January 2015

Geologic And Petrophysical Analysis Of The Three Forks Formation: Charlson Field, Williston Basin - North Dakota

Bailey Jo Bubach

GEOLOGIC AND PETROPHYSICAL ANALYSIS OF THE THREE FORKS FORMATION: CHARLSON FIELD, WILLISTON BASIN – NORTH DAKOTA

by

Bailey Jo Bubach
Bachelor of Science, University of North Dakota, 2012
Master of Science, University of North Dakota, 2015

A Thesis

Submitted to the Graduate Faculty
of the
University of North Dakota
in partial fulfillment of the requirements

for the degree of

Master of Science

Grand Forks, North Dakota
August
2015

This thesis, submitted by Bailey Bubach in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

Dr. Richard LeFever

Dr. Will Gosnold

Dr. Kegang Ling

This thesis is being submitted by the appointed advisory committee as having met all of the requirements of the School of Graduate Studies at the University of North Dakota and is hereby approved.

Wayne Swisher
Dean of the School of Graduate Studies

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Degree	Master of Science

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ACKNOWLEDGMENTS

This thesis was supervised by Dr. Richard LeFever, and I would like to thank him for support and contribution of his time and efforts in guiding this research. I would also like to thank Dr. Will Gosnold and Dr. Kegang Ling for serving on my advisory committee and giving their insight into my research project.

The Harold Hamm School of Geology and Geological Engineering for the support I was given during my master's degree and for the funded trainings I was able to attend due to the department's generosity.

ABSTRACT

With recent advancements in hydraulic fracturing and horizontal drilling technologies, there has been an increase in the production of hydrocarbons from unconventional reservoirs in the Williston Basin. The basin underlies parts of North Dakota, Montana, and South Dakota in the U.S. The Three Forks Formation in Williston Basin is an example of an unconventional reservoir that, according to the United States Geological Survey (Gaswirth, et al., 2013), has a potential of yield of 3.7 billion barrels of unrecovered oil. Charlson Field, located in McKenzie County, is a primary target for the Three Forks Formation, which has shown high potential for production with an increase in interest for further exploration. To enhance our knowledge of the field and locate prolific regions for future drilling, studies were conducted, including geological and petrophysical properties analysis for the means of oil in place (OIP) calculations.

The Devonian Three Forks Formation is unconformably overlain by the Bakken Formation and underlain by the Birdbear Formation. It is stratigraphically divided into five members. For the purpose of petroleum exploration and production, operators in the basin have identified four different benches through the Three Forks. The four benches are used to determine where the potential reservoirs are in the rock unit. The four benches were selected based on core analysis and distinguished from one another by their well log signatures.

In this study, the Three Forks Formation was evaluated from a lithological and petrophysical point of view. The preliminary step was to distinguish the pay zones, dolomitic

beds, from the non-productive shaly beds. The productive zones were given a numbered bench that was determined from the well log and core study. After digitizing the well logs using NeuraLog™, petrophysical properties such as porosity and water saturation were calculated by using Petra™. Finally, oil in place was calculated under volumetric methods by using estimated saturation, porosity and net pay from the well and log core data. This study provided us with an insight to the more suitable areas in Charlson Field where future operations should be conducted.

CHAPTER I

INTRODUCTION

The late Devonian Three Forks Formation in the Williston Basin has received increased attention and drilling activities in recent years due to its geological setting and petroleum production potential. The focus of this study is Charlson Field (Figure 1), where the Three Forks was first drilled horizontally in 2006 by Petro-Hunt, L.L.C. The field is located in McKenzie County, and has the highest producing Three Forks well to date, with a cumulative oil production of 1,492,540 bbls (Department of Mineral Resources, 2015). With recent advancements in horizontal drilling and fracturing technologies, the Three Forks became a new target for petroleum operators in the Williston Basin, with increased drilling in the formation since 2009 (Department of Mineral Resources, 2015).

The 2013 assessment that was released by the United States Geological Survey (USGS) estimated that the Three Forks Formation has a mean reserve of 3.73 billion barrels of oil. The Three Forks is part of the Bakken Total Petroleum System (TPS), which encompasses the Three Forks, Bakken, and the lower portion of the Mississippian Lodgepole Formations. The assessment separated the Bakken TPS into six continuous assessment units (AUs) and two conventional AUs, which is illustrated in Figure 2 (Gaswirth, et al., 2013). Charlson field is part of the Nesson-Little Knife Continuous Oil AU, which has a mean undiscovered resource of 1,149 million barrels of oil (MMBO) for the Bakken TPS (Table 1).

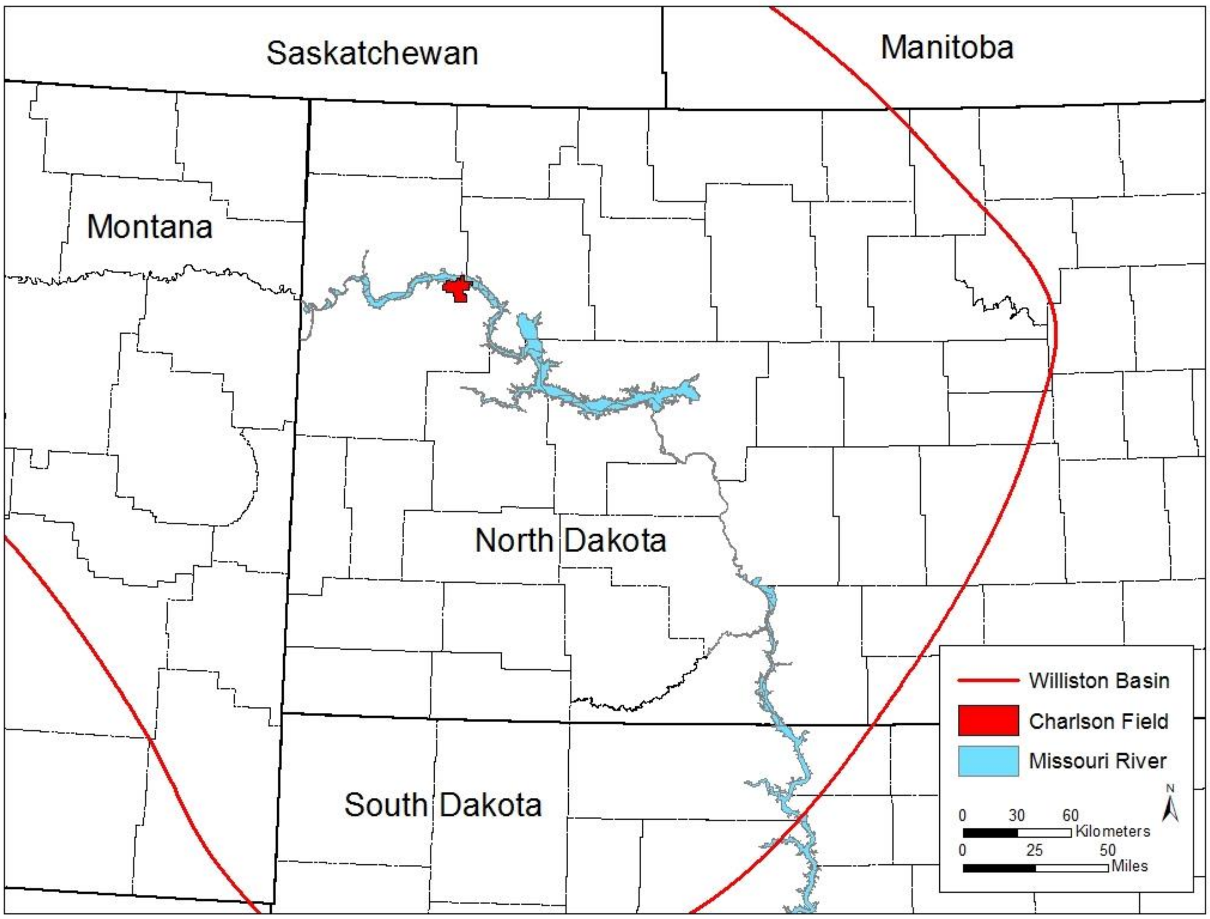

Figure 1. Map of study area. The Williston Basin is represented as the red boundary surrounding the North Dakota Oil Fields (gray) and Charlson Field (red) is represented on the map in the western portion of North Dakota.

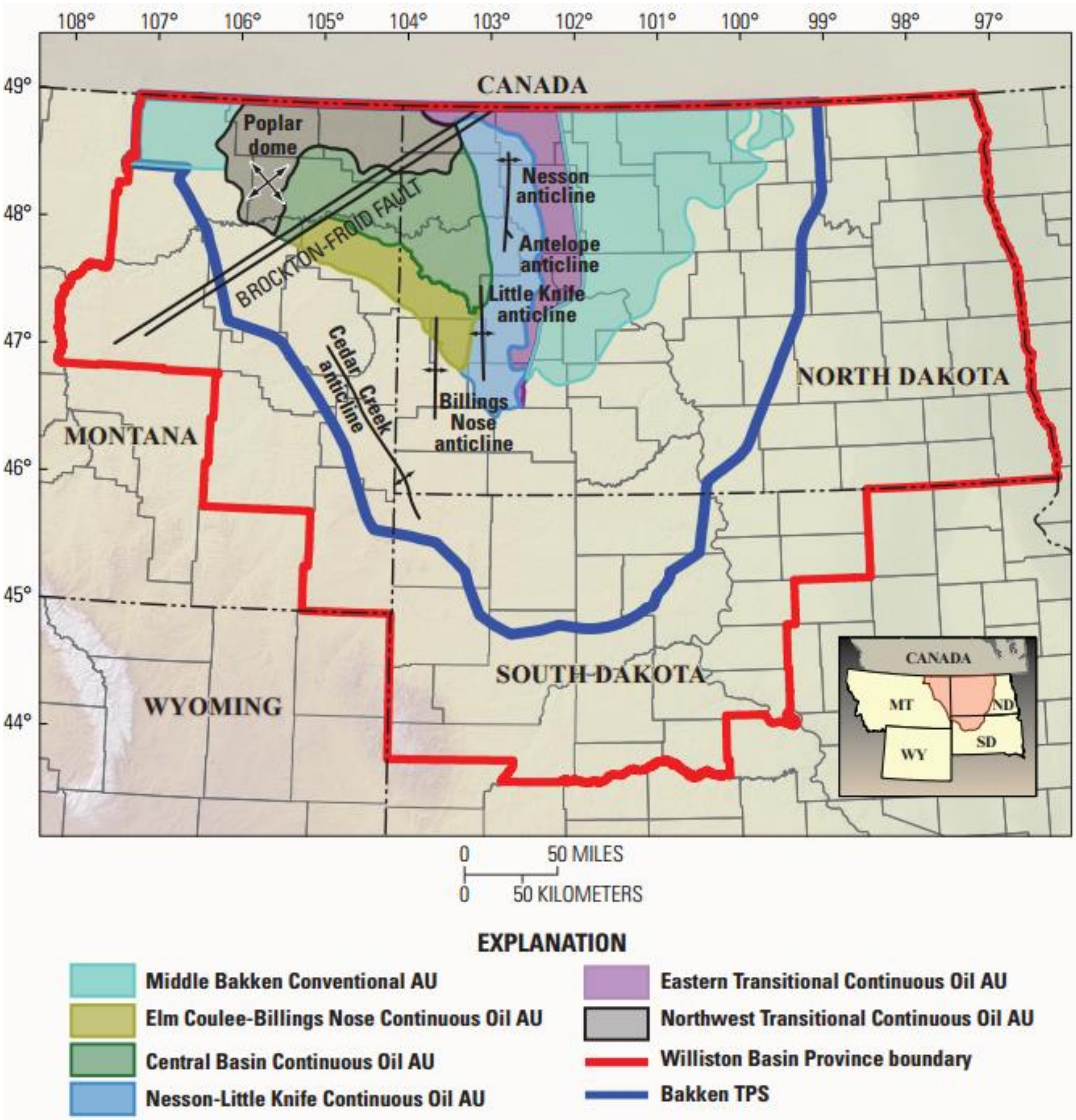

Figure 2. US Geological Survey Bakken TPS AUs map. Charlson field is located within the Nesson-Little Knife Continuous Oil AU (Gaswirth, et al., 2013).

Table 1. Bakken and Three Forks Formations assessment units base on continuous and conventional resources. This table shows the Undiscovered Resources for the Williston Basin. Charlson Field is located in the Nesson-Little Knife Continuous Oil AU (Gaswirth, et al., 2013).

Total Petroleum Systems (TPS) and Assessment Units (AU)	Field type	Total Undiscovered Resources											
		Oil (MMBO)				Gas (BCFG)				NGL (MMBNGL)			
		F95	F50	F5	Mean	F95	F50	F5	Mean	F95	F50	F5	Mean
Bakken TPS													
Elm Coulee-Billings Nose Continuous Oil AU5 0310161	Oil	218	281	355	283	174	278	410	283	11	21	36	22
Central Basin Continuous Oil AU 50310162	Oil	892	1,113	1,379	1,122	699	1,103	1,604	1,122	46	85	139	88
Nesson-Little Knife Continuous Oil AU 50310163	Oil	907	1,139	1,423	1,149	714	1,130	1,648	1,149	47	87	144	90
Eastern Transitional Continuous Oil AU 50310164	Oil	706	876	1,082	883	275	435	629	441	18	33	55	35
Northwest Transitional Continuous Oil AU 50310165	Oil	90	197	357	207	57	134	268	145	4	10	22	11
Three Forks Continuous Oil AU 50310166	Oil	1,604	3,440	6,834	3,731	1,508	3,286	6,685	3,583	105	252	553	281
Total continuous resources		4,417	7,046	11,430	7,375	3,427	6,366	11,244	6,723	231	488	949	527
Bakken TPS													
Middle Bakken Conventional AU 50310101	Oil	1	4	10	5	0	2	4	2	0	0	0	0
	Gas					0	0	0	0	0	0	0	0
Three Forks Conventional AU 50310103	Oil	0	3	7	3	0	1	3	1	0	0	0	0
	Gas					0	0	0	0	0	0	0	0
Total conventional resources		1	7	17	8	0	3	7	3	0	0	0	0
Total undiscovered oil and gas resources		4,418	7,053	11,447	7,383	3,427	6,369	11,251	6,726	231	488	949	527

The Three Forks Formation consists of five members. The lithology of the first member is mudstones mixed with sandstones and siltstones with anhydrite nodules and layers which is representative of a sabkha environment. The second member overlies the first and it consists of mudstones with anhydrite nodules and layers that were deposited in a sabkha to tidal mudflat environment. The third member is a red mudstone that represents a mudflat. The fourth and fifth member both represent a fining-upward sequence of interbedded mudstones at the base that are capped by a dolomitic mudstone. The sequences represent a tidal mudflat to intertidal to shallow offshore depositional environments (LeFever, LeFever, & Nordeng, Role of Nomenclature in Pay Zone Definitions, Bakken - Three Forks Formaitons, North Dakota, 2013).

For the purposes of petroleum exploration, operating companies in the region have divided the Three Forks Formation into four benches. The benches are representative of potential targets for drilling and production which show similar geological features. They are separated based on the rock lithology with the first bench being the top dolomitic limestone with shaly interbedding. The second and first benches are separated by a greenish-gray shale unit, which overlies the second bench. The second bench is a dolomitic limestone, which is similar in lithology to the first bench. The third bench is identified as a mudstone with anhydrite layers, and the fourth bench is consistent with member one, a mudstone with anhydrite beds and nodules.

Previous Work

The Three Forks Formation has had numerous studies completed on its general stratigraphy and depositional environments. The first stratigraphic examination of the Three Forks Formation completed was by Peale (1893). The study was conducted on Three Forks in the state of Montana, where Peale described the formation outcrops, named them, and completed geologic maps and cross sections of the region. Peale’s original name for the formation was the

Three Forks Shales which Haynes (1916) changed to the Three Forks Formation. Berry (1943) re-examined the initial study by Peale, and determined that some adjustsments in the boundary of the formation should be made based on fauna fossils.

A brief description of the Three Forks Formation can be found in a general geological overiew of the Williston Basin (Sandberg et al. (1958); Peterson and MacCarthy (1987); Gerhard et al. (1990)). Dumonceaux (1984), Berwick (2008) and Gantayo (2010) completed more in-depth studies about the facies of the Three Forks and its depositional enviornment. Nekhorosheva (2011) also completed an indepth study of Three Forks sequence stratigraphy, diagenesis and fracture analysis based on outcrop and thin section studies.

Geologic Setting

The Williston Basin underlies regions of the United States and Canada. The basin lies beneath four states and two Canadian Provinces which are North Dakota, Montana, South Dakota, Wyoming, Manitoba and Saskatchewan. It is part of the western North American Paleozoic craton, which consists of the Canadian Shield and the Transcontinental arch, an extensional portion of the shield (Peterson and MacCary, 1987). Within the Craton, the Transcontinental arch is located on the south western edge of the Canadian Shield. The Cordilleran shelf is located west of the Transcontinental arch and Canadian shield, and during most of the Mesozoic and Paleozoic Era it was the site where shallow marine cyclic sedimentation occurred. To the west of the shelf lay the Antler Orogenic belt, which during the Middle Devonian began actively growing. The Williston Basin was the major Paleozoic paleostructure in the Great Plains region that was affected by the growth and development of the Cordilleran shelf (Peterson & MacCary, 1987)(Figure 3).

Regional Stratigraphy and Sedimentology

The Williston Basin began subsiding during the Ordovician and Late Cambrian and it is characterized as an intracratonic irregular, structural and sedimentary basin (Sloss, 1987). The basin contains approximately 16,000 feet of sediment in its center, which range in age from Cambrian to Tertiary. Six major transgressive-regressive sequences can be identified in the basin, based on the relative rise and fall of sea level. The sequences are the Sauk, Tippecanoe, Kaskaskia, Absaroka, Zuni and Tejas (Sloss, 1963)(Figure 4).

Deposition in the basin was from cyclic transgressions and regressions over an uneven Precambrian surface that was due to shallow subsidence (LeFever et al., 1991). Initial sedimentation during the Late Cambrian and Early Ordovician, was primarily characterized by Paleozoic sandstones, fine-grained siliciclastics, and carbonates. These units were deposited during the Sauk transgression; the Williston Basin was not a defined structural feature until the end of the Sauk sequence. The Tippecanoe sequence refers to rocks that are Middle Ordovician through Silurian age. It consists of basal sand, shale and siltstone units that transitioned into carbonate units that show signs of major erosional events. By the end of the Tippecanoe sequence all major structures were present. Billings, Little Knife, Antelope, and Nesson anticlines are the major oil-producing structures that existed at the close of the sequence; the Cedar Creek anticline was present but not clearly defined (Gerhard et al., 1990).

