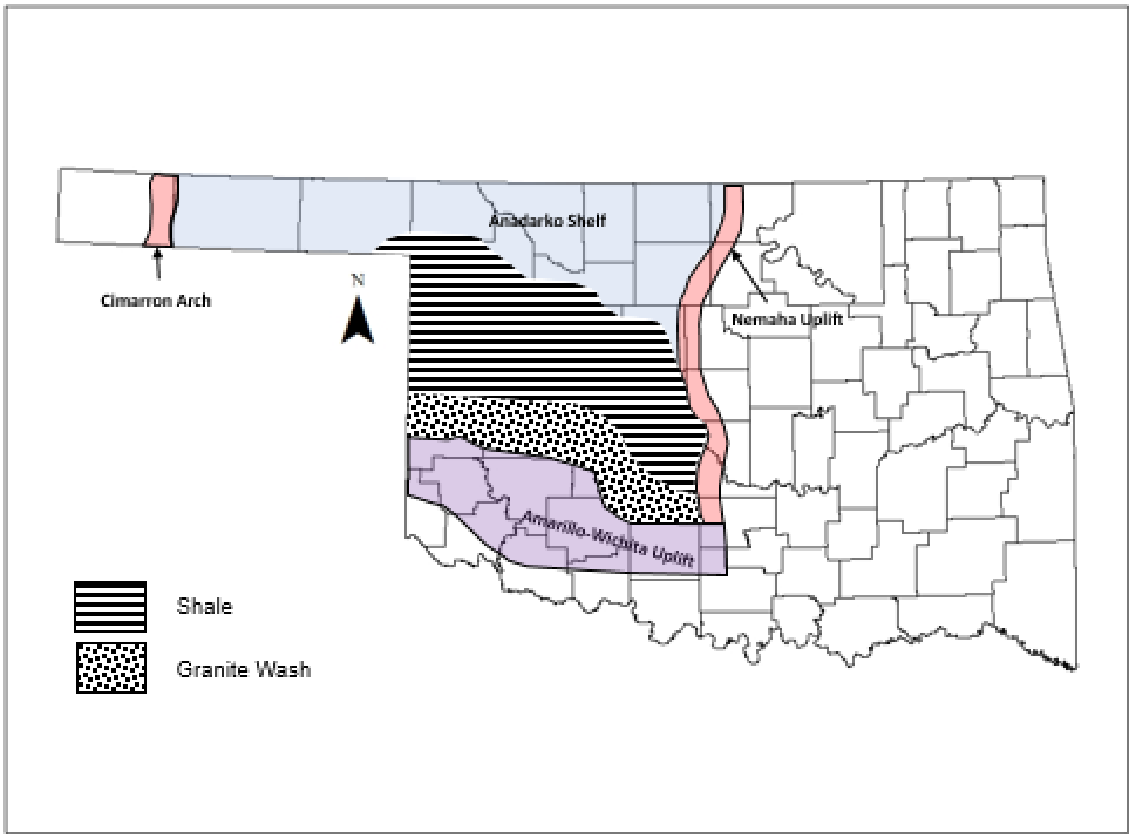

Figure 34: Depositional environments of the Anadarko Basin during the Late Desmoinesian Series, Marmaton Group during Deposition of Granite Wash sediments.

Influence of Faults on the Marmaton Group Deposition

Throughout the Marmaton Group, each Marmaton interval experiences several thickening and thinning sequences in Washita County (Figure 24 – 30), most likely due to a combination of proximal vs distal deposits across the basin axis combined with faulting across the county (Figure 24 - 30). The proximal lobe of the Granite Wash fan delta is located towards the southern portion of Washita County, and spans from adjacent to the Amarillo-Wichita Uplift in the south towards the north to the Mountain View Fault System (Figure 24 - 30)**.** Beyond the Mountain View Fault System are the medial and distal lobes of the fan. The greatest thickness of the Marmaton Group is located in the southern portion of Washita County, which is considered the proximal lobe of the fan delta system located in the county. Overall, the proximal lobe is the thickest deposit because it is located adjacent to the Mountain View Fault System, an area of sediment deposition.

There are several localized areas of thick deposits across the county. The area of greatest thickness is adjacent to the Mountain View Fault System within the proximal lobe, with several other instances of equal thickness in the distal lobe. These isolated thickening sequences typically are also adjacent to a fault or along the basin axis running through Washita County, which is bound on both sides by faults (Mountain View Fault and Cordell Fault). The faults associated with Washita County are thrust faults and extensional faults, and allow for more accommodation space adjacent to the fault block (Ball et al., 1988).

As the Marmaton Group intervals transverse from the Mountain View Fault System to the Cordell Fault then to the basin axis, the Marmaton Group rapidly thins throughout the medial lobe (Figure 24 - 30). The Marmaton Group is 1,700 – 1,800 feet thick at the Mountain View Fault System (Figure 30), and thinning to 1,100 – 1,200 feet thick at the Cordell Fault (Figure 30). This is due to the largest accommodation space being adjacent to the Mountain View Fault. The proximal lobe has the highest rate of sediment influx and the greatest accommodation space, creating the thickest portion of the Marmaton Group in Washita County. As the Marmaton Group continuous north into medial portion of the fan delta in Washita County the rock encounters the Cordell Fault and the process occurs once again.

The northern part of Washita County is considered the distal portion of the fan delta. After thinning across the basin axis, the Marmaton Group begins to thicken into the distal lobe (Figure 24 - 30). The distal lobe for every interval experiences various amounts of thinning and thickening across the region, ranging from 1,400 feet thick in the northwest and 950 feet thick in the northeast (Figure 30). This is controlled by unnamed faults and flooding surface shales. The area on the north boundary of the county is also affected by the numerous faults (Figure 24 - 30), including several unnamed smaller faults. These faults create accommodation space throughout the northern portion of the county allowing for isolated thickening and thinning sequences. Every interval shows a different thickness along the Mountain View Fault and Cordell Fault. It is determined that during the time of deposition of the Marmaton F and E, the faults were down dropping and creating accommodation space for the F and E sediments. As deposition continued, the down dropping of the fault continued; the faults had a higher rate of movement during or shortly before deposition of the Marmaton D and C, which are the thickest intervals of the Marmaton Group. This increase in accommodation space suggest the largest displacement of the faults during this time period. During deposition of the Marmaton B and A the faults slowed their rate of movement, or stopped down dropping, creating less accommodation space than in older deposition. This can be seen in the apparent thickness maps, as thickness gradually increases from the Marmaton F through the Marmaton C, then begins to thin in the Marmaton B and Marmaton A (Figure 24 – 29). The Marmaton F adjacent to the Mountain View Fault is 250 - 300 feet thick. The Marmaton Group begins to thicken slight up until deposition of the Marmaton C interval which reaches 450 feet thick at the Mountain View Fault System (Figure 24 – 29). Another interpretation is that sediment supply was at its greatest during the middle of the Marmaton Group deposition.