Lower Devonian through Upper Mississippian rocks are part of the Kaskaskia sequence. The sequence records two regional sea-level rises and an unconformity that separates the Upper Devonian from the Lower Devonian. Before the deposition of the Kaskaskia rocks, uplift of the Transcontinental arch occurred causing the depositional setting for the lower Kaskaskia rocks to change (Gerhard et al., 1990). This change reoriented the seaway to the north into the Elk Point

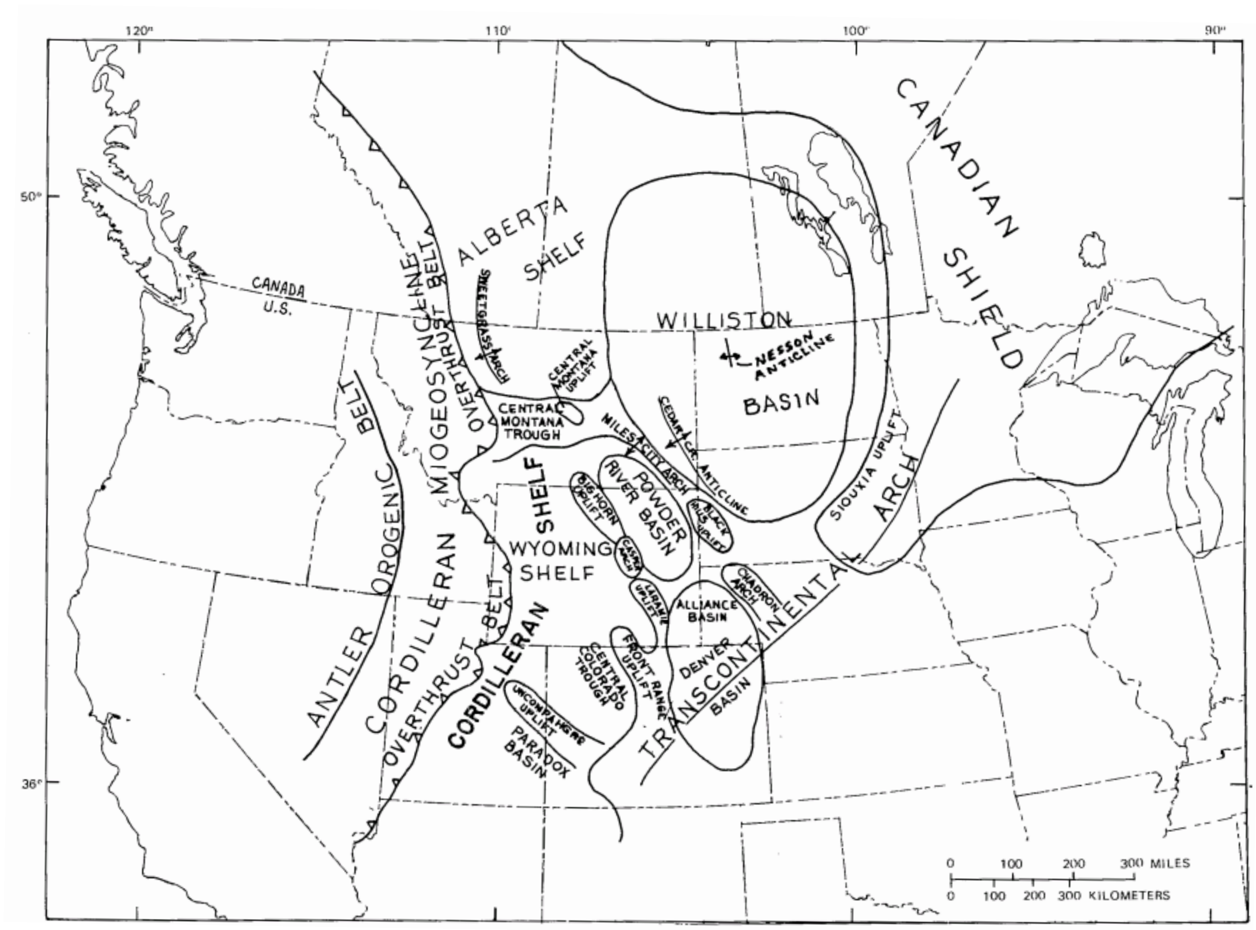

Figure 3. The Paleostructure and Paleogeography of North America and Canada. This map shows the paleostructure and paleogeography during the Paleozoic and Mesozoic. (Peterson & MacCary, 1987).

Basin of northwest Saskatchewan and eastern Alberta. The lower Kaskaskia deposits are carbonates that have been formed due to transgressive-regressive cycles. Reorientation occurred again during the Mississippian, beginning of the upper Kaskaskia, when the basin opened to the west through the central Montana trough. During this time, uplift occurred exposing the sediment to erosion that occurred in the northeastern portion of the basin. The southern portion of the basin was unaffected (LeFever et al., 1991). The erosional boundary between the upper and lower Kaskaskia is the Late Devonian Three Forks and Early Mississippian Bakken Formation. The upper Kaskaskia rocks were deposited in a rapid transgression and slow episodic progradation (Gerhard et al., 1990).

An extensional surface on the upper Kaskaskia sequence was developed at the end of the Mississippian due to widespread structural deformation. The Absaroka sequence, Pennsylvanian through Triassic time, rocks consist mostly of siliciclastic sediments, which contrasts to the previous carbonate and evaporite deposition. Tectonism during Late Mississippian and Pennsylvanian caused regional uplift of the Williston Basin, and the sediments that filled the basin were possibly derived from the Ancestral Rocky Mountain uplift of the Canadian shield and the Hartville uplift. The final major marine unit in the Williston Basin was the Cretaceous Pierre Shale during the Zuni sequence. The Tejas sequence only has a small representation in the basin (Gerhard et al., 1990)(Figure 5).

Devonian Rocks. In the central part of the basin, the total thickness of the Middle and Upper Devonian beds is more than 2,000 ft. Thinning occurs uniformly southward across Montana toward the Central Montana uplift and along the crest of the Cedar Creek Anticline. These two paleostructures underwent structural growth during the Devonian (Peterson & MacCary, 1987). The Devonian Period deposition consisted of a cyclic sequence of shallow

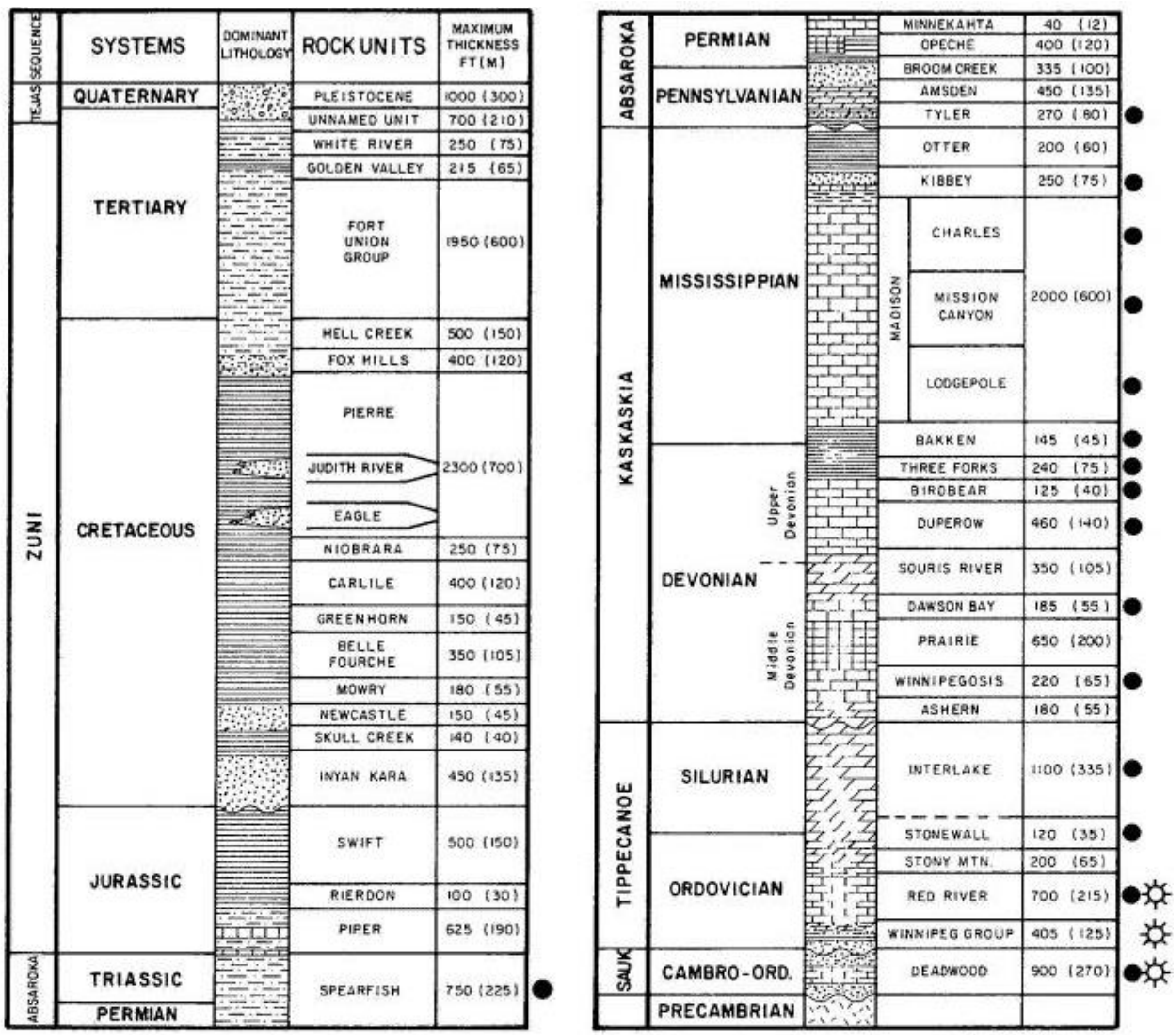

Figure 4. Stratigraphic Column for the Williston Basin. The figure shows the sequences of the Williston Basin and during which period they occurred. The black dots on the right side of the column are representative of which formations produce oil or gas (LeFever, 1992).

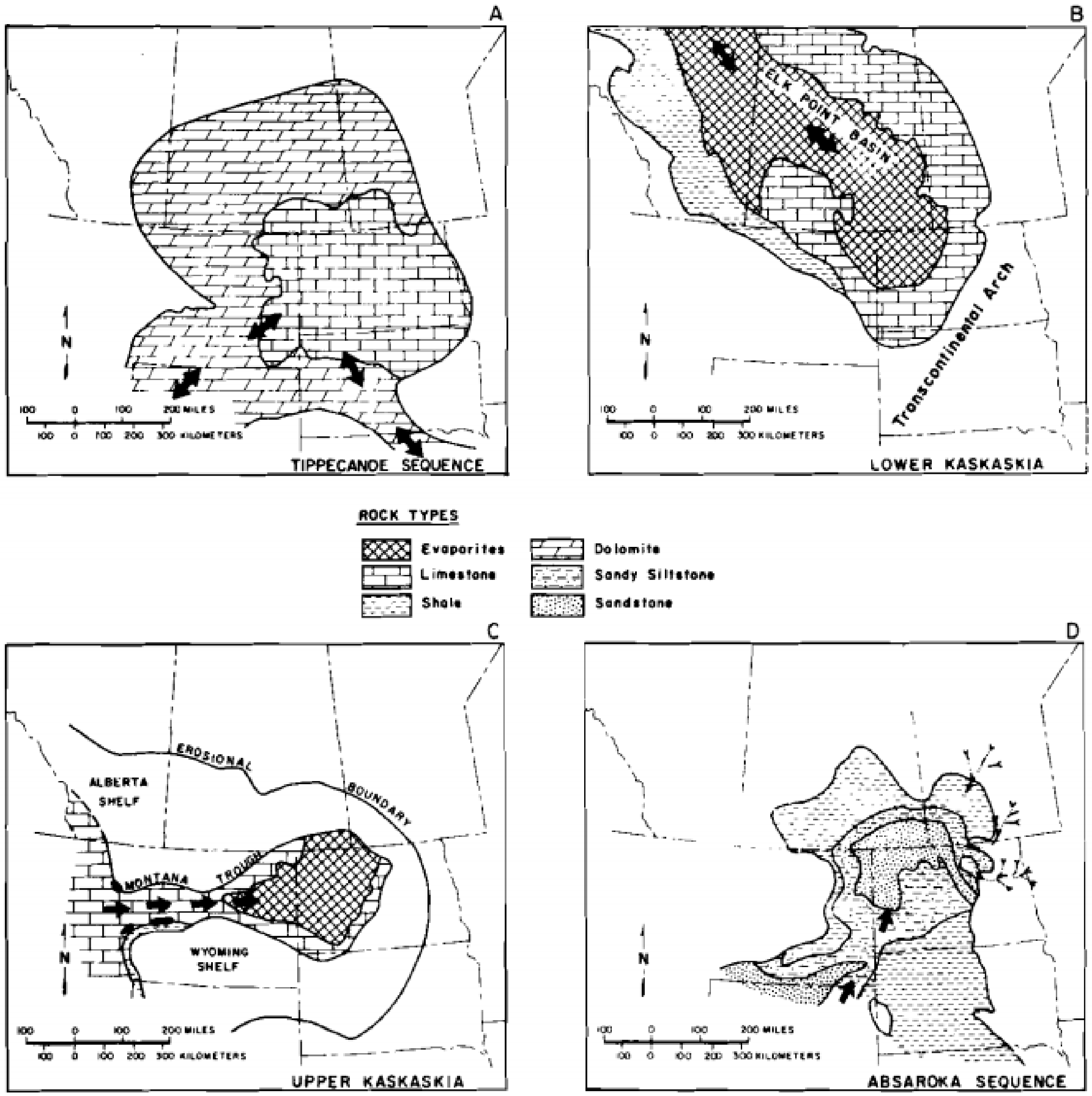

Figure 5. Times of marine communication sequentially. The arrows represent the direction of open communication: A. Tippecanoe sequence - open to the Cordilleran B. Lower Kaskaskia sequence - having connectivity with the Elk Point Basin in the Northwest C. Upper Kaskaskia sequence – connectivity with the Montana Trough D. Absaroka sequence – connectivity to the southwest with sediments from potential Rocky Mountain uplift (Gerhard et al., 1982).

water fossiliferous carbonates, shaly carbonates or shales, and evaporates.

Red dolomite, siltstones, and shale beds are the initial deposits of the Devonian seaway. These make up the Ashern Formation, which grades upwards into the Winnipegosis, a reef- and mound-bearing carbonate. The Middle Devonian Prairie Formation overlies the Winnipegosis, which consists of a lower unit of anhydrite, dolomite, thin-shale, and halite beds and an upper halite interval that consists of interbedded red shales. The Dawson Bay Formation overlies the Prairie Formation. The Dawson Bay is the final episode of Middle Devonian deposition, which contains a single carbonate-evaporite cycle (Peterson & MacCary, 1987).

The Upper Devonian rocks were deposited during the maximum transgression of the Devonian seaway. They consist of several cycles of carbonate-evaporite and fine clastic beds. The Souris River Formation is the first of the Upper Devonian units; it consists of several depositional cycles of upward grading clastics into dolomite or limestones capped by anhydrites. The Duperow Formation overlies the Souris River Formation; it is a cyclical carbonate-evaporite sequence (Peterson & MacCary, 1987).

The Duperow Formation underlies the Birdbear Formation, which is the final carbonate-evaporite cycle of the Devonian. It consists of four main depositional environments: subtidal, intertidal, lagoonal, and supratidal. The contact between the Birdbear Formation and the overlying Three Forks Formation is conformable with localized erosion (Peterson & MacCary, 1987). The lithology of the Birdbear is a dolostone overlain by sucrosic dolomite and is uniform in lithologic character (Sandberg, 1965). The Three Forks Formation is Upper Devonian and conformably overlies the Birdbear Formation and unconformably underlies the Bakken Formation. It has an average thickness of 150 feet and a maximum thickness of 250 feet in North Dakota (Webster, 1984). It is the focus of this study and was originally named the Three Forks

Shales by Peale (1983); it was given its name from the outcrop that overlies the Jefferson Group limestone near the town of Three Forks, Montana. Haynes (1916) renamed it the Three Forks Formation and divided it into seven members compared to Peale's two. The current division of the formation is five members with the removal of the Sanish unit from the top of the formation and changing the boundary so it is now a continuation of the Bakken Formation (LeFever et al., 2013).

The basal unit of the Three Forks is a sandstone siltstone mix with anhydrite bedding and nodules, this transitions into a red muddy siltstone. The top units are thinly-bedded silty dolostones with green claystones that represent a fining upward sequence (LeFever et al., 2013). The Three Forks Formation represents the final regressive phase of Devonian sedimentation (Peterson & MacCary, 1987).

Late Devonian and Early Mississippian Rocks. The Bakken Formation overlies the Upper Devonian Three Forks Formation. It is a relatively thin basal unit of predominantly carbonate rocks that were deposited during a cycle of onlap-offlap sedimentation. The formation is composed of three members, two shale units, an upper and a lower, and a middle member that consists of mudrocks and sandstone.

The upper and lower shale members are generally identical in lithology throughout their areal extent. They are mainly composed of organic material with lesser amounts of clay, silt and dolomite grains. The Lower Bakken shale has more clay, silt and dolomite with less organic content near the western flank of the basin where the formation pinches out. The Middle Bakken member is faintly laminated with some fine-scale crossbedding. It consists of dolomitic siltstone to a silty, fine-crystalline dolomite. It was deposited in a deep marine to shallow marine and tide-dominated coastal environment and is overlain by the Lodgepole Formation (Meissner, 1978).

Regional Structural Geology

During early Ordovician or Late Cambrian, the Williston Basin started taking shape as a distinctive area of crustal subsidence and sediment accumulation (Clement, 1987). The Superior craton, Trans-Hudson orogenic belt, and the Wyoming craton are three tectonic provinces that underlie the Williston Basin. The sedimentation and structure of the basin are strongly influenced by movement of basements blocks that were structurally defined during pre-Phanerozoic time (LeFever J. A., 1992; Gerhard et al., 1982). The northwestern-trending northern Rocky Mountain chain offset, is related to several notable structures present in the North American part of the basin. The Cedar Creek, Antelope and Poplar anticlines are northwest trending. The Nesson, Billings, and Little Knife anticlines are north trending structures (Gerhard et al., 1982)(Figure 6).

The Cedar Creek Anticline had significant tectonic activity from early Paleozoic through Middle Tertiary time. The four major periods of growth for the anticline were during Early Devonian, Late Devonian, Late Mississippian – Triassic, and Post –Paleocene (Clement, 1976). The Cedar Creek evolved as a northwest striking structure due to uplift and erosion that affected the entire craton in the Early Devonian. The Late Devonian event caused uplift of the Cedar Creek block causing it to be significantly tilted northward and eastward, this was the first pronounced fault movement. Extensive erosion occurred during this time removing all Devonian sediments from locally uplifted regions (Clement, 1987). Tectonism occurred during the Late-Mississippian through Triassic causing fault reversal. The greatest uplift of the Cedar Creek block occurred during the post-Paleocene, the northwestward regional plunge and eastward dip were significantly increased (Clement, 1987).

The Nesson anticline, along with the Cedar Creek, has produced most of the basin's hydrocarbon. The Nesson anticline is the most prominent feature in the Williston Basin and dates back to the Precambrian (LeFever et al., 1991). It is a north trending, south plunging fold that extends from the Killdeer Mountains to just south of the Canadian border. A notable change in the fold occurs in Charlson field where the Nesson fold splits into three folds: 1) Antelope anticline oriented to the southwest; 2) the continuation of the main branch of the Nesson anticline; 3) a secondary fold that is not well developed that is in line with Clear Creek and Camel Butte Fields (LeFever et al., 1987).

There are two faults that occur near the Nesson anticline. The first one, the Nesson fault, is on the western side of the anticline. It has existed since the Precambrian and its dominant direction of movement is west side down. The second fault occurs along the northeast side of the Antelope anticline (LeFever et al., 1987). The direction of movement for the second fault is northeast side down.

Geologic Overview of Charlson Field

Charlson Field is located in the northeastern part of McKenzie County, North Dakota. The Amerada Hess Corporation drilled the first well in the field in 1953 the Cora McKeen 1. The well was dry and the following wells drilled in the field did not produce. The initial target for the field was the Madison Formation.

In July of 1991, the first well that targeted the Three Forks Formation was productive. The well was vertical and was perforated throughout the Three Forks Formation. The resultant total production was very low. It took 15 more years for the next Three Forks well to be completed. In July of 2006 the first horizontal Three Forks well was drilled. At this point, the technology had advanced and horizontal wells were more common in drilling practices. The difference in production was over 150,000 barrels of oil (bbls). Due to the recent advancements in drilling, horizontal wells are common in current drilling practices for unconventional

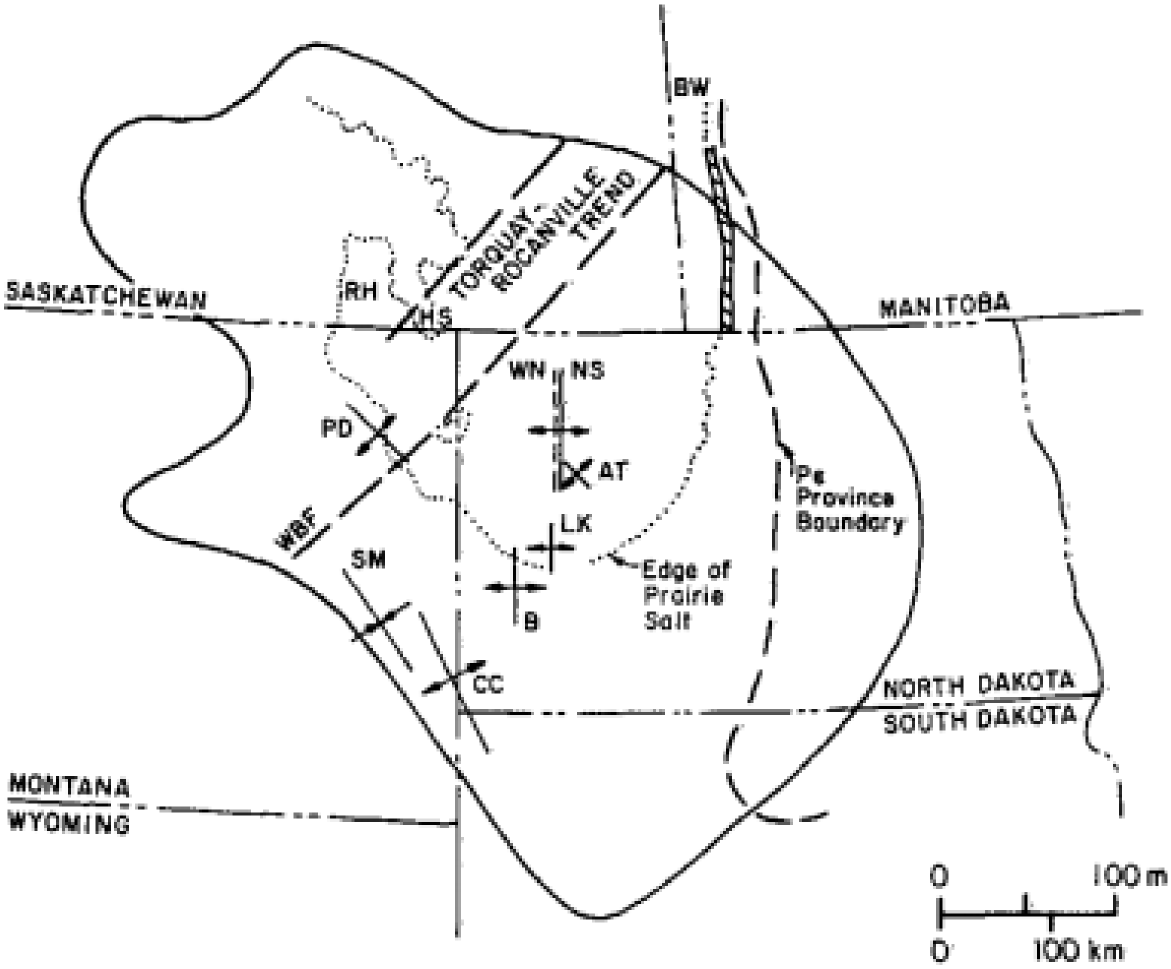

Figure 6. Major Structural features within the Williston Basin. Western Nesson Fault (WN); Nesson anticline (NS); Antelope anticline (AT); Little Knife anticline (LK); Cedar Creek anticline (CC); Weldon-Brockton-Froid Fault Zone (WBF) (LeFever, Martiniuk, Dancsok, & Mahnic, 1991).

reservoirs. The increase of exposure of the formation to the wellbore greatly increases the production of the formation. Since this method has been deployed, the production from wells have increase, which can viewed from past to current production totals.

Charlson Field is still active with new wells being drilled. As of June 12th, 2015, 397 wells have been drilled in the field (Department of Mineral Resources, 2015). The total thickness of the Three Forks Formation in Charlson Field ranges from 200 to 230 feet (Figure 7).

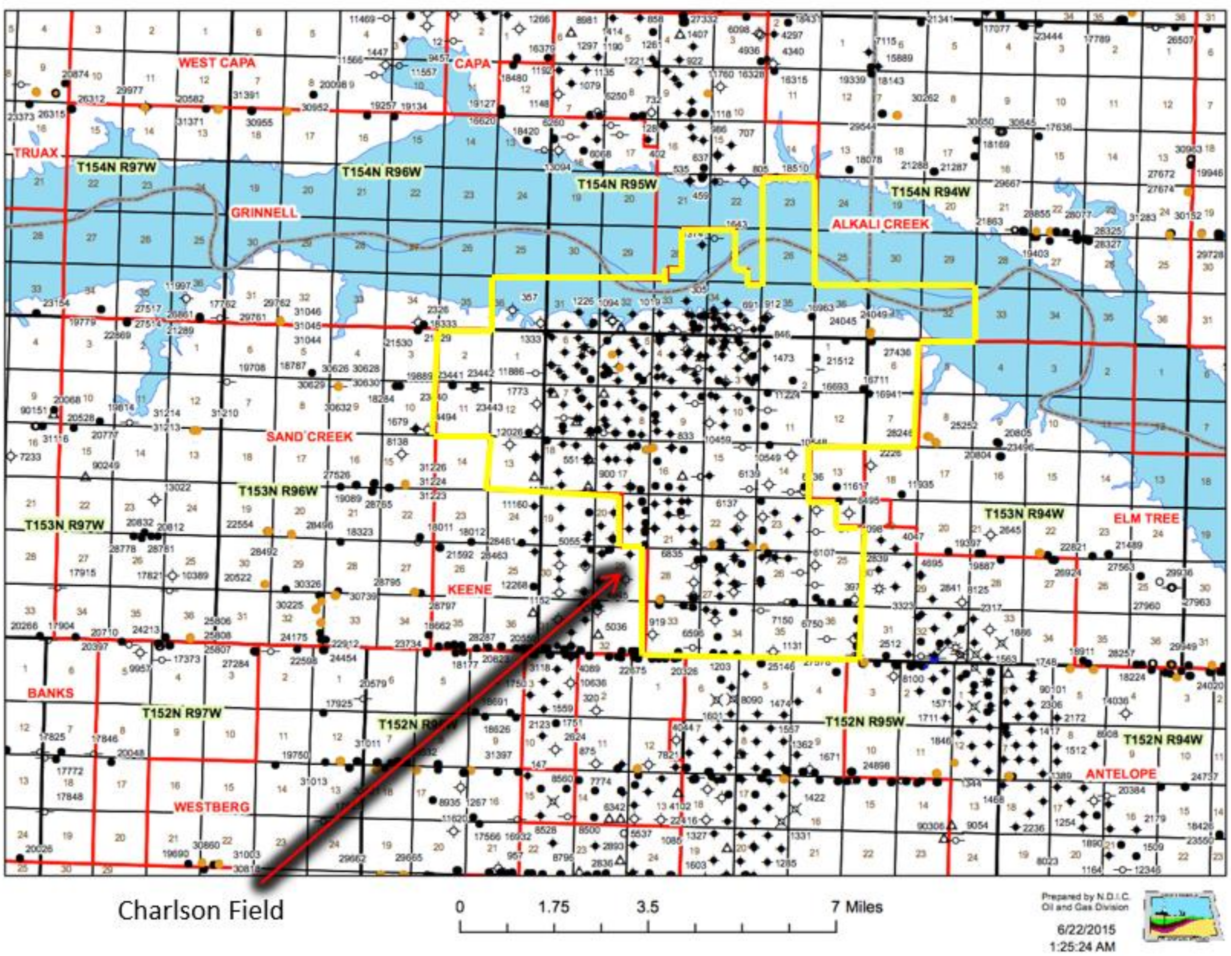

Figure 7. Drilled wells in Charlson Field, Williston Basin. The map represents all of the drilled wells (black circle) in Charlson Field, North Dakota.

CHAPTER II

METHODS

This chapter discusses different steps that were taken to prepare the well log data for petrophysical analysis and hydrocarbon pore volume (HCPV) estimation. Included is: data preparation beginning with digitizing well logs to gain numerical well log data for equation parameters such as porosity, net pay and saturation; subsurface correlation to find the producing intervals/reservoirs; calculating oil in place or equivalent hydrocarbon pore volume to distinguish productive areas in the field; mapping the results for visual understanding.

Well Log Analysis

Well logs can be used for many different purposes such as correlating zones, lithology, porosity, and permeability estimation; they are considered as one of the most important tools for subsurface petrophysical interpretation (Asquith et al., 2004). With petrophysical analysis, details such as drilling location, productive zones, reservoir fluids, and hydrocarbon reserves can be obtained. The physical properties of rocks that are recorded are the electrical properties, porosity, lithology, mineralogy, permeability, and water saturation.

Some sedimentary rocks are naturally radioactive and due to these properties they can be measured by a Gamma Ray log. The Gamma Ray (GR) log measures the natural radioactivity of the rock. The logs generally represent the shale content of the formation, where rocks containing clay minerals or the fine particles of shale show high levels or natural radioactivity, are considered dirty and carbonates or sandstones that exhibit a low level of natural radioactivity, are considered clean (Swanson, 1960). The purpose of the log is to determine lithology of subsurface rocks due to its ability to determine the shaliness of the formation. GR is measured in API with the scale of 0-100 with 0 being free of radioactive elements.

The resistivity logs are normally run with the gamma ray log. The purpose is to measure the electrical resistivity of the combination of the rock and fluids in the formation. The probe takes measurements of various radii intervals horizontally into the formation from the borehole wall as it ascends or descends the well during the logging process. Several horizontal depths of investigation are important as changes occur in the electrical resistivity properties due to the invasion of the drilling mud into the formation. A high resistivity may indicate there is hydrocarbon within the pores of the rock. If the resistivity measurement is low it indicates the formation fluids are salt water with a low probability of oil.

Formation density is determined by using a radioactive source that bombards the formation with protons. When the protons are emitted into the formation, they are absorbed, scattered, or pass through. Then a separate receiver measures the ability of the formation to scatter the protons. The flux density of protons that return is inversely proportional to the electron density of the rock, which is in return proportional to the rock density. This measure is then converted to a porosity measurement. The formation lithology and pore fluid can affect the density reading, so the log should be calibrated based on the matrix of the formation.

The compensated neutron log is used to determine the porosity of the formation. The probe measures the neutron length travelled based on time from the distances of its source. Due to the content of the pore spaces in the formation, the neutrons that are emitted come into contact with hydrogen (water, oil or gas), and are either transmitted through the formation or scatter returning to a separate receiver. From the receiver, a high number of counted neutrons reflect low formation porosity and a low number of counted neutrons reflect high formation porosity. When dealing with gas zones, neutron porosity should not be evaluated alone, but combined with other measuring tools to gain an accurate reading. All logs should be combined to determine if the formation is a reservoir for hydrocarbons (Dresser Atlas, 1982).

Digitizing and Editing

The wells in the Three Forks Formation were digitized using the NeuraLog™ software. Digitizing uses a well log image, or a raster log which is a TIFF or JPEG, and the software is used to transform the image into a set of digital data that is pulled from the log. The software works by calibrating the raster log so the scale of the log is set; next the user manually traces the well curve in the image to create data points or numbers. Once all of the curves are traced, the image is turned into a text file (LAS) so that the data can be imported into Petra™. While digitizing, the logs were checked for quality and despiked; when the tool has a poor signal the curve may have an abrupt change or spike. Where these spikes occurred, the data were removed and smoothed. The well logs that were digitized were caliper (Cal), gamma ray (GR), resistivity (R_t), and compensated neutron density (CND) to be used in petrophysical calculations. In Charlson field 77 wells contained these logs and were digitized.

Depth Shifting

Logging tools can encounter problems when being run through the borehole. The tools can get caught on a ledge or seem in the drill rod or casing when descending or ascending, which can cause errors in the depth correlation of well log readings. When this occurs each set of logs from a well should be compared to take into account any offset that has occurred or stretching in the logs. The purpose is to match log responses with the corresponding depth in the well while the recorded depth on the log could be different. This process is called depth shifting. Depth shifting was completed for all 77 wells in this study. The gamma ray log was used as a reference for comparison between the log suites of the resistivity and compensated neutron density logs. A point should be used to correlate between the log suites. For the Three Forks Formation the top of the first bench was used as a marker because its dolostone to shale transition shows a distinct pattern on the gamma ray log making it easy to identify for accurate correlations. Any logs with greater than a two foot discrepancy were adjusted.

Well Log Correlation

The correlation and mapping of the Three Forks Formation benches was done by the acquisition of well data for 77 wells in Charlson Field (Department of Mineral Resources, 2015) (Figure 8). All well data that were used were vertically drilled wells that either partially or fully penetrated the Three Forks Formation. The data from the horizontally drilled wells were not used in this study, since tools are not normally run down the lateral. The digital raster copies of the well logs were imported into Petra™, a geologic mapping and correlation software. The additional available data from the NDGS and Operators was also loaded into the appropriate section; the data included cores, production data, spud date, well depth, etc. The type log for correlating was the Uberwachen 22-34 (Figure 9), it fully penetrates the Three Forks Formation was logged with an advanced suite of well logs and has an available core. The tops were picked for each of the four benches (Figure 10 and Figure 11), and also for the lower Bakken Shale member, Pronghorn Member (when present), Three Forks Formation and the Birdbear Formation.

The tops for each bench, member, and formation were picked in all 77 wells; they were used to create structural contour and isopach maps for each interval. Structural maps delineate

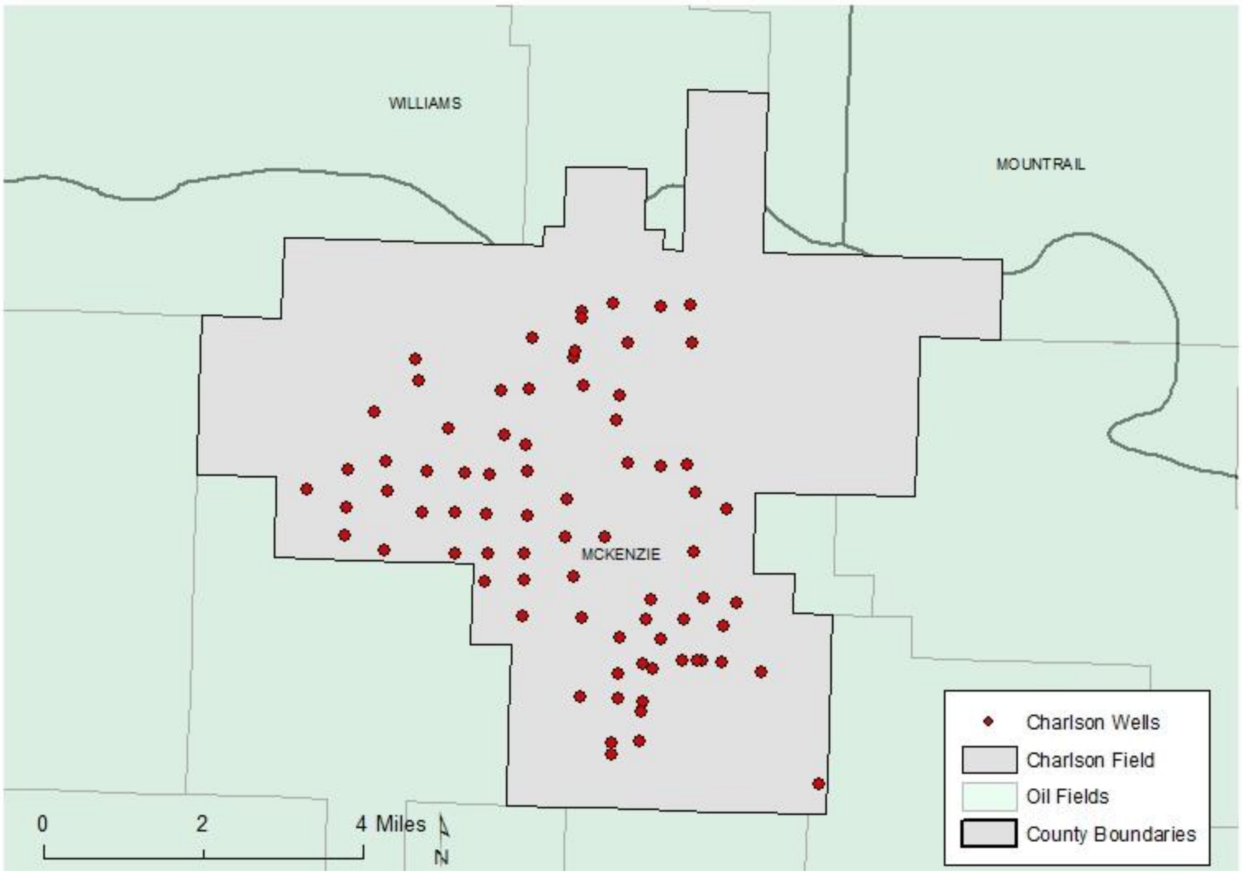

Figure 8. Wells in Charlson Field used for this study. These are the vertical wells in Charlson Field that were used to correlate and map the Three Forks Formation in Charlson Field.

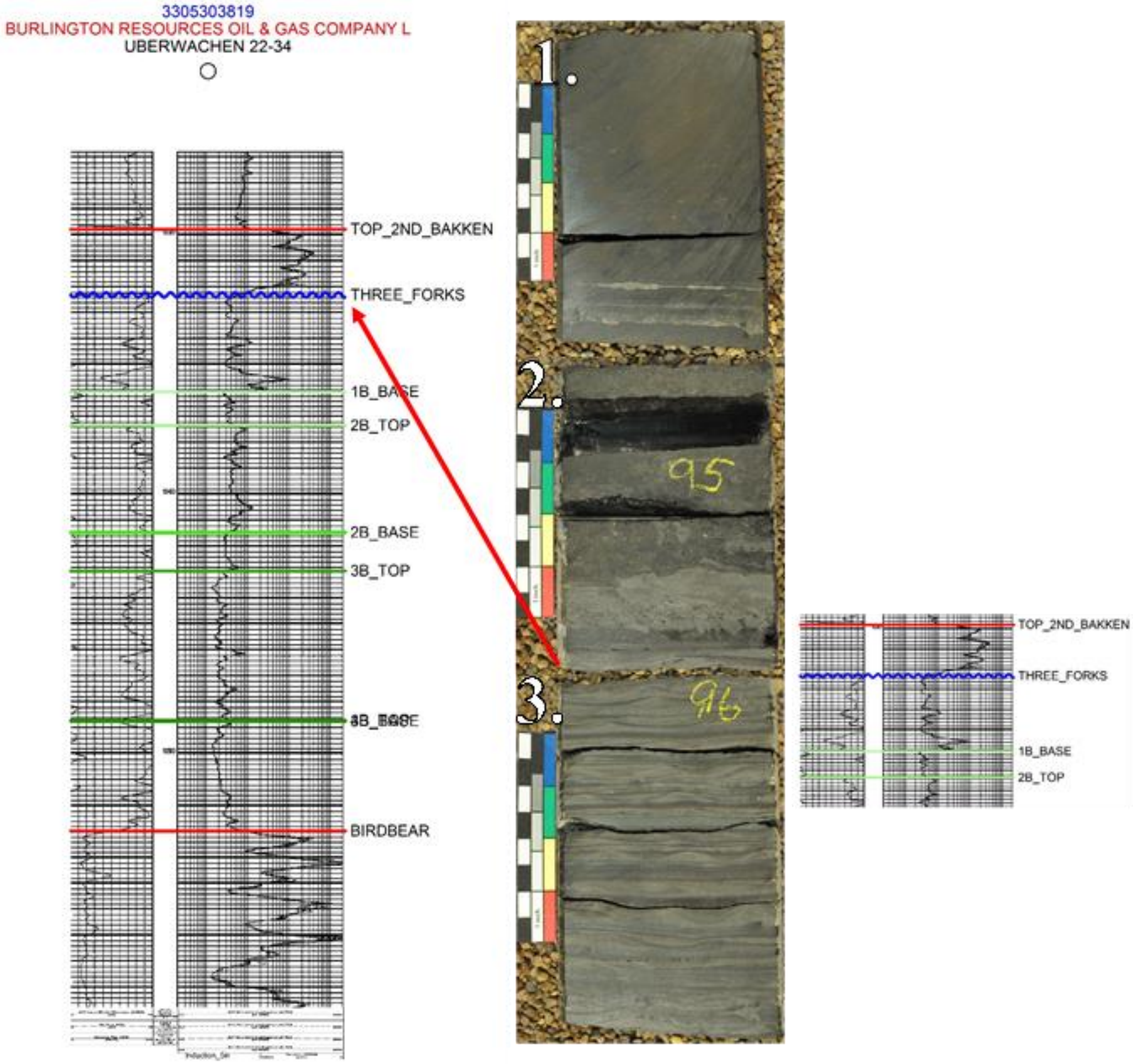

Figure 9. Type section for Three Forks correlating. The well logs were correlated to the core to determine where the Three Forks Formation and benches begin. In the figure the core for the Uberwachen 22-34 core is on the right and it starts at the depth of 10924 (1) and the well log suite is on the left.