Another controlling factor of the Marmaton Group thickness is the flooding zone shale deposition between the intervals (Figure 35). The shales were deposited from the north to the southern proximal lobe. The thickest portion of the flooding zone shales is located in the distal lobe of the Marmaton Group, and thins as it comes out of basin axis and cross the Cordell Fault. With the high structural relief just north of the Mountain View Fault, the flooding zone shales thin in south Washita County (Figure 36). In well 3514921589, the flooding zone shale is at its thickest, approximately 90 feet. In well 3514921182, the flooding zone shale is a thickness of 50 feet. In the proximal lobe well 3514920997, the flooding zone shale cannot be determined. One interpretation is that the flooding zone shale is missing, as suggested by the density porosity reading of 8%, and the neutron porosity 12%, whereas the flooding shales typically have neutron porosity and density porosity both over 20%.

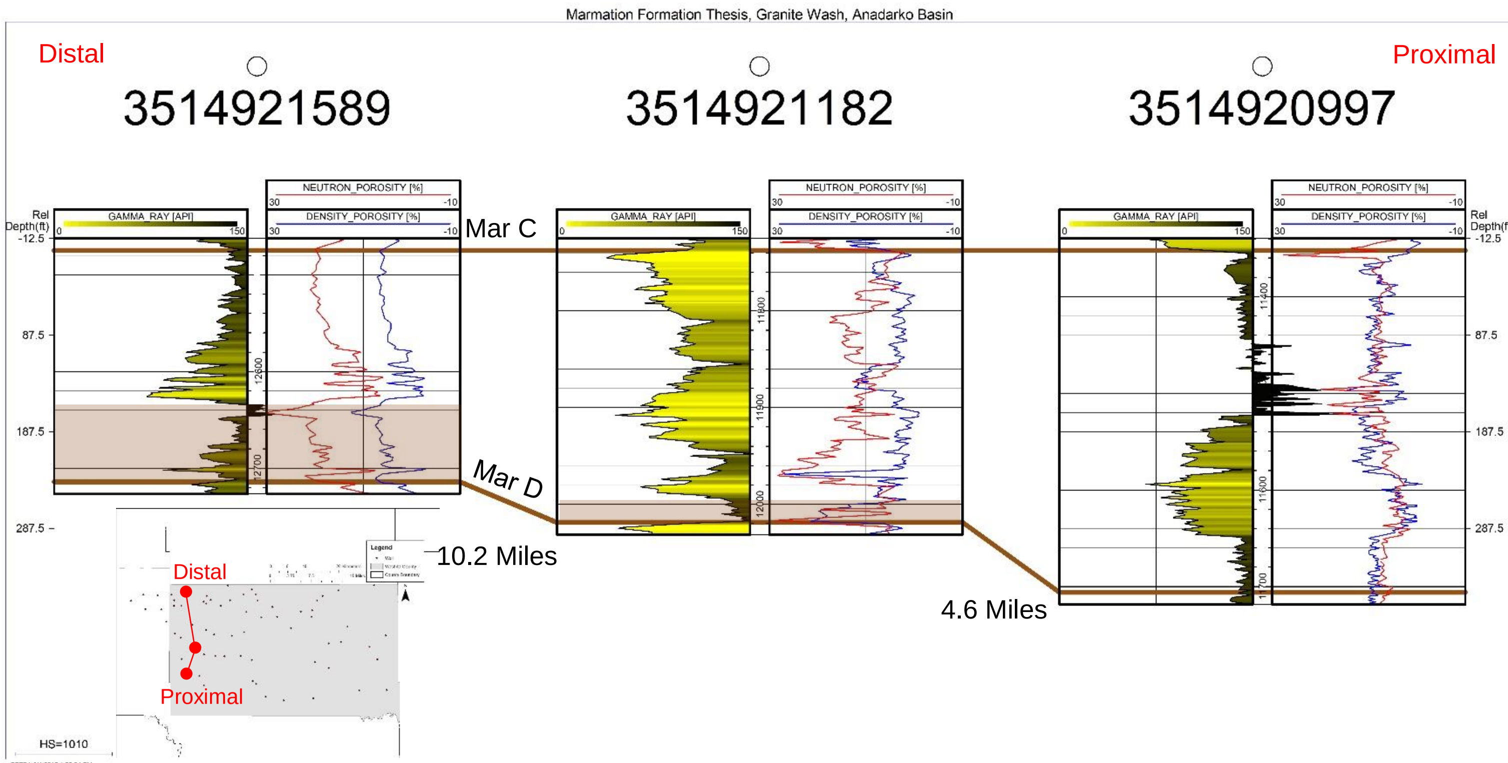

Figure 35: Cross section in western Washita County that shows the loss of shale from distal to proximal lobe. Shale highlighted in brown boxes.

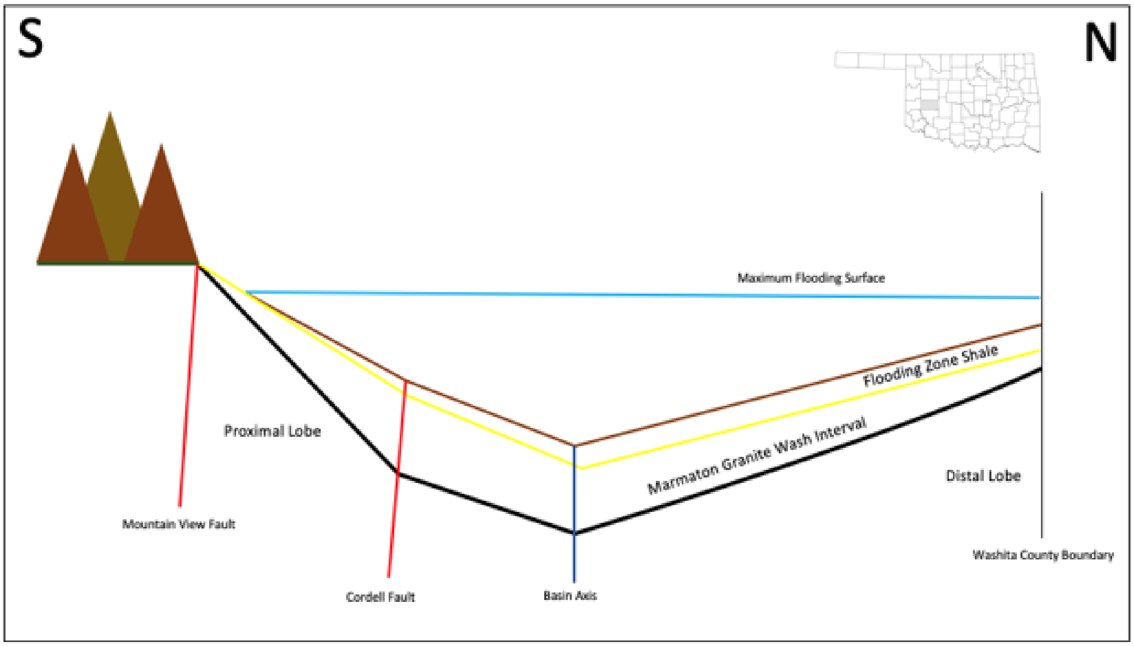

Figure 36: Diagram of Granite Wash deposition from the southern Amarillo-Wichita Uplift and Flooding Zone Shale deposition from the north.