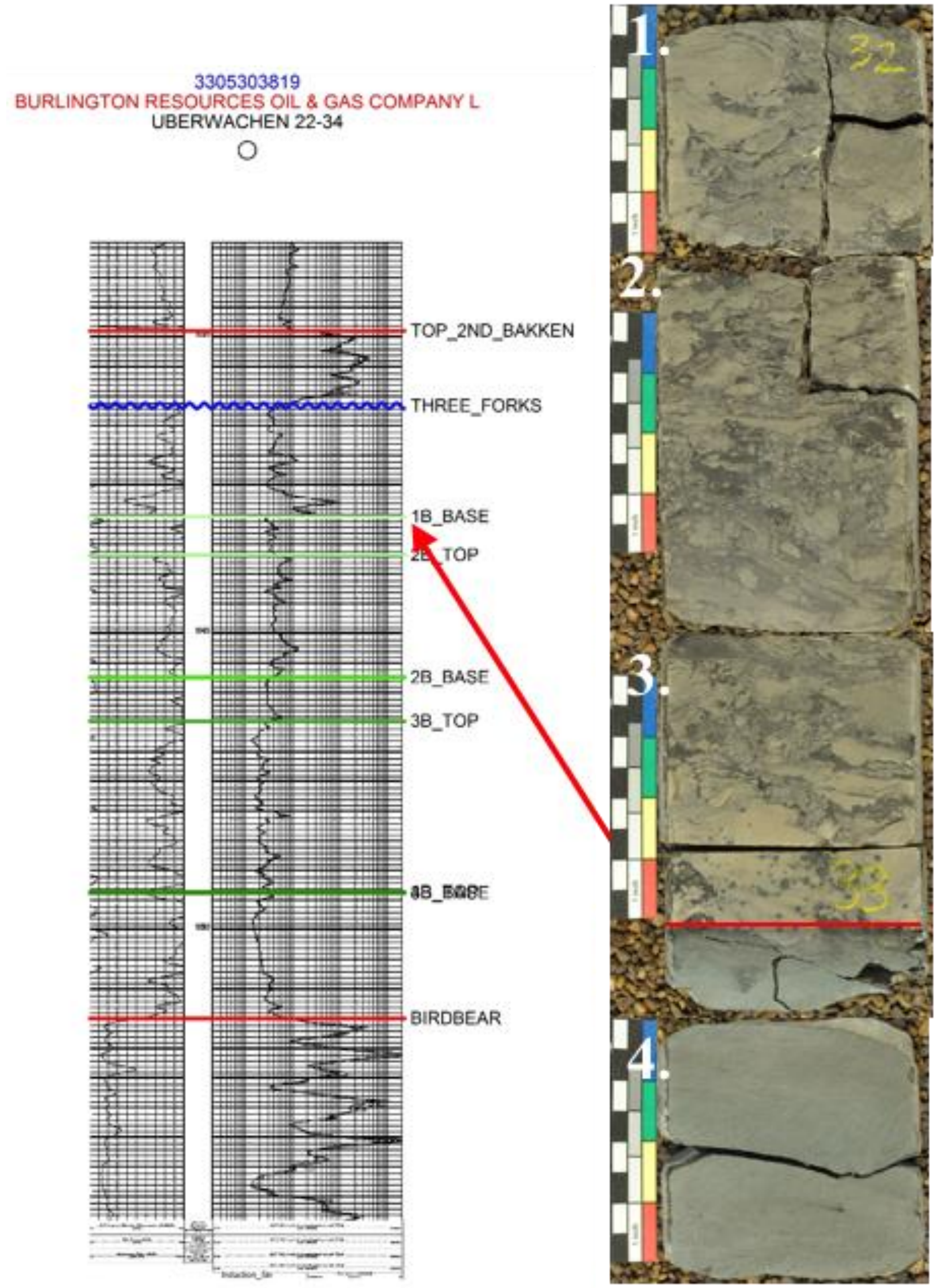

Figure 10. First bench core and log correlation. The well logs were correlated to the core to determine where the first bench begins. In the figure the core for the Uberwachen 22-34 core is on the right and the well log suite is on the left. The transition from the fist bench to the shale unit that underlies it (3).

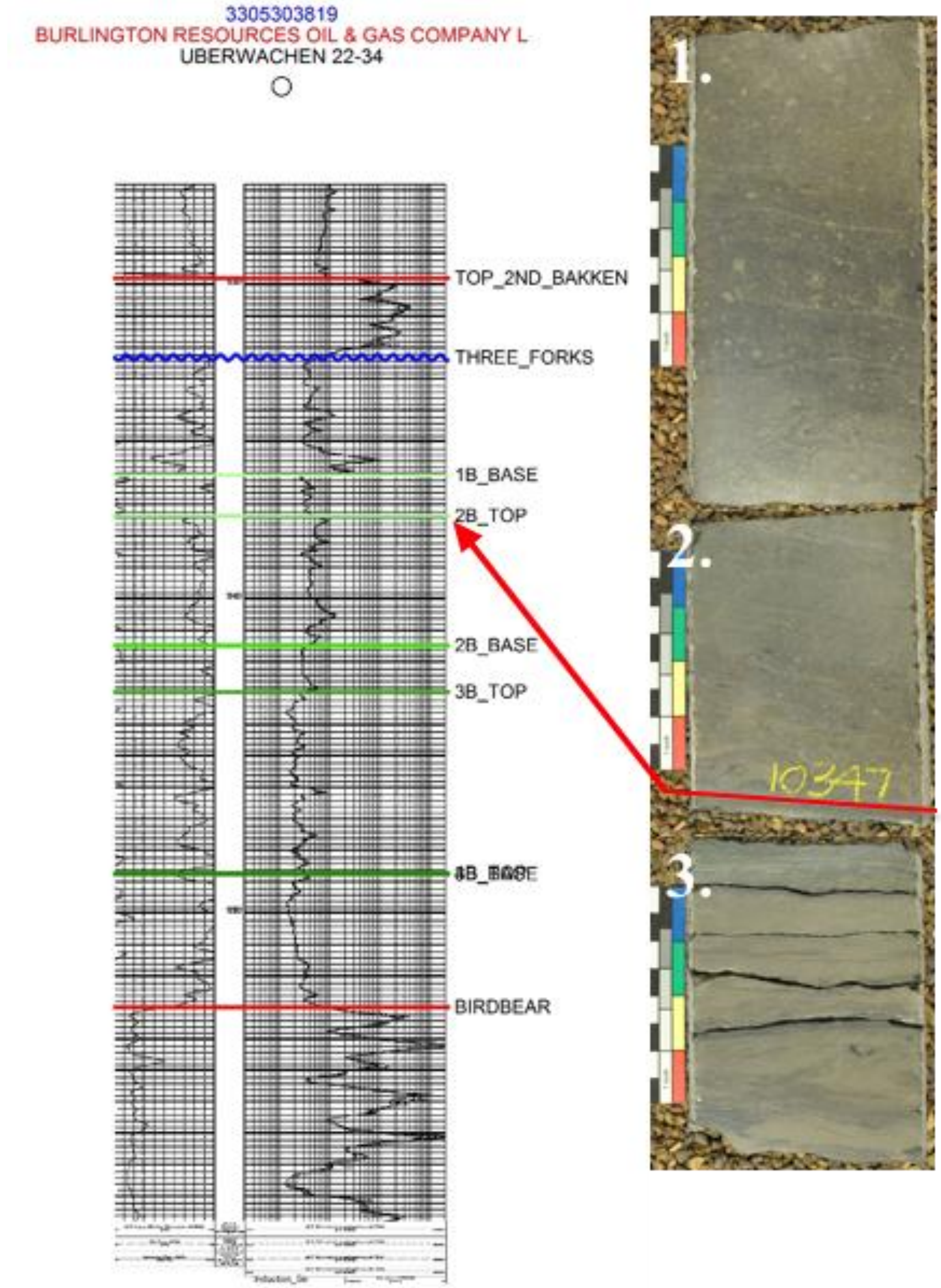

Figure 11. Second bench core and log correlation. The well logs were correlated to the core to determine where the second bench begins (2), transition from the shale unit to dolomite. In the figure the core for the Uberwachen 22-34 core is on the right and the well log suite is on the left.

the formation outline and the isopach maps reveal the formation and bench thicknesses. From the maps it can be deduced where a pinch out occurs, to locate potential stratigraphic traps.

Petrophysical Analysis

In order to acquire subsurface data, well logs and cores retrieved from a well are used to represent the rock properties in the subsurface. They are able to provide estimations of reservoir properties such as porosity, permeability, and lithology. The gathered data can be used for calculating water saturation and hydrocarbon pore volume (HCPV), which leads to evaluating and potential production. However, before data can be obtained from the logs they must go through a series of corrections and editing such as environmental and shale volume calculations. These corrections should be applied to each well to assure data accuracy and quality to improve calculations and final results.

Core data can also be used to understand the properties of the rocks in the subsurface. Water saturation, oil saturation, porosity and permeability are additional information that can be extracted from core analysis. The core data is an additional assessment that can be applied to make the analysis more accurate. These methods were used on each bench of the Three Forks Formation to determine the potential sweet spots.

Shale Volume Correction and Porosity Calculation

The presence of shale in a formation can cause complications when interpreting well logs. Shaly formations have an effect on the well-logging tool measurements; in some situations, this effect can cause a large discrepancy in the final estimations for reservoir potential. The logs that can be greatly affected by the presence of shale are the R_t (resistivity) and CND logs. The clay bound water in shale causes the R_t log to decrease; as a result the S_w will be overestimated, causing the reservoir potential estimation to decrease. The clay bound water also affects the porosity logs by causing the porosity signature on the log to increase, since the CND log counts the number of hydrogen's present. This creates an over estimation of porosity due to the water that is bound in the clay and not in the pore space of the rock. In the presence of shale, calculations are used to correct the logs that are affected.

The Three Forks Formation has shaly laminations throughout the first and second bench. Since the laminations are less than 2 feet, the correction cannot be completed. The resolution of the shale is less than the resolution of the logs, so a more advanced analysis should be completed. The advanced study is called thin bed analysis (TBA) and it uses a Nuclear Magnetic Resonance (NMR) tool. From NMR, the clay bound water, oil saturation, and porosity can all be determined (Boyd et al., 1995). The equipment for this test is not widely available and the cost to run the analysis was not feasible for this study. The porosity data was acquired from the Compensated Neutron Density (CND) logs that were present in 77 wells. The porosity that was used for the Three Forks Formation was the cross-plot porosity, which is the average of Density and Neutron porosity logs:

$$\phi_{x-plot} = \frac{(\phi_{CNL} + \phi_{FDC})}{2} \quad (1)$$

Where: $\phi_{x\text{-}plot}$ = cross-plot porosity

ϕ_{CNL} = compensated neutron log porosity

ϕ_{FDC} = formation density compensated porosity

Data from the cores were then compared to their corresponding log calculations for $\phi_{\text{x-plot}}$ to verify that the values were similar.

Resistivity and Water Saturation Calculations

Formation Water Resistivity (R_w) analysis was carried out for the Three Forks Formation. R_w is in situ resistivity of the formation waters and it is measured in ohm-m or ppm. A correction needs to be completed for this measurement due to the changing salinity of the formation fluids from the decreasing temperature as the sample is tested at surface conditions. The first step in the calculation is to determine the mean annual surface temperature of the oilfield. The data in Table 2 represents the mean monthly temperature. To estimate the mean annual temperature, the data was averaged and found to be 42˚F in Charlson Field. After the annual surface temperature is acquired, the temperature gradient should be calculated for the water samples acquired from the wells in the field. The well water sample data was from the North Dakota Department of Mineral Resources, North Dakota Geological Survey. Either an equation or chart can be used to determine the temperature gradient; the equation was used in this study and cross-referenced with the chart (Figure 12).

Table 2. Average monthly and annual temperature, Charlson Field. The table represents the average annual and monthly temperature for Charlson field. The data was acquired from NOAA http://www.idcide.com/weather/nd/new-town.htm.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Max °F	21.0	28.9	40.8	57.0	69.6	77.8	83.9	84.3	72.1	58.6	37.2	25.3	54.7
Mean °F	10.8	18.6	29.6	43.5	55.5	64.1	69.4	69.2	57.9	45.6	27.6	15.4	42.3
Min °F	0.5	8.3	18.3	30.0	41.4	50.4	54.8	54.0	43.7	32.6	18.0	5.5	29.8

$$m = \frac{y - c}{x} \tag{2}$$

Where: m = temperature gradient

y = bottom hole temperature (BHT)

c = mean annual surface temperature

x = total depth (TD)

The well header lists the additional information that is required to calculate the temperature gradient. The BHT and TD are read from the header, and the data can be input into the equation.

Once the gradient has been calculated, the temperature for the formation that the sample was taken from should be adjusted.

$$y = mx + c \quad (3)$$

Where: y = formation temperature

m = temperature gradient

x = formation depth

c = surface temperature

The final step of calculating R_w is to insert all previously calculated information and the remaining data from the water chemistry data into the following equation or use the chart (Figure 13). The Fluid Resistivity Chart uses the measured R_w at surface temperature, and based on the formation temperature, it will give an estimated value for the Resistivity at formation depth.

$$R_{TF} = \frac{R_{temp}(Temp + 6.77)}{T_f + 6.77} \quad (4)$$

Where: R_{TF} = resistivity at formation temperature

R_{temp} = resistivity at a temperature other than formation temperature

$Temp$ = temperature at which resistivity was measure

T_f = formation temperature

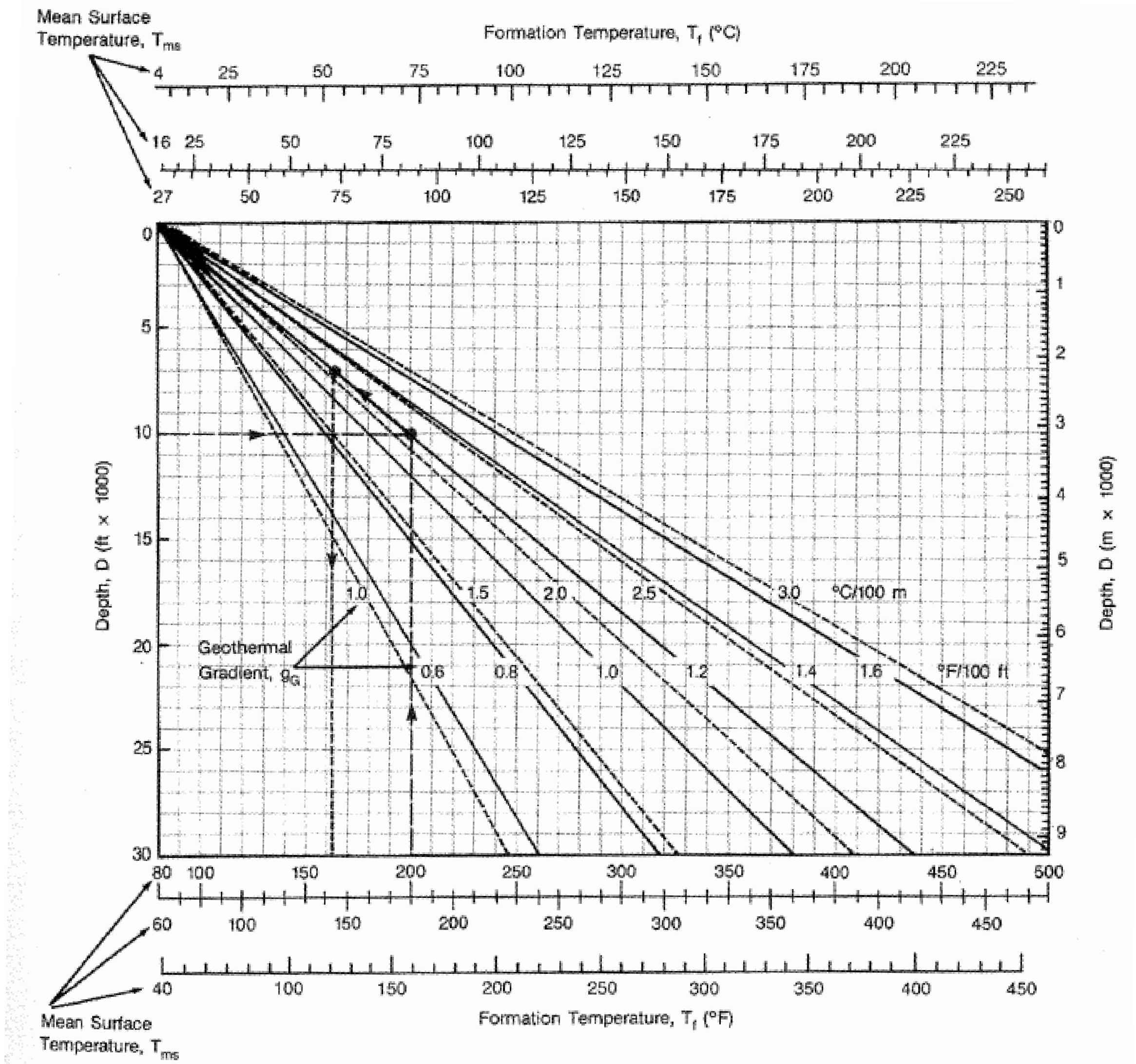

Figure 12. Chart to estimate formation temperature with depth. Based on the calculated geothermal gradient, the mean surface temperature, and the bottom hole temperature the formation temperature can be estimated (Asquith, Krygowski, Henderson, & Hurley, 2004).

Water saturations (S_w) were then calculated by using the standard Archie saturation equation:

$$S_w = \left(\frac{a \times R_w}{R_t \times \phi^m}\right)^{\frac{1}{n}} \quad (5)$$

Where: S_w = water saturation of uninvaded zone

R_w = formation water resistivity

R_t = formation resistivity (uninvaded zone)

ϕ = porosity

a = tortuosity factor

m = cementation exponent

n = saturation exponent

The R_w was determined by the water analysis data; R_t values are taken from the deep resistivity curve from the digitized well log data, and the porosity values that are used are from the cross-plot porosity that is calculated, $\phi_{x\text{-plot}}$. The saturation exponent, *n*, is the dependency on the presence of hydrocarbons in the pore-space (Asquith et al., 2004).

The tortuosity factor, *a*, is measured as the resistance of fluids to flow on a specific path. In sedimentary rocks the route is the path between the pores, which the fluid can flow. The cementation exponent, *m*, can change based on grain size, grain-size distribution, and the tortuosity of the rock. The saturation exponent, *n*, is the dependency on the presence of hydrocarbons in the pore-space (Asquith et al., 2004). The values are best determined by laboratory experiments.

When available, a, m, and n are calculated from the core and log data. Core plugs, cylindrical rock samples, are taken from specific intervals from the core and tests are run to determine a, m and n. For the logs, an iterative process can be completed on the resistivity logs and porosity logs to get a more accurate value for m and n. For the Three Forks Formation, this process is not possible due to the clay bound water that cannot be corrected. There was no data on the m and n core values for Charlson Field, but based on the lithology of the rock (Table 3), the most common values were used in the S_w equation. The tortuosity factor (a) was assumed to be 1, the saturation exponent (n) was 2, and the cementation exponent (m) was 2.

The Water Saturation (S_w) for each well is then calculated by using the digitized well data and variables. The resultant values will be based on a percentage scale of 0-100% saturation of water. A new set of data is created in Petra that is displayed on the well log that represents the total water saturation of the well based on 2 ft intervals.

Formation Pay Calculation

The next phase of calculations is to complete a log analysis by comparing the Gamma Ray log, the cross-plot porosity log, the caliper, and the calculated water saturation for each well. These logs should be analyzed simultaneously to gain information about the rock type (GR), if the well bore is in good condition (CAL), what is the potential capacity of the formation to accumulate fluid (PHI), and how much of the fluid is water/oil (S_w). By using Petra, the analysis can be completed based on a two-foot interval for all 77 wells in the study.

The result of the analysis will determine how much total pay is in the formation. Pay signifies if the formation has enough resources to be economical and productive of hydrocarbons, or if the formation will just produce water. The following parameters were used to determine if a specific interval can produce economical amounts of hydrocarbon:

- Gamma Ray <= 100
- S_w <= 50%
- Φ => 5%
- Caliper <= 14

Hydrocarbon Pore Volume

The final stage of calculations in determining potential productive regions in the Three Forks Formation is Hydrocarbon Pore Volume (HCPV) analysis. The calculation is based on the lithologic unit or bench, average cross-plot porosity, the total pay (ft), and the average Oil Saturation (S_o):

$$HCPV = S_o \times \phi_{avg} \times H_{net} \tag{6}$$

Where: HCPV= Hydrocarbon Pore Volume

- S_o = oil saturation
- ϕ_{avg} = average porosity
- H_{net} = net pay

Oil saturation is calculated water and gas saturation.

$$100\% = S_o + S_w + S_g$$

Where: S_o = oil saturation

S_w = water saturation

S_g = gas saturation

The reservoir saturation should total 100% and in this study gas saturation is assumed to be 0%.