CONCLUSIONS

The Pennsylvanian Marmaton Group is a part of the Granite Wash clastic wedge in the southern Anadarko Basin, adjacent to the north flank of the Amarillo-Wichita Uplift. The Marmaton Group was deposited in the Anadarko Basin by a fan delta system during the Pennsylvanian. The Marmaton Group consists of arkosic sandstones and conglomerate intervals that are separated by flooding interval shales, creating the stacked tight sandstone and conglomerate intervals that are present throughout the area (Mitchell, 2014). The stacked tight sand and conglomerates intervals are a prolific reservoir rock in the county. As demonstrated by previous production numbers in the Granite Wash play (Mitchell, 2014).

In this study over 90 wells logs were correlated throughout Washita County, and two sets of core were examined in the Marmaton Group to better understand the Marmaton Group in Washita County, Oklahoma. In conclusion, the Marmaton Group is highly variable throughout Washita County. There is high stratigraphic uncertainty and thickness in the area, and the facies can vary due to faulting in the county. Each of the intervals within the Marmaton Group have different characteristics in thickness and discontinuous sandstone and conglomerate reservoirs between well logs. As the Marmaton Group was examined from proximal to distal lobes, the gamma ray reading of well logs decrease as potassium and lithic fragments were weathered during deposition further from the source, creating an atypical log response aiding in the difficulty of mapping the Marmaton Group. It is also determined that the thickness of the Marmaton Group is determined by a variety of reasons, such as changes in accommodation space due to fault movement during basin subsidence. Fault movement is the greatest in the middle portion of the Marmaton Group. Deposition is also be controlled by sediment supply, as the Marmaton Group was source from the Amarillo-Wichita Uplift, and a higher sedimentation rate will be adjacent to the uplift in southern Washita County compared to northern Washita County. Finally, flooding zone shale deposition from the north controls thickness variations across the county, with the thickest flooding zone shales in the north and thinnest to the south.

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APPENDIX A

Mobil-Edler #2 (API: 3514920475)

12,703-12,704.1 ft.

Sandstone, 100%, coarse to medium sized grains, quartz, plagioclase, orthoclase, lithic fragments, moderately sorted, subangular.

12,704.1-12,704.4 ft.

Sandstone, 60%, orthoconglomerate (composed of gravel-sized framework grains, matrix is 15% or less sand or finer material), 40%. Fining upward sequence where the bottom section is granule to medium sand in grain size, quartz, plagioclase, orthoclase, lithic fragments, moderately sorted, subangular to subrounded, light tan in color, top section is medium sand to silt grain size, contains crossbedding, moderately sorted, subrounded, light tan in color.

12,704.4-12,705.2 ft.

Sandstone, 60%, orthoconglomerate, 40%, fining upward sequence, bottom section is granule to medium sand in grain size, quartz, plagioclase, orthoclase, lithic fragments, moderately sorted, subangular to subrounded, light tan in color, top section is medium sand to silt size, contains crossbedding and planar laminations, moderately sorted, subrounded, light tan in color.

12,705.2-12,706.10 ft.

Sandstone, 100%, fining upward sequence, bottom section is coarse to medium grain size, quartz, plagioclase, orthoclase, lithic fragments, moderately sorted, subrounded, light grey in color, medium sand to silt grain size, silt flaser laminations, moderately sorted, subrounded, light tan in color. Last ¼ inch of facies is a black shale lenses, 100% clay particles.

12,706.10-12,709.8 ft.

Sandstone, 100%, interbedded coarse to fine sandstone, quartz, plagioclase, orthoclase, lithic fragments, subrounded, moderately sorted

12,709.8-12,710.5 ft.

Sandstone, 100%, fining upward sequence, coarse to fine sandstone, bottom section is coarse to medium grain size, quartz, plagioclase, orthoclase, lithic fragments, moderately sorted, subangular to subrounded, top section is medium to fine sand grain size, moderately sorted, subrounded, light grey in color.

12,710.5-12,711.5 ft.

Sandstone, 100%, fining upward sequence, coarse to fine sandstone, bottom section is coarse to medium grain size, quartz, plagioclase, orthoclase, lithic fragments, moderately sorted, subangular to subrounded, top section is medium to fine sand grain size, moderately sorted, subrounded, light grey/tan in color. Silty wavy bedding.

12,711.5-12,712 ft.

Paraconglomerate (50% or more matrix composition of mud, gravel grains are scattered and not connected), 100%, light grey lithic fragments, supported in black mud matrix, gravel to medium sand grain size, subangular to subrounded, poorly sorted.

12,712-12,713 ft.

Orthoconglomerate, 100%, light grey to light tan lithic clasts, gravel to medium sand grain size, quartz, plagioclase, orthoclase, lithic fragments, poorly sorted, subangular to subrounded, clasts range from ¼ to 2 ¼ inch.

12,713-12,718 ft.

Sandstone, 100%, contains silty flaser laminations. Light grey in color, coarse sand to medium sand in grain size, quartz, plagioclase, orthoclase, lithic fragments, poorly sorted, subangular to subrounded.

12,718-12,718.6 ft.

Sandstone, 100%, black in color. Coarse sand to medium sand grain size, plagioclase, orthoclase, lithic fragments, small amounts of quartz, moderately sorted, subangular, some mud lenses.

12,719-12,720.4 ft.

Silty shale, black silty shale layer with planar laminations.

12,720.4-12,723 ft.

Paraconglomerate, 100%, light grey lithic fragments, supported in black mud matrix, gravel to medium sand grain size, subangular to subrounded, poorly sorted.

12,723-12,974 ft.

Missing core footage.

12,974-12,976 ft.

Sandstone, 100%, medium sand grain size, quartz, plagioclase, orthoclase, lithic fragments, well sorted, subrounded, even sandstone facies.

12,976-12,978 ft.

Shale, 100%, black in color.

12,978-12,980 ft.

Siltstone, 100%, quartz, plagioclase, orthoclase, grey in color, well sorted, well rounded.

Clements-Littke #1 (API: 3514920485)

12,473-12,474.5 ft.

Sandstone, 100%, light grey, coarse to medium sand grain size, quartz, plagioclase, orthoclase, lithic fragments, subrounded, moderately sorted.

12,474.5-12,476 ft.

Paraconglomerate, 90%, 10% flaser mud laminations-dark grey. Paraconglomerate contains light grey lithic clasts, supported in black mud matrix, gravel to medium sand grain size, subangular to subrounded, poorly sorted,

12,476-12,477 ft.

Sandstone, 60%, wavy mud laminations 40%, medium to fine grain sandstone, clay grain size for mud laminations, quartz, plagioclase, orthoclase, lithic fragments, clay, moderately sorted, subrounded. Soft sediment deformation in facies.

12,477-12,478 ft.

Orthoconglomerate, 100%, light grey lithic clasts, supported by sand grains, gravel to fine sand grain size, quartz, plagioclase, orthoclase, lithic fragments, subangular to subrounded, poorly sorted, clasts over 2” in diameter, most clasts 0.5” to 1”.

12,478-12,482 ft.

Sandstone, 90%, flaser mud laminations-dark grey, 10%, coarse sand to fine sand grain size with clay laminations, quartz, plagioclase, orthoclase, lithic fragments, clay, moderately sorted, subrounded.

12,482-12,483.3 ft.

Sandstone, 100%, coarsening upwards sequence, light tan to light grey, coarse sand to medium sand at top of sequence, quartz, plagioclase, orthoclase, lithic fragments, moderately sorted, subangular to subrounded, bottom of sequence is medium sand to find sand grain size, well sorted, subrounded.

12,483.3-12,487.3 ft.

Sandstone, 70%, siltstone, 30%, coarsening upward sequence, bottom section is silt to fine sand grain size, top section is coarse sand to granule grain size, quartz, plagioclase, orthoclase, lithic fragments, light grey/light tan color, poorly sorted, and subangular to subrounded.

12,487.3-12,487.5 ft.

Shale, 100%, 2 inch thick claystone flooding surface, black in color. Bottom of coarsening upward sequence.

12,487.5-12,488.4 ft.

Orthoconglomerate, 100%, light grey to light tan lithic clasts, gravel to medium sand grain size, quartz, plagioclase, orthoclase, lithic fragments, poorly sorted, and subangular to subrounded, clasts range from 0.5” to 1.0”.

12,488.4-12,489.6 ft.

Sandstone, 90%, siltstone, 10%, fining upward sequence, bottom section is granule to fine sand grain size, top section is medium to silt grain size, quartz, plagioclase, orthoclase, lithic fragments, bottom section is moderately sorted, subangular, light grey, silt flaser laminations, top sections is well sorted, subrounded, light grey/tan, and silt flaser laminations.

12,489.6-12,490.6 ft.

Paraconglomerate, 100%, light grey lithic fragments, supported in black mud matrix, gravel to medium sand grain size, subangular to subrounded, poorly sorted.

12,490.6-12,491.2 ft.

Silty sandstone, 80%, paraconglomerate, 20%, fining upward sequence, bottom section is gravel grain size in a black mud matrix, 0.25” to 1.0” clasts, top section is silty sandstone, medium sand to silty grain size, light grey/tan in color, moderately sorted, and subrounded.

12,491.4-12,492.9 ft.

Sandstone, 100%, fining upwards sequence, bottom section is coarse sand to fine sand grain size, quartz, plagioclase, orthoclase, lithic fragments, moderately sorted, subangular, light tan in color, top section is medium sand to silt grain size, silt flaser lenses, moderately sorted, subangular, and light tan in color.

12,492.9-12,494.5 ft.

Sandstone, 100%, fining upwards sequence, bottom section is coarse sand to fine sand grain size, quartz, plagioclase, orthoclase, lithic fragments, moderately sorted, subangular, light tan in color, top section is medium sand to silt grain size, silt flaser lenses, moderately sorted, subangular, and light tan in color.

12,494.5-12,494.10 ft.

Sandstone, 50%, shale, 50%, fining upward sequence, bottom section is coarse to medium sand, quartz, plagioclase, orthoclase, lithic fragments, grey in color, moderately sorted, subangular, top section is shale that is interfingered with medium tan sand.

12,494.10-12,495.5 ft.

Sandstone, 50%, shale, 50%, fining upward sequence, bottom section is coarse to medium sand, grey in color, moderately sorted, subangular, top section is shale that is interfingered with medium tan sand.

12,495.5-12,497.5 ft.

Sandstone, 50%, shale, 50%, fining upward sequence, bottom section is coarse to medium sand, quartz, plagioclase, orthoclase, lithic fragments, grey in color, moderately sorted, subangular, top section is shale that is interfingered with medium tan sand. Recumbent folding and soft sediment deformation.

12,497.5-12,498.3 ft.

Sandstone, 80%, orthoconglomerate, 20%, fining upward sequence, bottom section is a orthoconglomerate with light grey lithic clasts and the matrix is medium sand, clasts are 0.5-1.0” in diameter, top section is coarse to fine sand, quartz, plagioclase, orthoclase, lithic fragments, grey in color, well sorted, subrounded.

12,498.3-12,500 ft.

Sandstone, 80%, orthoconglomerate, 20%, fining upward sequence, bottom section is an orthoconglomerate with light grey lithic clasts with a medium sand matrix, poorly sorted, subrounded, and the top section is fine sand grain size, quartz, plagioclase, orthoclase, lithic fragments, well sorted, subrounded, light/dark grey in color, overturned beds.

12,500-12,501.2 ft.

Sandstone, 80%, orthoconglomerate, 20%, fining upward sequence, bottom section is an orthoconglomerate with light grey lithic clasts with a fine sand matrix, light grey in color, poorly sorted, subrounded, and the top section is coarse to fine sand grain size, quartz, plagioclase, orthoclase, lithic fragments, moderately sorted, subrounded, and light grey/tan in color.

12,501.2-12,502.5 ft.

Sandstone, 95%, orthoconglomerate, 5%, fining upward sequence, bottom section is an orthoconglomerate with light grey lithic clasts with a fine sand matrix, poorly sorted, subrounded, the top section is wavy laminated sandstone, fine sand to clay grain size, quartz, plagioclase, orthoclase, lithic fragments, well sorted, subrounded to rounded, light tan fine sand, and grey mud laminations.

12,502.5-12,503 ft.

Sandstone, 100%, fining upward sequence, bottom section is coarse sand grain size, quartz, plagioclase, orthoclase, lithic fragments, light grey in color, moderately sorted, subrounded, top section is fine sand in grain size, well sorted, and subrounded.

12,503-12,506.4 ft.

Shale, 100%, black-grey laminated shale. At bottom of shale section a ¼ inch fine sand occurs, well rounded, well sorted, grey in color.

12,506.4-12,507 ft.

Shale, 100%, black-grey laminated shale. At bottom of shale section a ¼ inch fine sand occurs, well rounded, well sorted, grey in color.

12,507.4-12,517 ft.

Shale, 100%, black laminated shale.

APPENDIX B

Mobil-Edler #2 Core

Box 1-3: 12,703-12,712 ft.