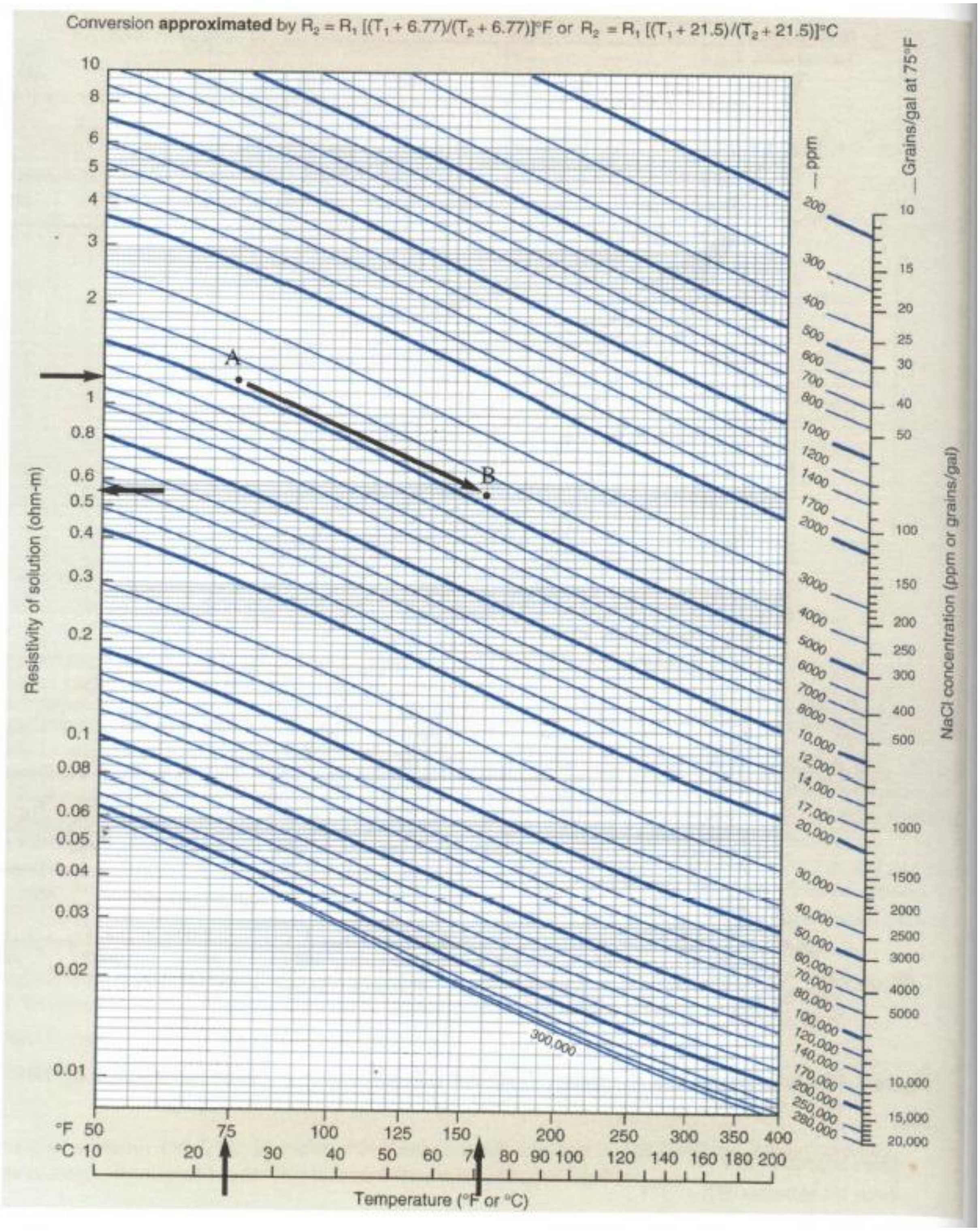

Figure 13. Fluid resistivity chart. This chart is used to determine the fluid resistivity based on the original depth and temperature of the sample (Asquith, Krygowski, Henderson, & Hurley, 2004).

Table 3. Coefficients and exponents used to calculate S_w. This table shows *a* and *m* values that have been concluded from test for different rock lithologies. Based on the rock type of the Three Forks Formation, Carbonate, a value of m=2 and a =1 were used (Asquith et al., 2004).

***a*: Tortousity factor**	***m*: Cementation exponent**	**Comments**
1.0	2.0	Carbonates[1]
0.81	2.0	Consolidated sandstones[1]
0.62	2.15	Unconsolidated sands (Humble formula)[1]
1.45	1.54	Average Sands (after Carothers, 1968)
1.65	1.33	Shaly sand (after Carothers 1968)
1.45	1.70	Calcareous Sad (after Carothers, 1968)
0.85	2.14	Carbonates (after Carothers, 1968)
2.45	1.08	Pliocene Sands, Southern California (After Carothers and Porter, 1970)
1.97	1.29	Miocene sands, Texas-Louisiana Gulf Coast (After Carothers and Porter, 1970)
1.0	$\phi^{(2.05-\phi)}$	Clean granular formations (after Sethi, 1979)

[1]*Most Commonly Used*

While the HCPV is calculated for each bench in the Three Forks Formation, maps are made. Production well data from the Three Forks Formation was obtained from the NDGS webpage. This data was used to determine the initial monthly production for each well. By analyzing the Drill Time Sample report (DTS), it was determined the specific target bench for production through the Three Forks Formation. The initial monthly production was used to decide the cutoff s for HCPV for the first bench. The laterals were overlain on the HCPV map and the HCPV value for each lateral was calculated. Then by using the HCPV and average initial daily production a cutoff was determined.

The cutoff was used to determine the efficiency of a well drilled in specific HCPV zones. When drilling horizontal wells, the initial daily production should be high enough for the well to be cost effective. Based on the depth of the Three Forks Formation in the study area, which is approximately 10,000 feet deep, the well should have a minimum initial daily production of 450 bbls. If the well falls below 450 bbls daily production, the well does not produce enough hydrocarbons to be considered commercial.

CHAPTER III

RESULTS AND DISCUSSION

Calculation Results

Table 4 represents the final results for R_w (formation water resistivity). In order to calculate R_w, water chemistry samples are taken directly from the formation, however in Charlson Field there was no water chemistry data available for the Three Forks Formation. The relevant data from the Silurian Interlake, Mississippian Bakken, Devonian Birdbear and Devonian Deadwood were used to calculate formation water resistivity. Statistical analysis was run, using Minitab™, to determine variance of the data to measure the accuracy of the calculations. The data variance for R_w. was found to be .000003 and the average was .0169, the average was later used as R_w for calculations in this study (Figure 14).

Maps

Several maps were generated as the result for this study including, structure contour isopach, porosity, water saturation, net pay, and hydrocarbon pore volume. The structure contour maps were created for the Three Forks Formation, second, third, and fourth benches (Figure 15, 16, 17, 18). These maps show what the structure is for the region and also help to identify where there are potential production trends for the already producing Three Forks wells. The isopach maps were generated for the Three Forks Formation, first, second, third, and fourth benches (Figure 19, 20, 21, 22, 23). These maps show the thickness of the formation and help to determine potential targets for drilling.

Figure 24 shows the average porosity of the Three Forks Formation, where higher porosity is shown with dark purple and the lower porosity lighter in color. Figure 25 and Figure 26 depicts the average porosity for the first and second bench. The water saturation maps represent the formation or bench with more than 50% water saturation, whereas the lighter areas show less than half of the pore volume is filled with water.The Three Forks Formation, first bench and second bench respectively water saturation maps are represented in Figure 27, Figure 28 and Figure 29

The next set of maps illustrates the formation and benches net pay. The net pay is measured in 2-foot intervals, where they are counted be either productive or non-productive. The pay maps for the Three Forks Formation (Figure 30), first bench (Figure 31), second bench (Figure 32), third bench (Figure 33), and fourth bench (Figure 34); show that the darker regions poses a larger amount of net pay while the lighter regions have less pay intervals.

The last two maps are the hydrocarbon pore volume maps. These maps represent the Three Forks Formation and first bench hydrocarbon pore volume (Figure 35 and Figure 36). The first bench is considered the primary drilling target for The Three Forks wells in Charlson Field, therefor the first bench can only be analyzed for HCPV. The commercial cut off for a productive pay for Three Forks was determined to be 2.358, based on the relationship between HCVP and production. The first bench HCPV cut off was set to .5745. The maps displayed here represent the areas with that have an HCPV above the cutoff.

Table 4. R_w final calculations. The table represents the water chemistry data along with all calculations for the final Formation Water Resistivity results for each well.

API	Well Number	Formation Top (ft)	Formation Bottom (ft)	Formation Name	Measure Rm (ohm-m)	R_{temp} (F)	Three Forks Depth (ft)	BHT (F)	m (F/ft)	Three Forks temp (F)	R_w (ohm-m)
3305300449	2602	10047	10058	DB	0.050	68	9804	231	0.018	226.429	0.016
3305301135	7825	10343	10573	DD	0.051	77	9878	251	0.019	237.788	0.017
3305301706	10224	10822	10843	DD	0.045	77	10240	268	0.020	255.877	0.014
3305301742	10367	12013	12085	SI	0.040	77	10227	240	0.016	210.789	0.015
3305301753	10426	12080	12109	SI	0.052	77	10243	258	0.017	225.947	0.019
3305301757	10438	12061	12084	SI	0.043	77	10252	226	0.015	199.317	0.017
3305301773	10499	12030	12160	SI	0.049	77	10283	250	0.016	219.128	0.018
3305301843	10802	12056	12164	SI	0.046	77	10299	242	0.016	212.562	0.018
3305301933	11103	12062	12144	SI	0.050	77	10263	248	0.016	217.332	0.019
3305301958	11194	11918	11971	SI	0.043	77	10149	244	0.016	214.473	0.016
3305302027	11429	10300	10347	MBK	0.044	77	10400	250	0.019	251.024	0.014
3305302027	11429	12115	12150	SI	0.044	77	10400	250	0.016	221.193	0.016
3305302027	11429	10650	10715	DB	0.041	77	10400	250	0.019	244.120	0.014
3305302063	11553	12080	12150	SI	0.042	77	10417	250	0.016	221.473	0.015
3305302082	11647	11970	11978	SI	0.049	77	10145	251	0.017	220.241	0.018
3305302113	11802	10850	10870	DD	0.046	77	10374	246	0.018	237.056	0.016
3305302157	11983	11792	11906	SI	0.053	77	9996	238	0.016	207.840	0.021
3305302157	11983	11852	11878	SI	0.046	77	9996	238	0.016	208.212	0.018
3305302167	12031	12060	12186	SI	0.046	77	10117	256	0.017	221.024	0.017
3305302167	12031	12063	12150	SI	0.057	77	10117	256	0.017	221.531	0.021
3305302167	12031	12176	12186	SI	0.071	77	10117	256	0.017	221.024	0.026
3305302407	13429	10413	10421	DB	0.044	77	10160	202	0.015	198.193	0.018

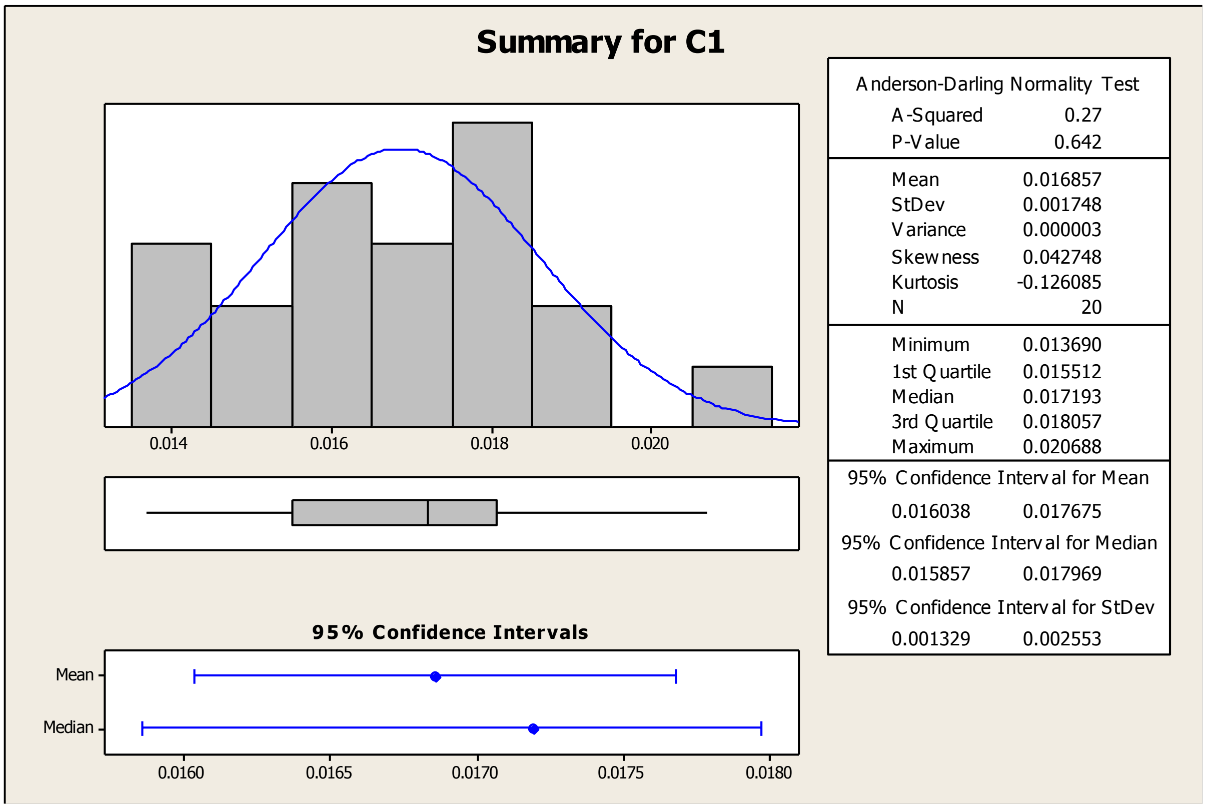

Figure 14. Statistical analysis of R_w. Minitab was used to calculate the variance and mean water resistivity values for the water chemistry data for Charlson Field.

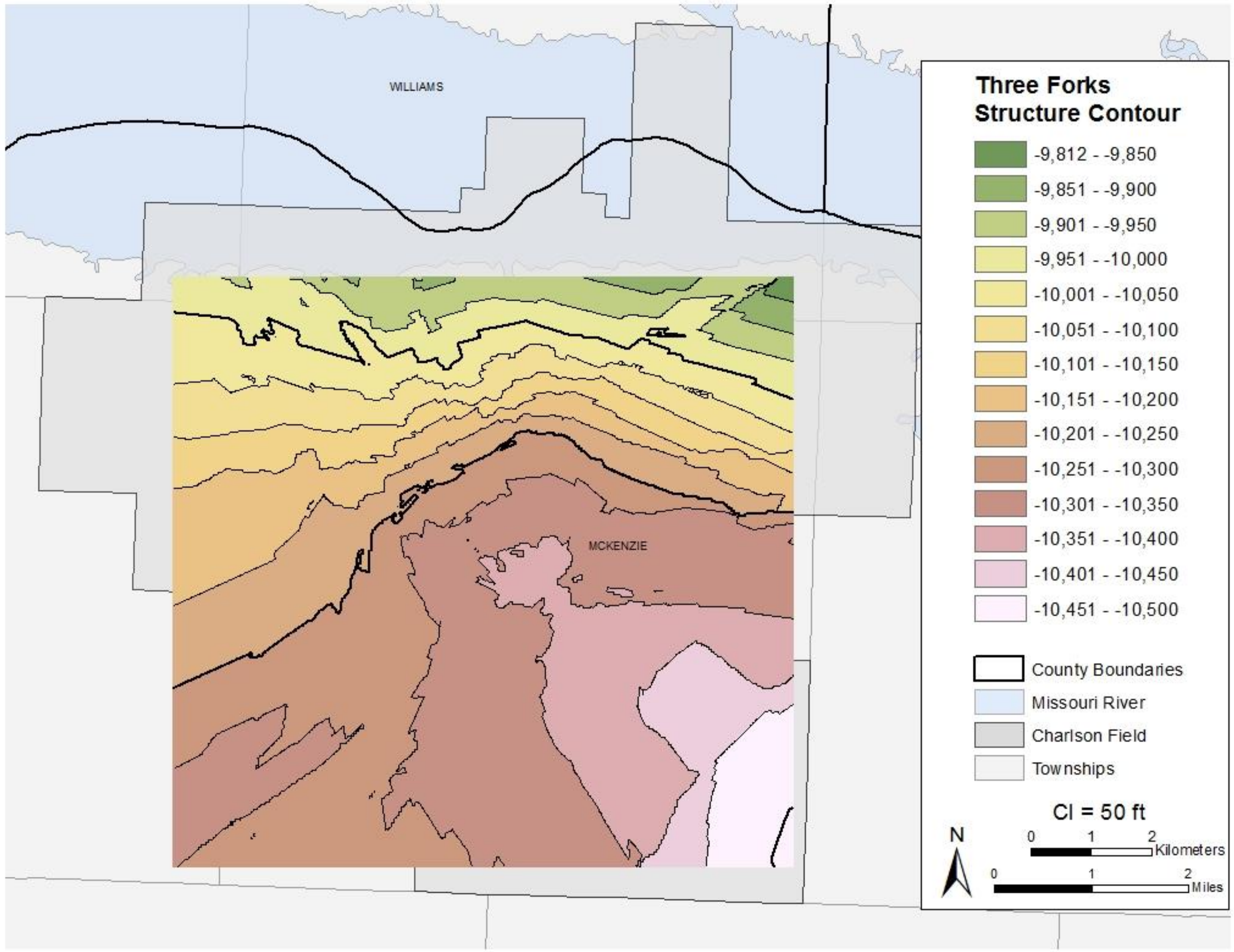

Figure 15. Three Forks structure contour map. Structure contour map that has a contour interval of 50ft, showing the structure of the Three Forks Formation and the top of the first bench.

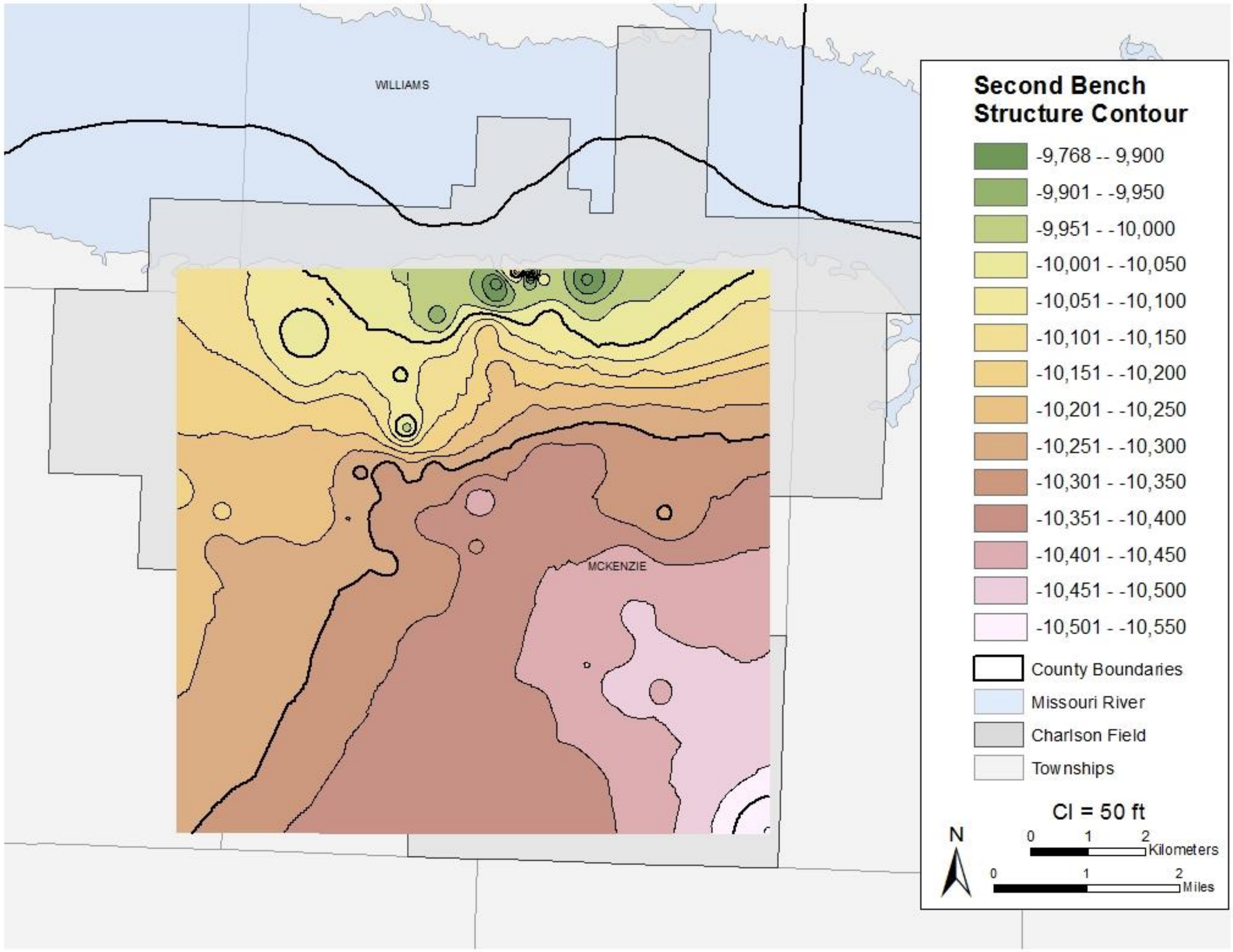

Figure 16. Second bench structure contour map. Structure contour map that has a contour interval of 50ft, showing the structure of the second bench.

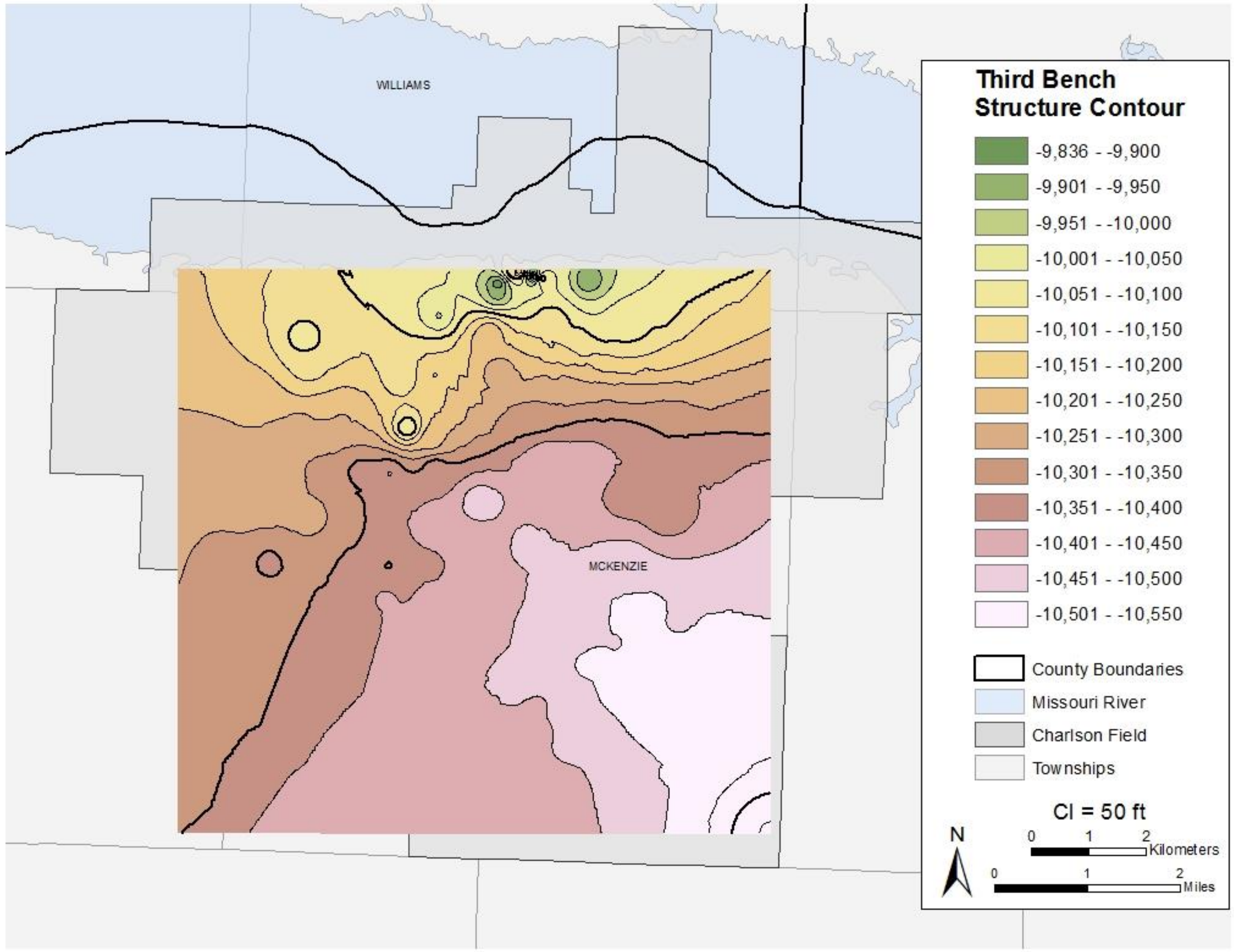

Figure 17. Third bench structure contour map. Structure contour map that has a contour interval of 50ft, showing the structure of the third bench.

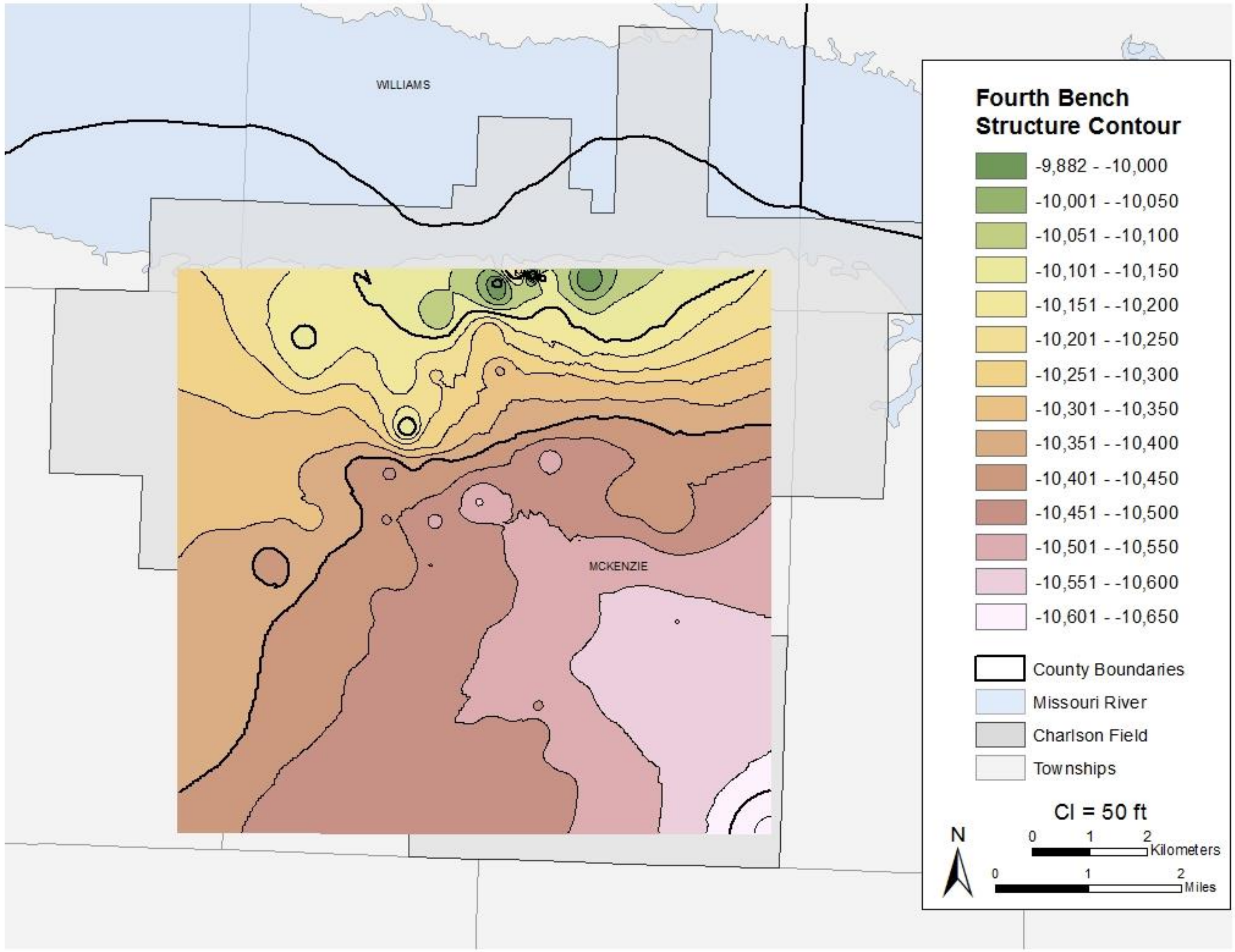

Figure 18. Fourth bench structure contour map. Structure contour map that has a contour interval of 50ft, showing the structure of the fourth bench.

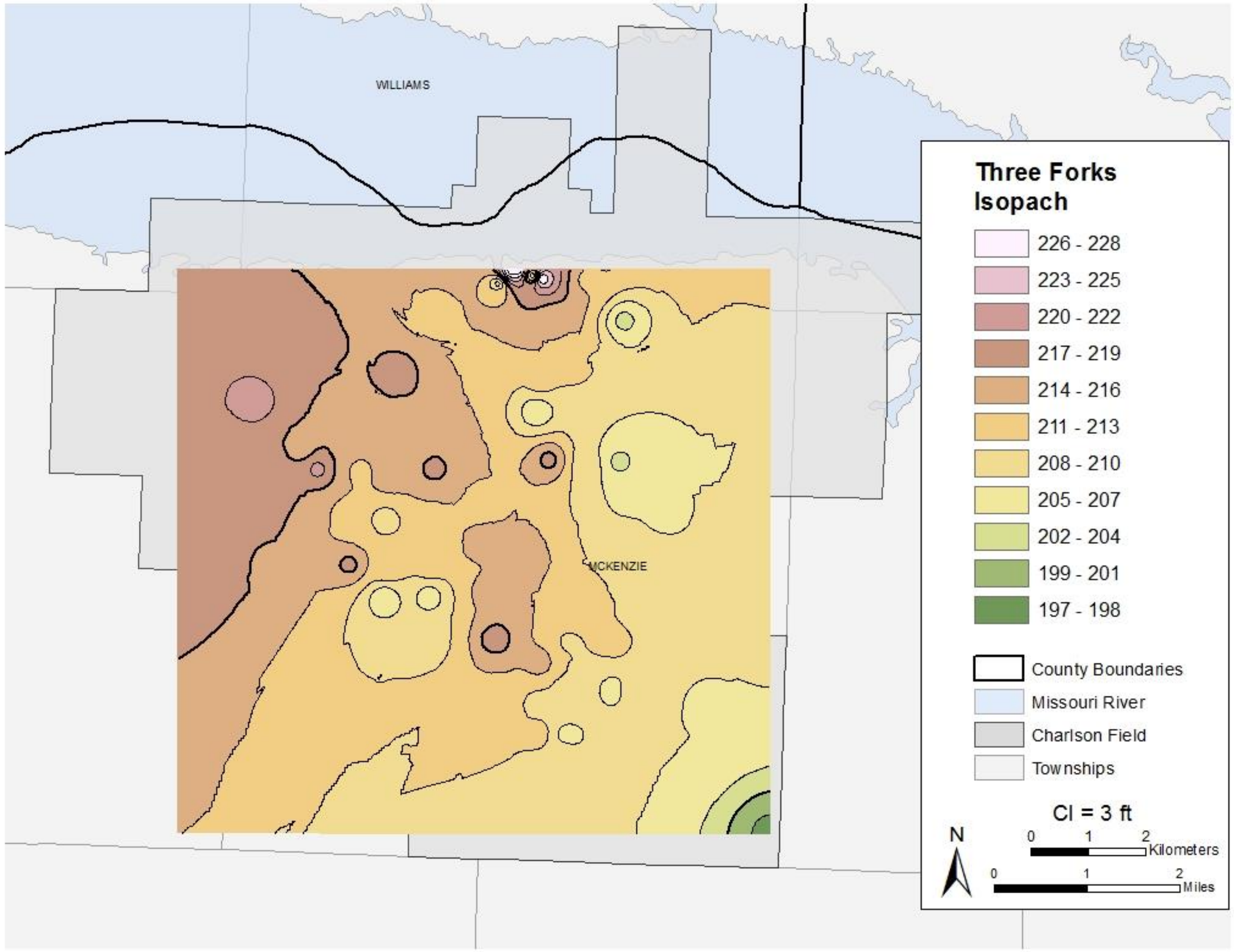

Figure 19. Three Forks isopach map. Formation thickness map for the Three Forks formation, the contour interval is 3 feet.

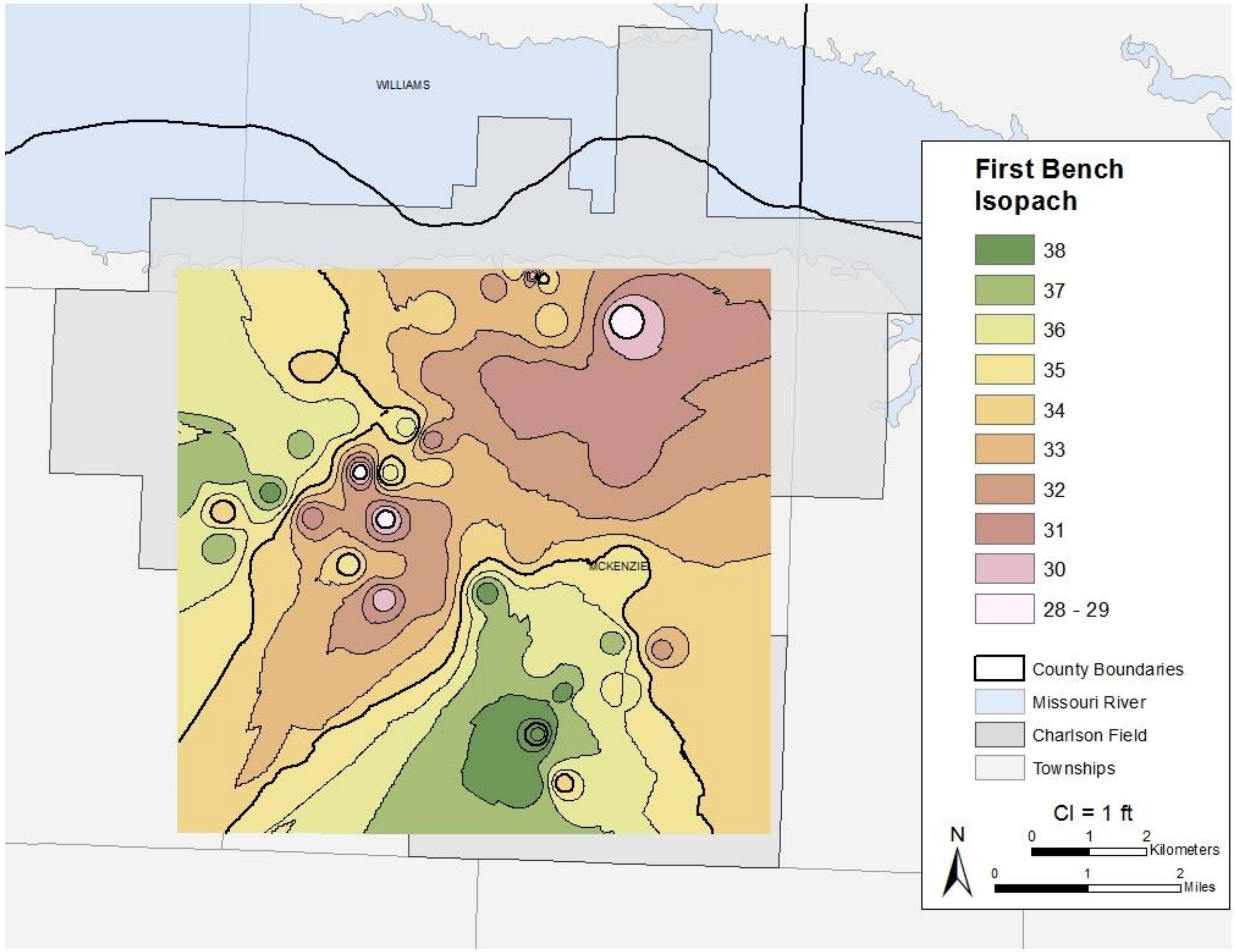

Figure 20. First bench isopach map. Bench thickness map for the first bench, the contour interval is 1 foot.

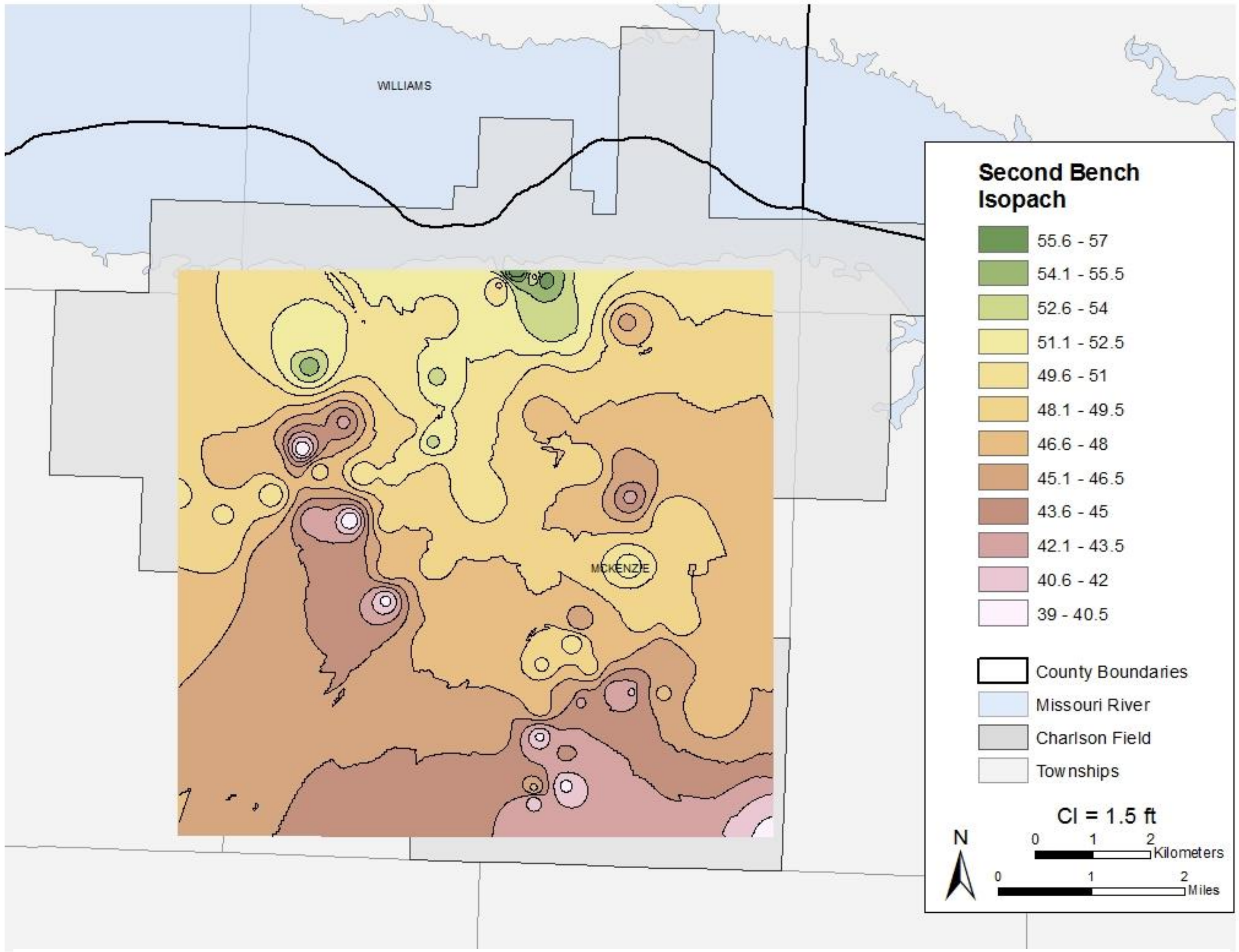

Figure 21. Second bench isopach map. Bench thickness map for the second bench, the contour interval is 1.5 feet.