Bright Red- Orthoconglomerate

Purple- Paraconglomerate

Gold- Coarse Sandstone

Orange- FUS Sandstone- Conglomerate

Blue- Silty Sandstone

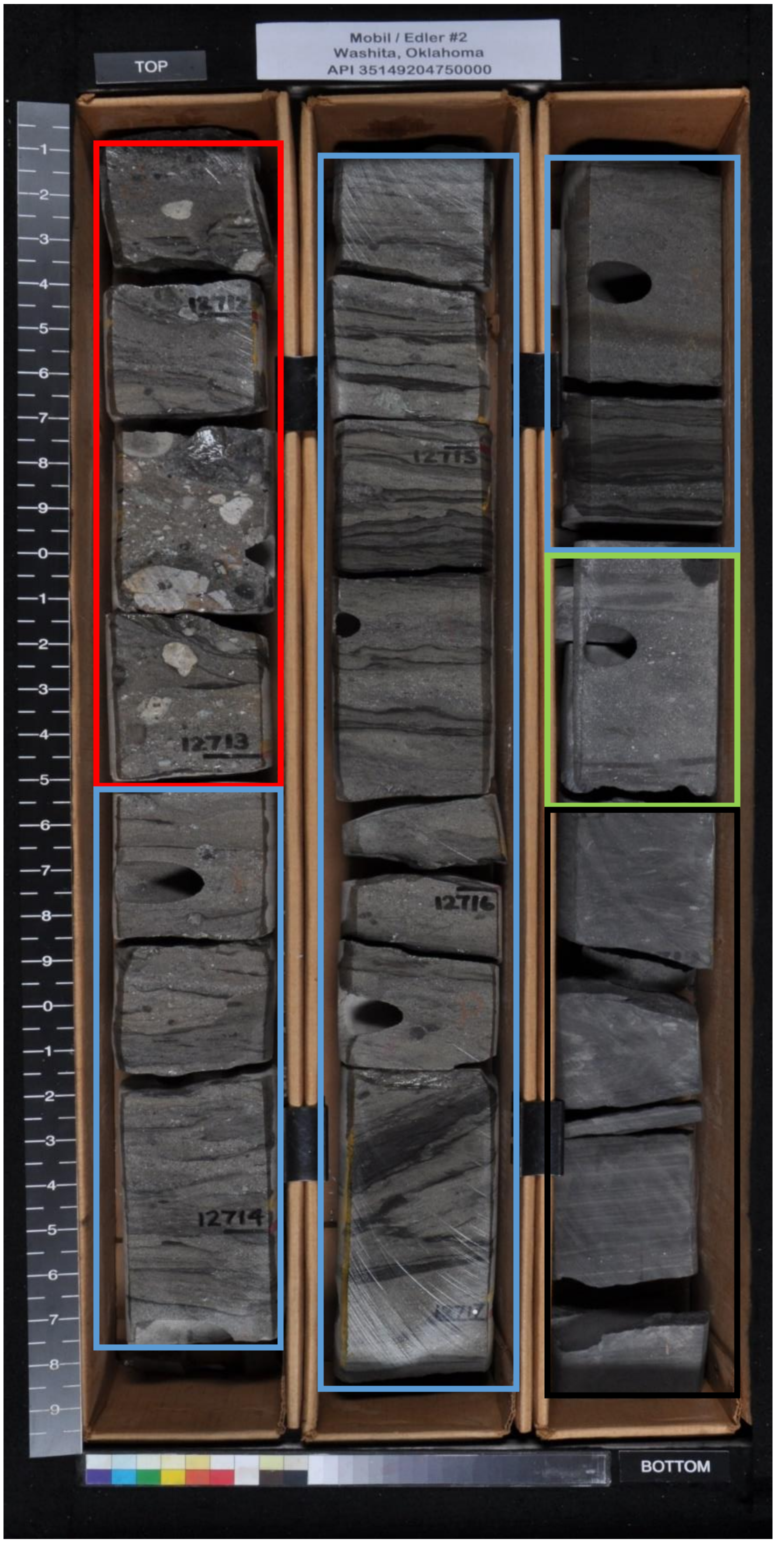
Black- Shale

Green- Even Sandstone facies

Grey-Siltstone

Dark Red- Interfingered Shale and Sandstone

Brown- FUS Fine Sand- Coarse Sand



Mobil-Edler #2 Core

Box 4-5: 12,712-12,720 ft.