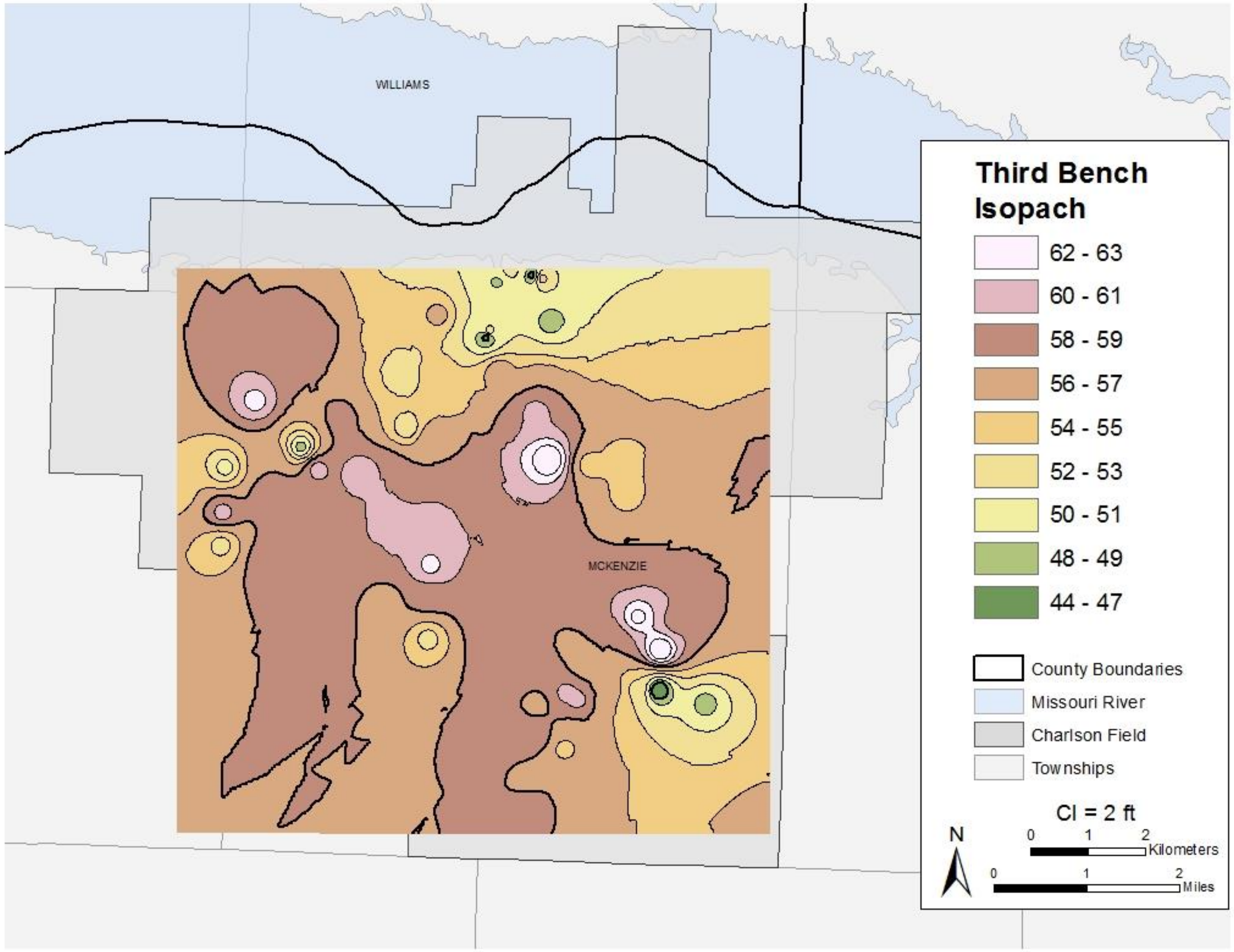

Figure 22. Third bench isopach map. Bench thickness map for the third bench, the contour interval is 2 feet.

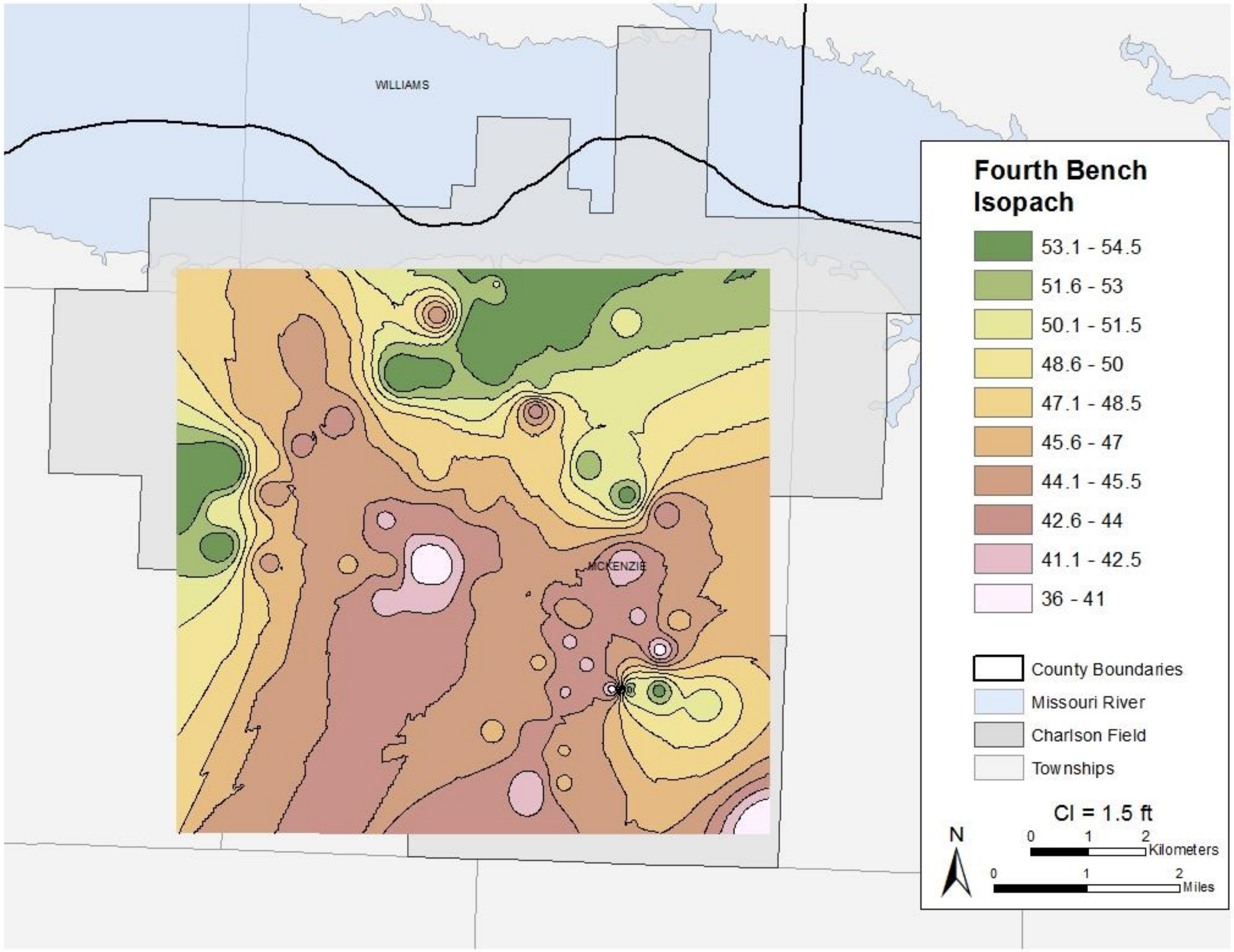

Figure 23. Fourth bench isopach map. Bench thickness map for the fourth bench, the contour interval is 1.5 feet.

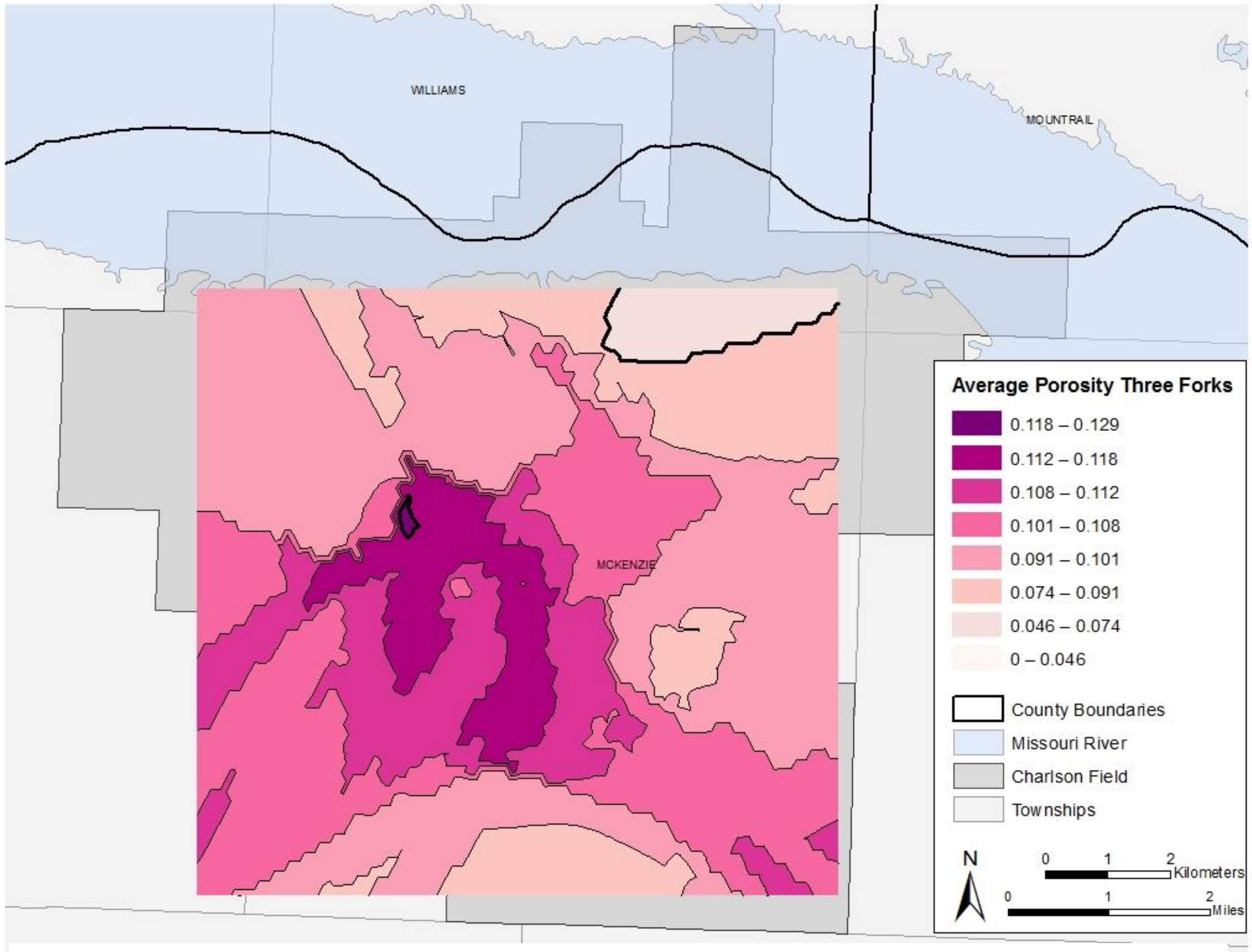

Figure 24. Average Three Forks porosity. The map represents the average Three Forks Porosity throughout the formation. The dark purple regions represent a higher average porosity and the lighter colors indicate low average porosity.

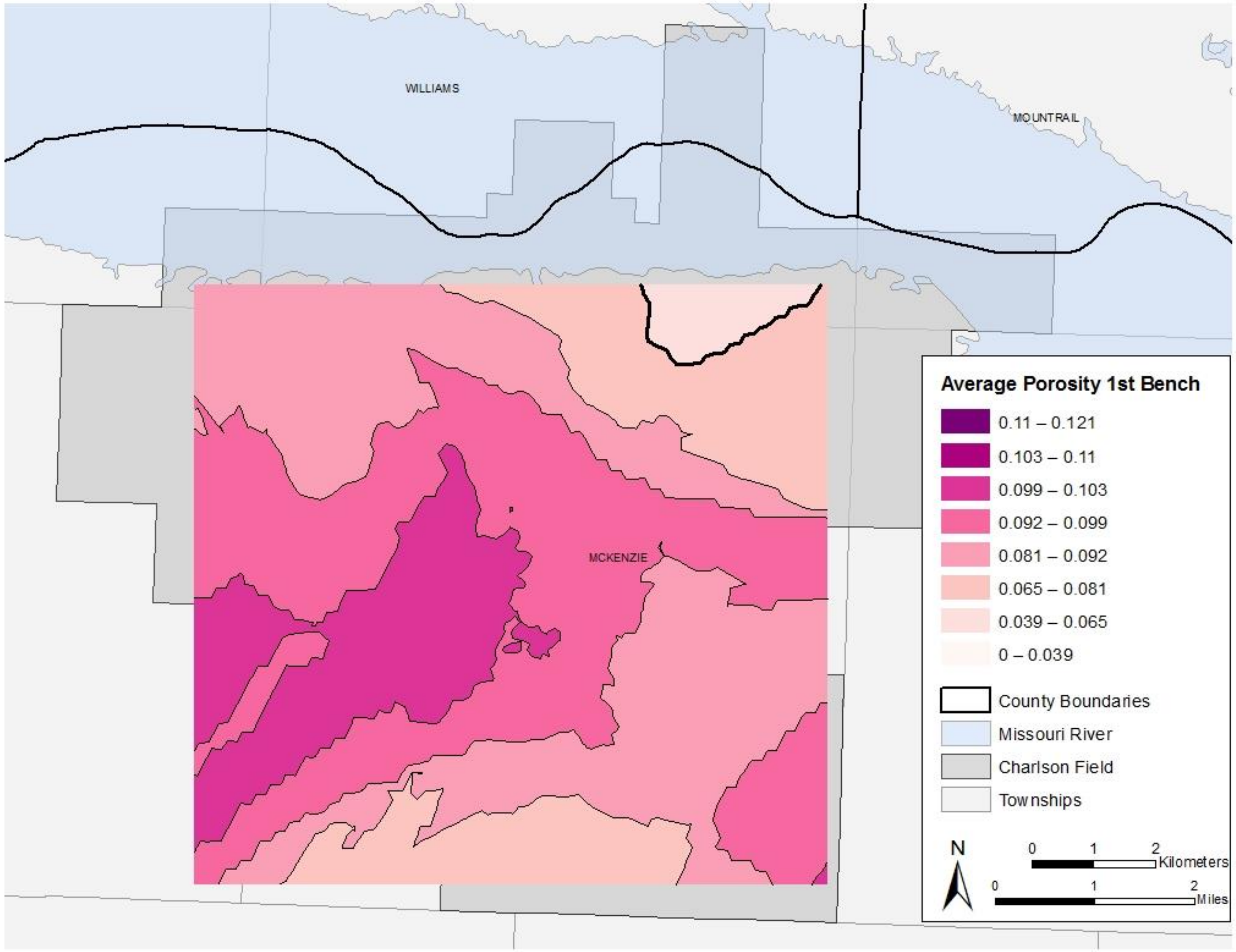

Figure 25. Average first bench porosity. The map represents the average first Bench Porosity. The dark pink regions represent a higher average porosity and the lighter colors indicate low average porosity.

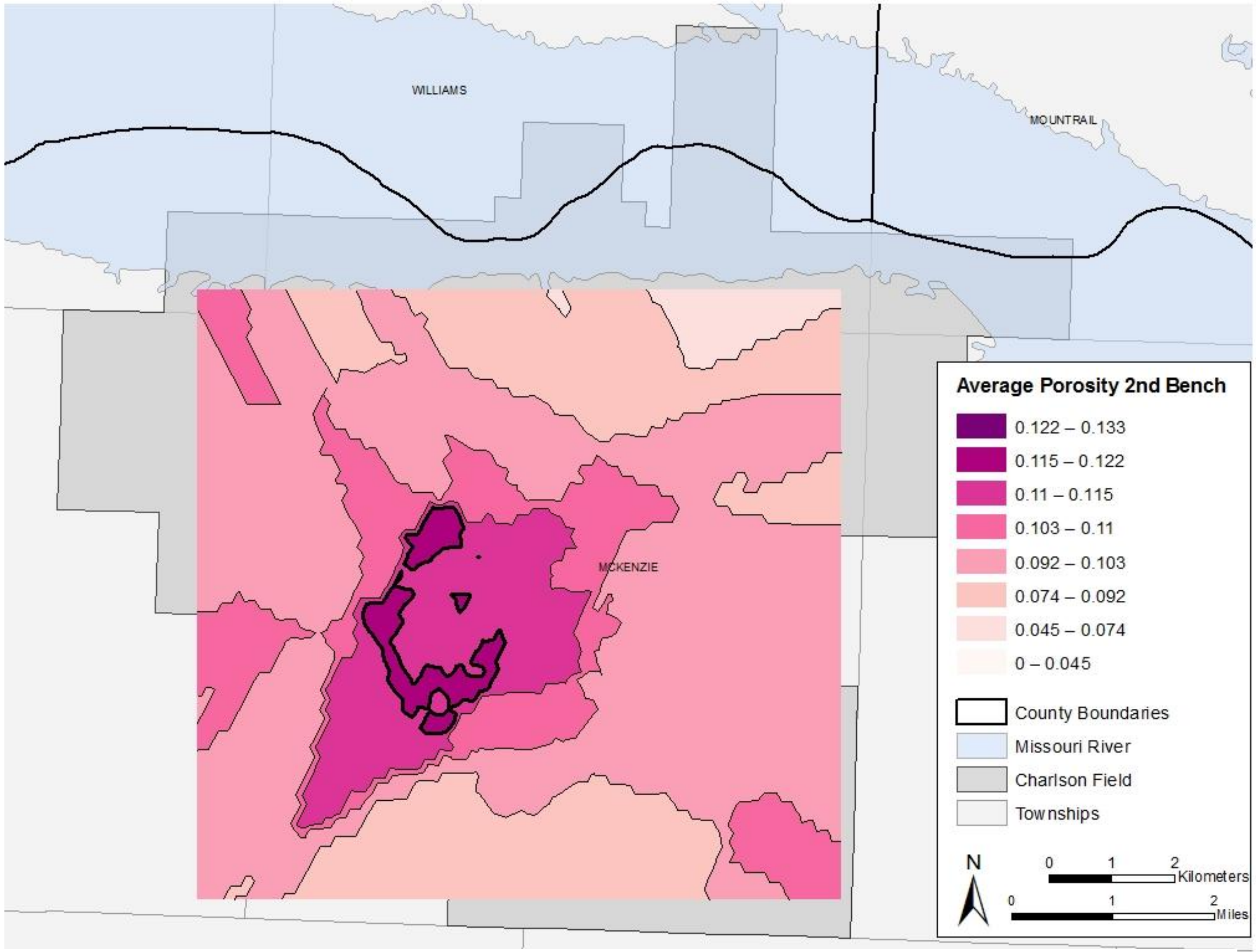

Figure 26. Average second bench porosity. The map represents the average second Bench Porosity. The dark pink regions represent a higher average porosity and the lighter colors indicate low average porosity.

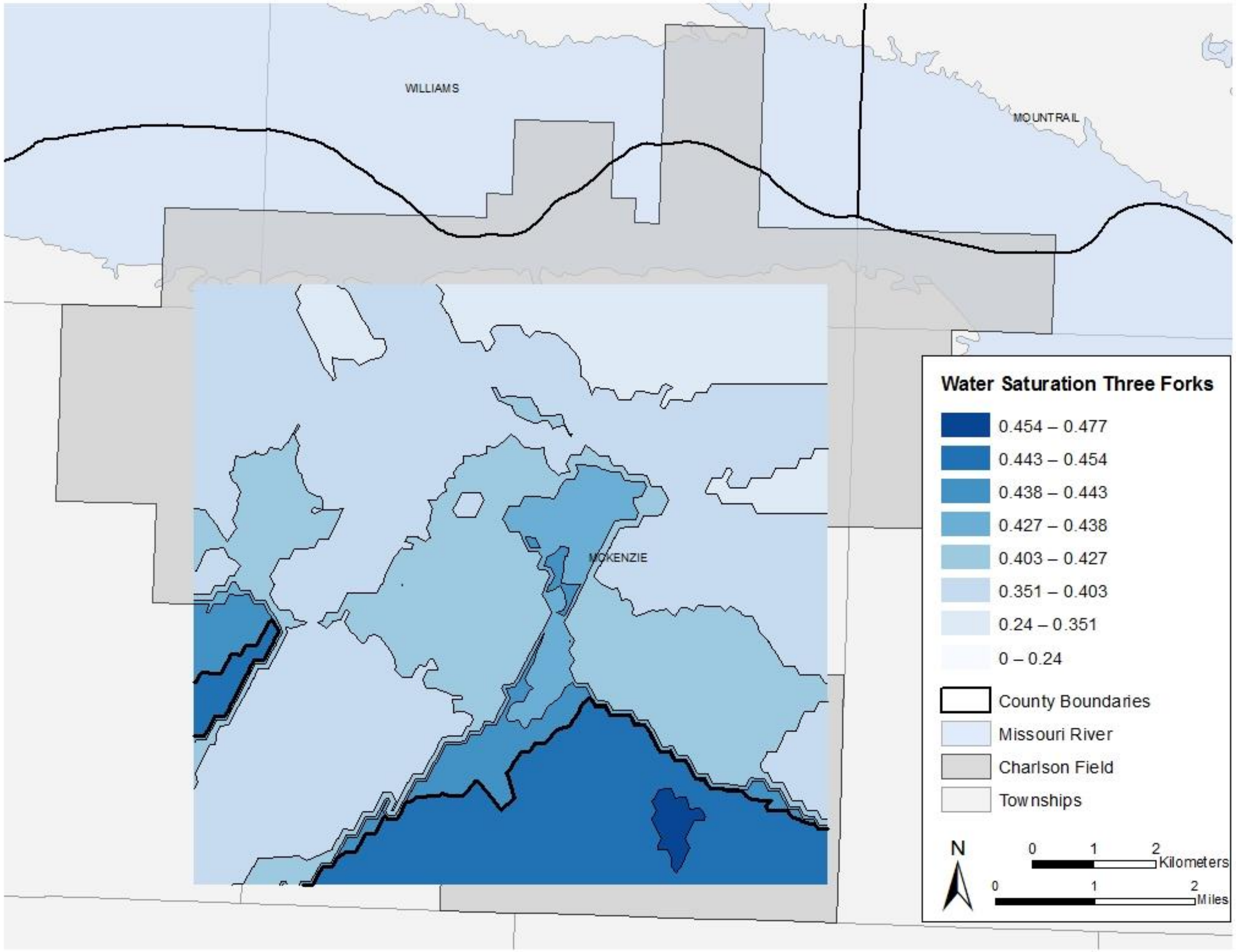

Figure 27. Average Three Forks water saturation. The map represents the average water saturation for the entire Three Forks, the dark blue regions represent a higher saturation of water and the lighter colors indicate low saturation of water.