Bright Red- Orthoconglomerate

Purple- Paraconglomerate

Gold- Coarse Sandstone

Orange- FUS Sandstone- Conglomerate

Blue- Silty Sandstone

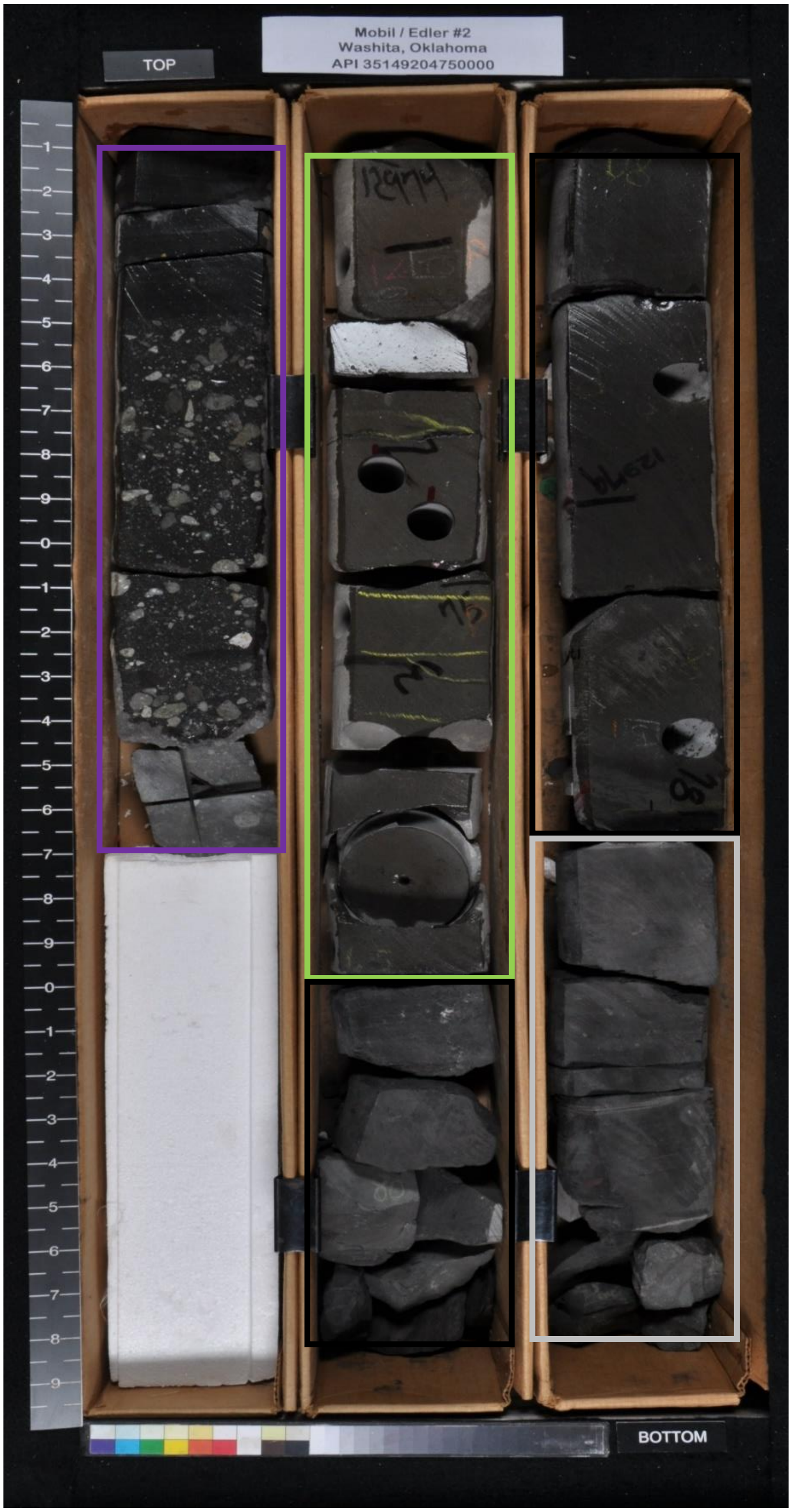
Black- Shale

Green- Even Sandstone facies

Grey-Siltstone

Dark Red- Interfingered Shale and Sandstone

Brown- FUS Fine Sand- Coarse Sand



Mobil-Edler #2 Core

Box 7: 12,720-12,721.6 ft.

Box 8-9: 12,974-12,980 ft.

Bright Red- Orthoconglomerate

Purple- Paraconglomerate

Gold- Coarse Sandstone

Orange- FUS Sandstone-Conglomerate

Blue- Silty Sandstone

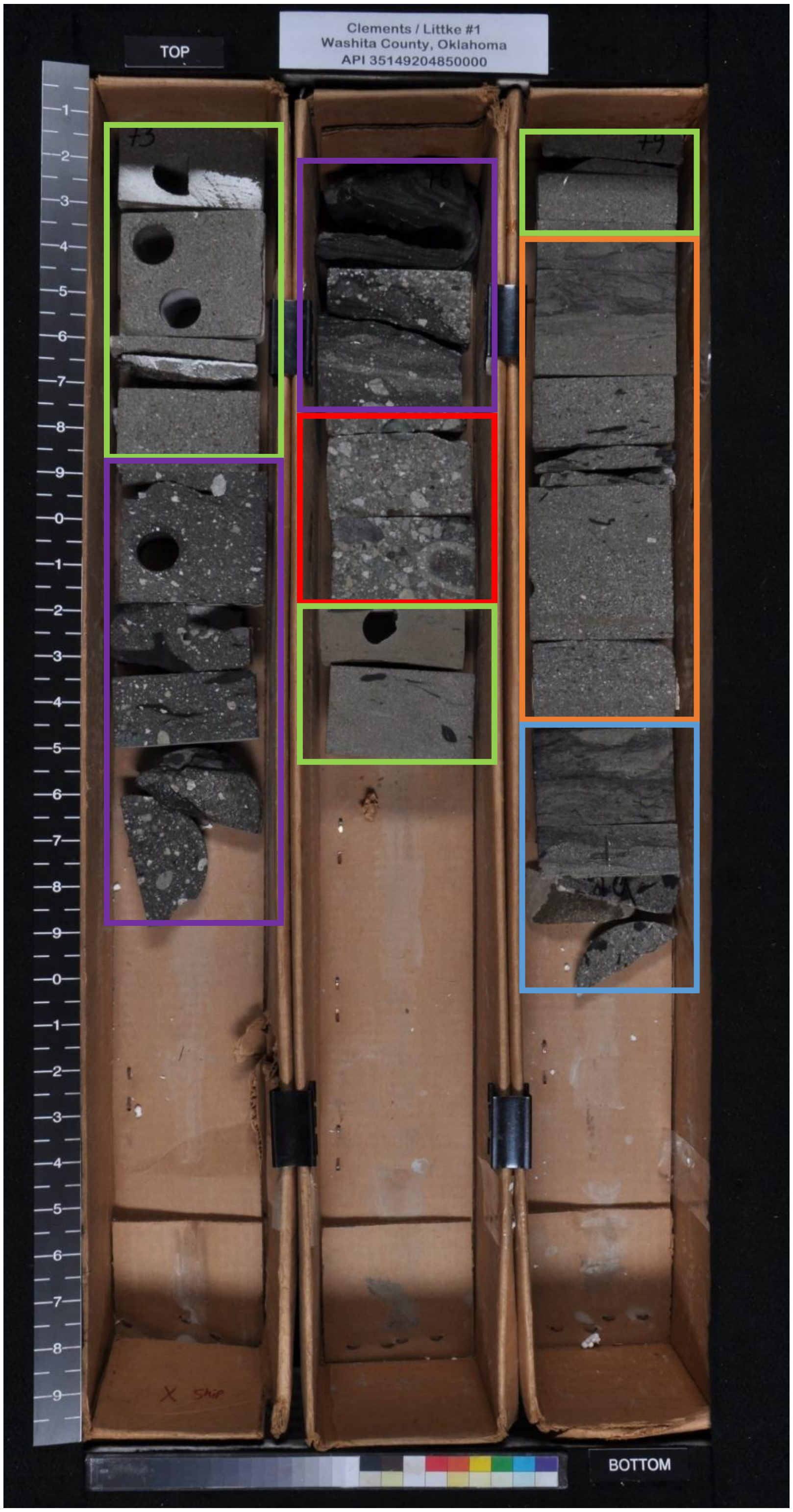
Black- Shale

Green- Even Sandstone facies

Grey-Siltstone

Dark Red- Interfingered Shale and Sandstone

Brown- FUS Fine Sand-Coarse Sand



Clements-Littke #1 Core

Box 1-3: 12,473-12,482 ft.

Bright Red- Orthoconglomerate

Purple- Paraconglomerate

Gold- Coarse Sandstone

Orange- FUS Sandstone-Conglomerate

Blue- Silty Sandstone

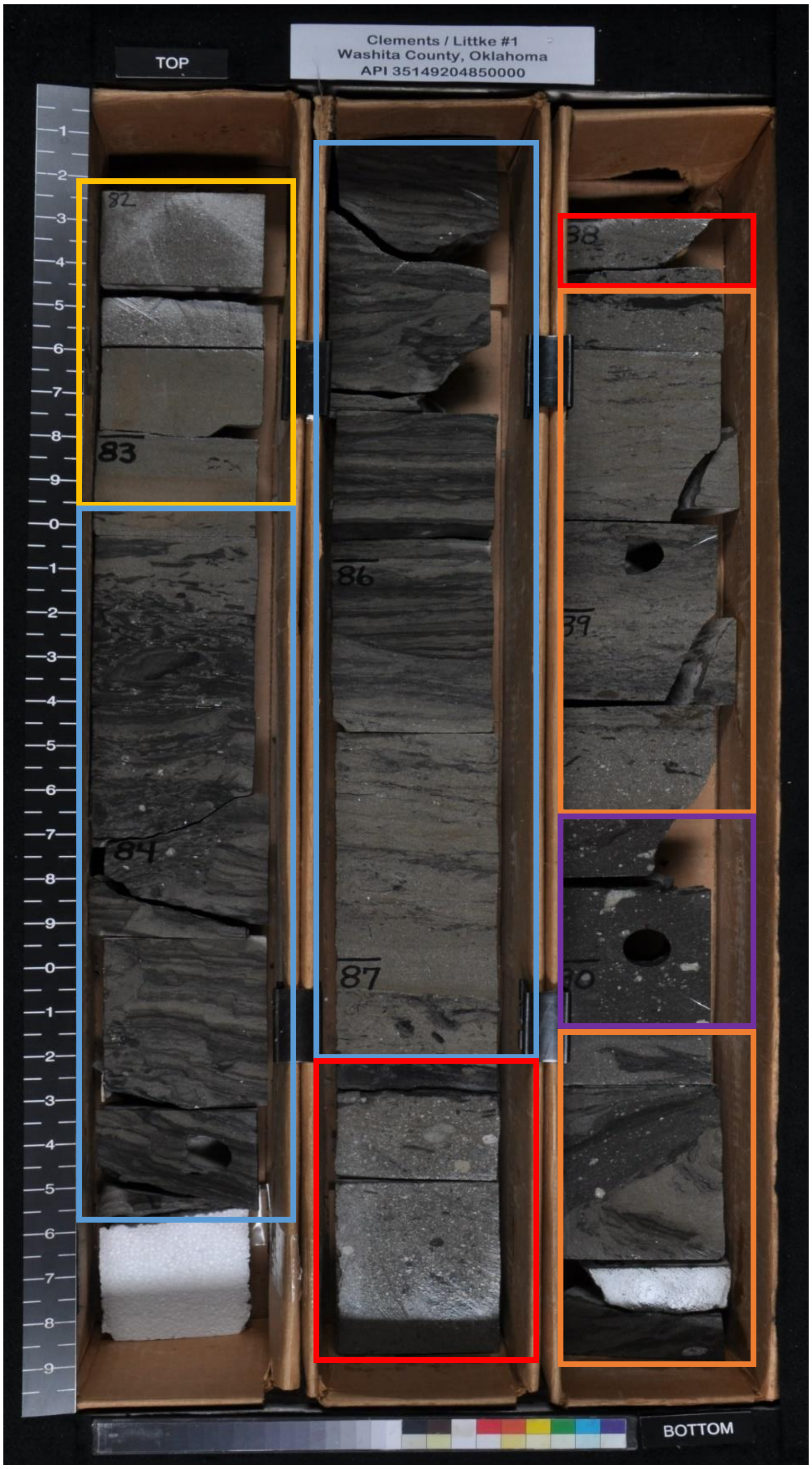
Black- Shale

Green- Even Sandstone facies

Grey-Siltstone

Dark Red- Interfingered Shale and Sandstone

Brown- FUS Fine Sand-Coarse Sand



Clements-Littke #1 Core

Box 4-6: 12,482-12,491 ft.

Bright Red- Orthoconglomerate

Purple- Paraconglomerate

Gold- Coarse Sandstone

Orange- FUS Sandstone- Conglomerate

Blue- Silty Sandstone

Black- Shale

Green- Even Sandstone facies

Grey-Siltstone

Dark Red- Interfingered Shale and Sandstone

Brown- FUS Fine Sand- Coarse Sand

Clements-Littke #1 Core

Box 7-9: 12,491-12,500 ft.

Bright Red- Orthoconglomerate

Purple- Paraconglomerate

Gold- Coarse Sandstone

Orange- FUS Sandstone- Conglomerate

Blue- Silty Sandstone

Black- Shale

Green- Even Sandstone facies

Grey-Siltstone

Dark Red- Interfingered Shale and Sandstone

Brown- FUS Fine Sand- Coarse Sand

Clements-Littke #1 Core

Box 10-12: 12,500-12,508 ft.

Bright Red- Orthoconglomerate

Purple- Paraconglomerate

Gold- Coarse Sandstone

Orange- FUS Sandstone-Conglomerate

Blue- Silty Sandstone

Black- Shale

Green- Even Sandstone facies

Grey-Siltstone

Dark Red- Interfingered Shale and Sandstone

Brown- FUS Fine Sand-Coarse Sand

Clements-Littke #1 Core

Box 13-15: 12,508-12,517 ft.

Bright Red- Orthoconglomerate

Purple- Paraconglomerate

Gold- Coarse Sandstone

Orange- FUS Sandstone-Conglomerate

Blue- Silty Sandstone

Black- Shale

Green- Even Sandstone facies

Grey-Siltstone

Dark Red- Interfingered Shale and Sandstone

Brown- FUS Fine Sand-Coarse Sand

APPENDIX C

UWI (API)	SKINNER_SH	MAR_F	MAR_E	MAR_D	MAR_C	MAR_B	MAR_A	Surf Lat	Surf Lon	ELEV_KB
3514921589	13326	13098	12918	12714	12475	12387	11993	35.43735	-99.3577	2025
3514921004	12875	12773	12611	12437	12197	12058	11935	35.42397	-99.2306	1798
3514921404	12572	12434	12301	12176	11847	11726	11452	35.45148	-99.0086	1675
3514920998	12728	12589	12490	12290				35.44881	-98.8154	1611
3514921388	13079	12933	12877	12783	12443	12294	12111	35.46278	-98.7	1725
3514921184	12721	12482	12284	12126	11831	11725	11556	35.3343	-99.3462	1934
3514921343	12994	12866	12710	12594	12199	12090	11882	35.3314	-99.2189	1966
3514921515	12910	12678	12517	12340	12054	11913	11733	35.37742	-99.0662	1669
3514921526	12855	12715	12543	12411	12075	11940	11722	35.34865	-98.9694	1535
3514921620	12889	12726	12580	12377	12096	11830	11633	35.30859	-98.8478	1518
3514921117	12582	12389	12162	12015	11716	11532	11371	35.28903	-99.2669	1828
3514921123	12632	12466	12292	12081	11734	11609	11440	35.27427	-99.1857	1866
3514921438	12233	11961	11732	11573	11218	11106	10909	35.20837	-99.0941	1562
3514921320	12819	12612	12471	12288	11991	11760	11594	35.25862	-98.8924	1493
3514921597	12857	12709	12563	12357	12051	11847	11649	35.26581	-98.6898	1563
3514921341	12232	11928	11711	11547	11186	11072	10873	35.2006	-99.0835	1678
3514921272	12188	11928	11701	11493	11133	10981	10778	35.1962	-99.2515	1675
3514921296	12269	11899	11607	11369	11122	10953	10695	35.16672	-99.0523	1681
3514921238	12210	11809	11494	11312	10998	10839	10535	35.15729	-98.9937	1746
3514921266	11990	11760	11472	11261	10975	10819	10633	35.16225	-98.8973	1560
3514921486	12820	12675	12490	12282	12002	11807	11596	35.18363	-98.7486	1448
3514921545	12910	12762	12591	12405	12099	11900	11696	35.18388	-98.6606	1539
3514920475	12935	12769	12636	12413	12152	12012	11763	35.41844	-99.2529	1819
3500921752	13670	13490	13359	13217	12929	12788	12520	35.4207	-99.4894	2199
3500921608	13264	13068	12837	12620	12339	12263	12088	35.39835	-99.3906	1944
3514921456	12732	12618	12452	12201	11855	11756	11568	35.37883	-98.9037	1576
3500921455	13387	13047	12810	12591	12345	12281	12203	35.36571	-99.3745	1914
3500921826	13310	13063	12840	12667	12383	12307	11924	35.43576	-99.4022	1994
3514921158	12923	12686	12511	12364	11973	11833	11579	35.44282	-99.3037	1885
3514921500	12919	12699	12564	12321	11938	11870	11721	35.40807	-99.1975	1817

UWI (API)	SKINNER_SH	MAR_F	MAR_E	MAR_D	MAR_C	MAR_B	MAR_A	Surf Lat	Surf Lon	ELEV_KB
3514921500	12919	12699	12564	12321	11938	11870	11721	35.40807	-99.1975	1817
3514921417	12922	12773	12639	12546	12217	12093	11951	35.42277	-99.1678	1713
3514921311	12989	12893	12763	12639	12314	12199	12028	35.4225	-99.0779	1721
3514921249	12785	12734	12698	12571	12253	12127	11965	35.4382	-99.0838	1735
3514921626	12920	12760	12560	12428	12156	11994	11778	35.39218	-99.1155	1703
3514921261	13132	12954	12836	12677	12326	12213	11986	35.35784	-99.2903	1935
3514921030	12626	12430	12211	12016	11761	11632	11490	35.32317	-99.3271	1944
3514921185	12206	11926	11695	11541	11169	11066	10850	35.22138	-99.2666	1732
3514920997	12321	12059	11848	11706	11352	11236	11001	35.23532	-99.303	1727
3514921538	13399	13200	13044	12883	12591	12523	12416	35.40813	-99.3492	1990
3514921558	13357	13234	13112	12991	12686	12514	12259	35.40815	-99.3258	1992
3500921779	13405	13269	13116	12930	12641	12533	12208	35.43716	-99.4495	2090
3500921551	13268	13082	12841	12540	12283	12223	12066	35.39845	-99.4418	1995
3514921489	13450	13229	13123	12914	12623	12549	12418	35.42243	-99.3491	2028
3514921182	12580	12378	12165	12019	11737	11557	11384	35.30074	-99.29	1804
3514921175	13025	12849	12764	12596	12279	12201	11946	35.34424	-99.2453	1972
3514921260	13003	12829	12692	12583	12254	12117	11894	35.32891	-99.1618	1906
3514920966	12434	12178	11963	11825	11382	11328	11148	35.2664	-99.3243	1859
3514921121	12948	12795	12680	12567	12234	12093		35.46178	-99.1745	1738
3514921227	12786	12715	12649	12542	12228	12111	11956	35.43815	-99.1239	1772
3514921018	12938	12753	12633	12504	12101	11923	11734	35.43435	-99.2436	1791
3514921033	12838	12729	12595	12326	12076	11879	11726	35.41415	-99.2452	1839
3514921202	12315	12053	11838	11699	11247	11202	10952	35.2441	-99.1998	1846
3514921313	10806	10705	10645	10465	10160	10096	9995	35.27873	-99.1146	1837
3514921153	12611	12383	12161	11996	11740	11569	11400	35.27895	-99.252	1848
3514921354	12643	12471	12310	12107	11873	11721	11519	35.27515	-99.2148	1881
3514921398	12693	12521	12359	12098	11866	11694	11501	35.27512	-99.1326	1880
3514921177	12940	12777	12647	12513	12140	12006	11847	35.33849	-99.1217	1760
3514921544	12837	12602	12411	12201	12021	11868	11670	35.37892	-99.0141	1536
3514921453	12654	12523	12325	12096	11902	11795	11601	35.3932	-98.9382	1574
3514921536	12870	12682	12523	12408	12028	11847	11588	35.40552	-99.0306	1665
3514921247	12811	12643	12404	12235	11938	11732	11596	35.35262	-98.7866	1568

UWI (API)	SKINNER_SH	MAR_F	MAR_E	MAR_D	MAR_C	MAR_B	MAR_A	Surf Lat	Surf Lon	ELEV_KB
3514921211	12817	12627	12496	12285	12022	11787	11591	35.32881	-98.6631	1477
3514921588	12728	12580	12509	12319	11970	11837	11701	35.43485	-98.8674	1521
3514921542	12651	12545	12433	12308	11900	11813	11657	35.42242	-98.8858	1461
3514920000	12839	12651	12525	12318	12033	11800	11622	35.31193	-98.8076	1517
3514921520	12867	12695	12550	12354	12049	11848	11652	35.2987	-98.7162	1614
3514921541	12802	12664	12459	12290	11974	11740	11575	35.24354	-98.8484	1541
3514921373	12765	12585	12437	12160	11927	11777	11541	35.26421	-99.0974	1774

VITA

Cole Hatchel graduated from Oklahoma Christian School, Edmond, Oklahoma, May of 2013. He entered Oklahoma State University at Stillwater, Oklahoma, August of 2013. While at Oklahoma State University, Cole was an intern hydrologist for the U.S. Geological Survey in Oklahoma City, Oklahoma, from May 2016 to May 2017. He received a Bachelor of Science degree with a major in Geology from Oklahoma State University May of 2017.

In August 2017, he enrolled in the Geology graduate program at Stephen F. Austin State University in Nacogdoches, Texas. Cole received his Masters of Science degree in August of 2019.

Since April of 2019, Cole has joined Inspiration Energy, Tyler, Texas, as a Exploration Geologist working in the East Texas, North Louisiana, and Mississippi Salt Dome Basins.

Permanent Address: 1887 Southerly Ridge
Edmond, OK 73025

This thesis was typed by Cole A. Hatchel