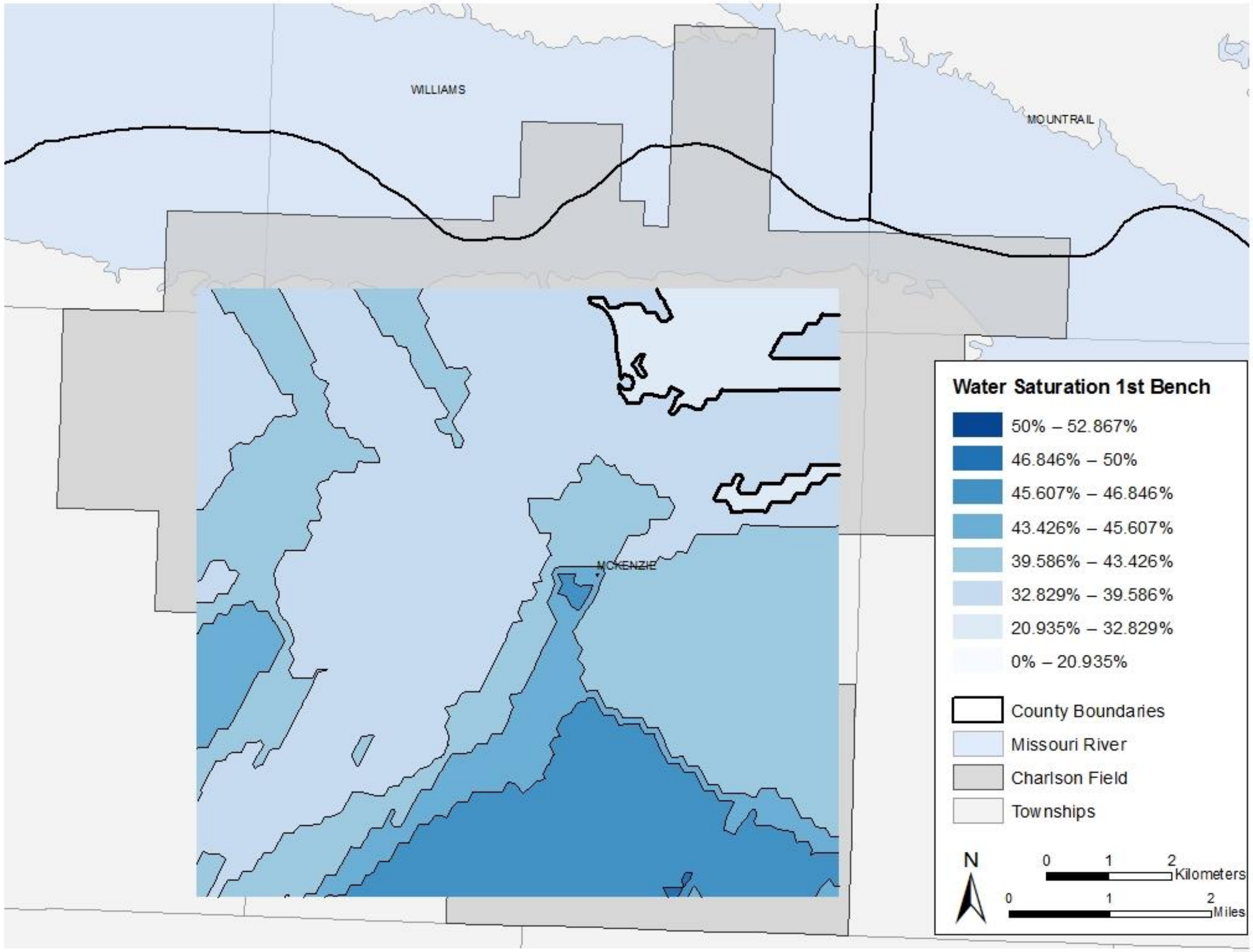

Figure 28. Average first bench water saturation. The map represents the average water saturation for the entire first Bench, the dark blue regions represent a higher saturation of water and the lighter colors indicate low saturation of water.

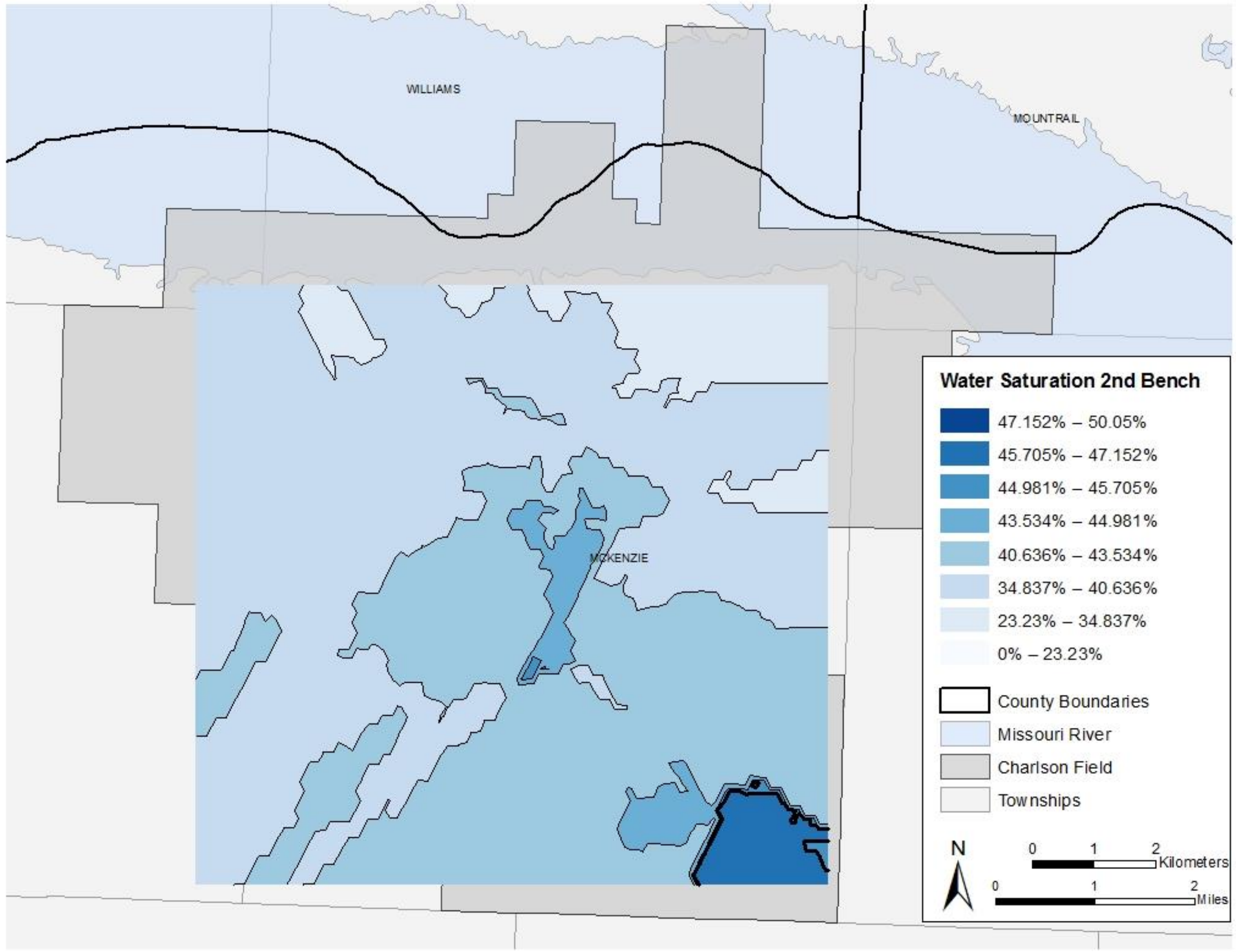

Figure 29. Average second bench water saturation. The map represents the average water saturation for the entire second bench, the dark blue regions represent a higher saturation of water and the lighter colors indicate low saturation of water.

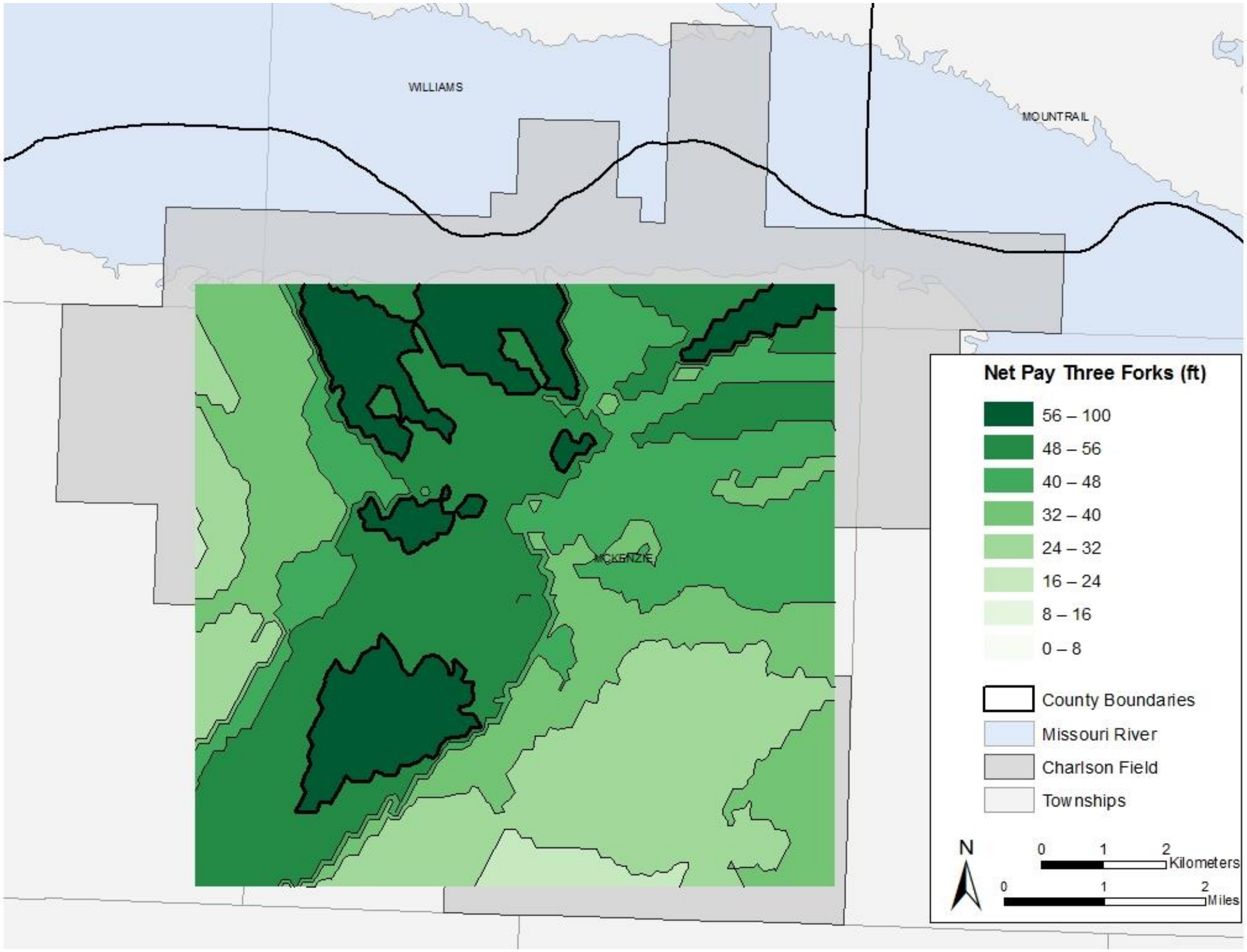

Figure 30. Net pay for Three Forks Formation. The darker green regions represent a larger amount of pay and the lighter green/white regions represent a low amount of pay.

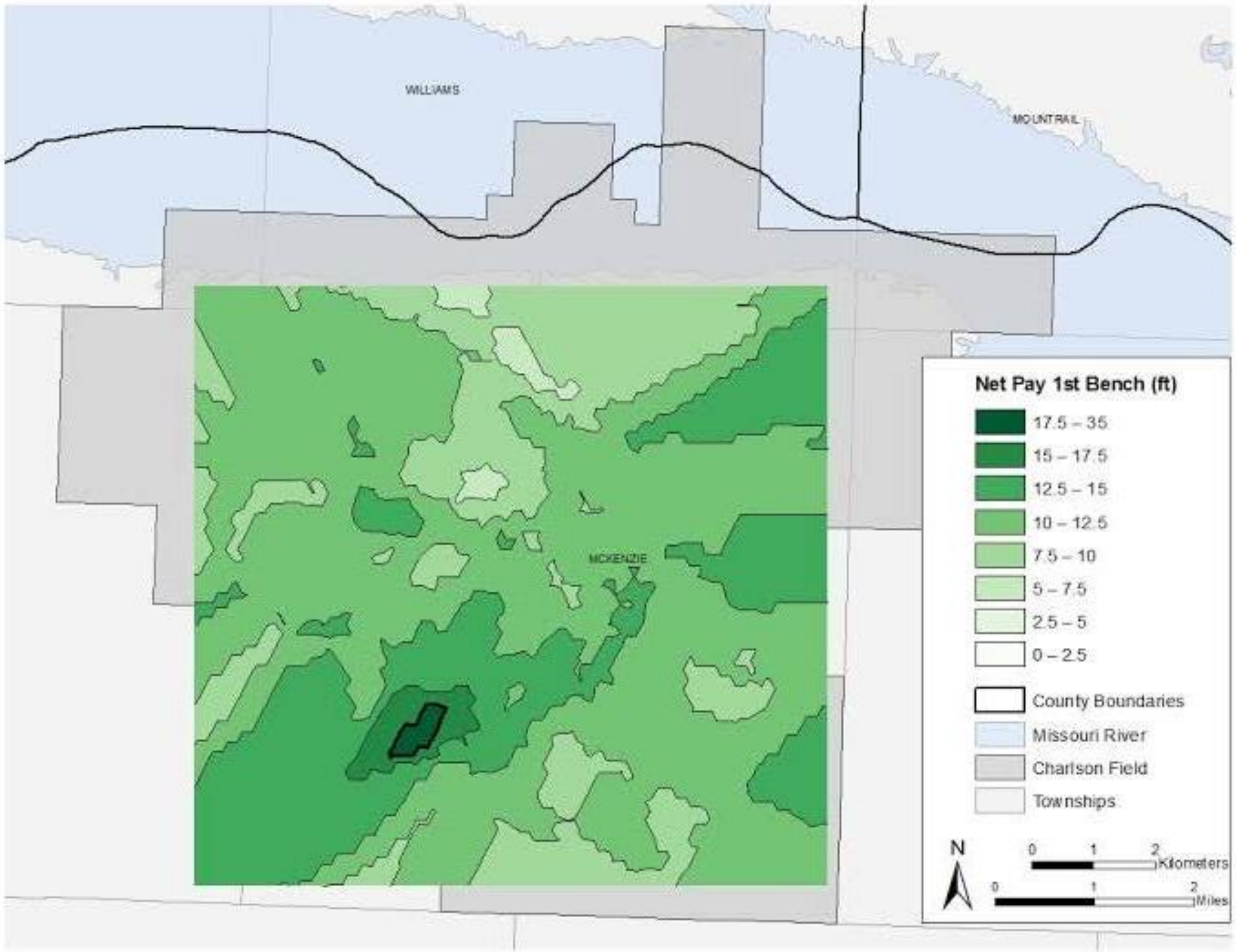

Figure 31. Net pay for first bench of Three Forks Formation. The darker green regions represent a larger amount of pay and the lighter green/white regions represent a low amount of pay.

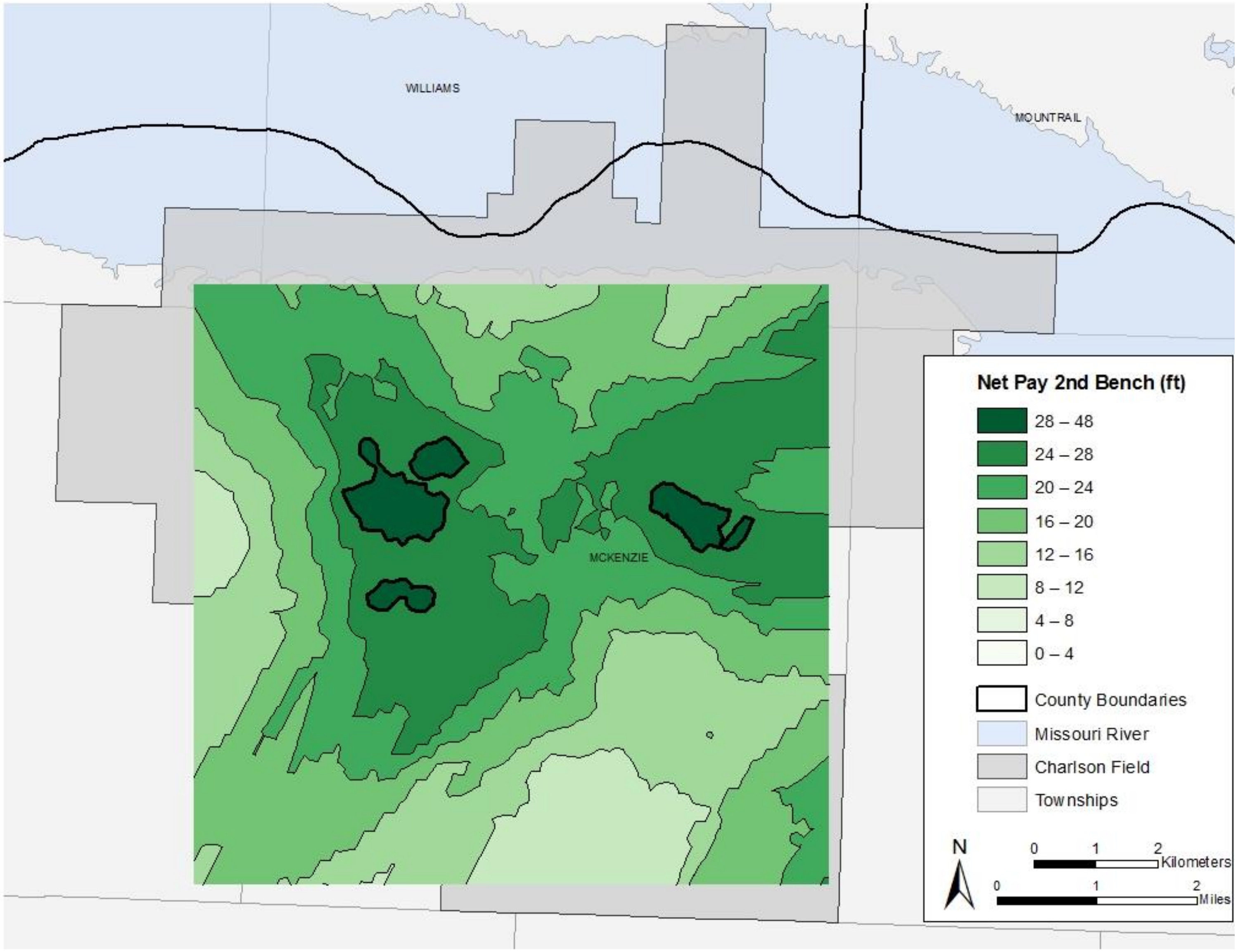

Figure 32. Net pay for second bench of Three Forks Formation. The darker green regions represent a larger amount of pay and the lighter green/white regions represent a low amount of pay.

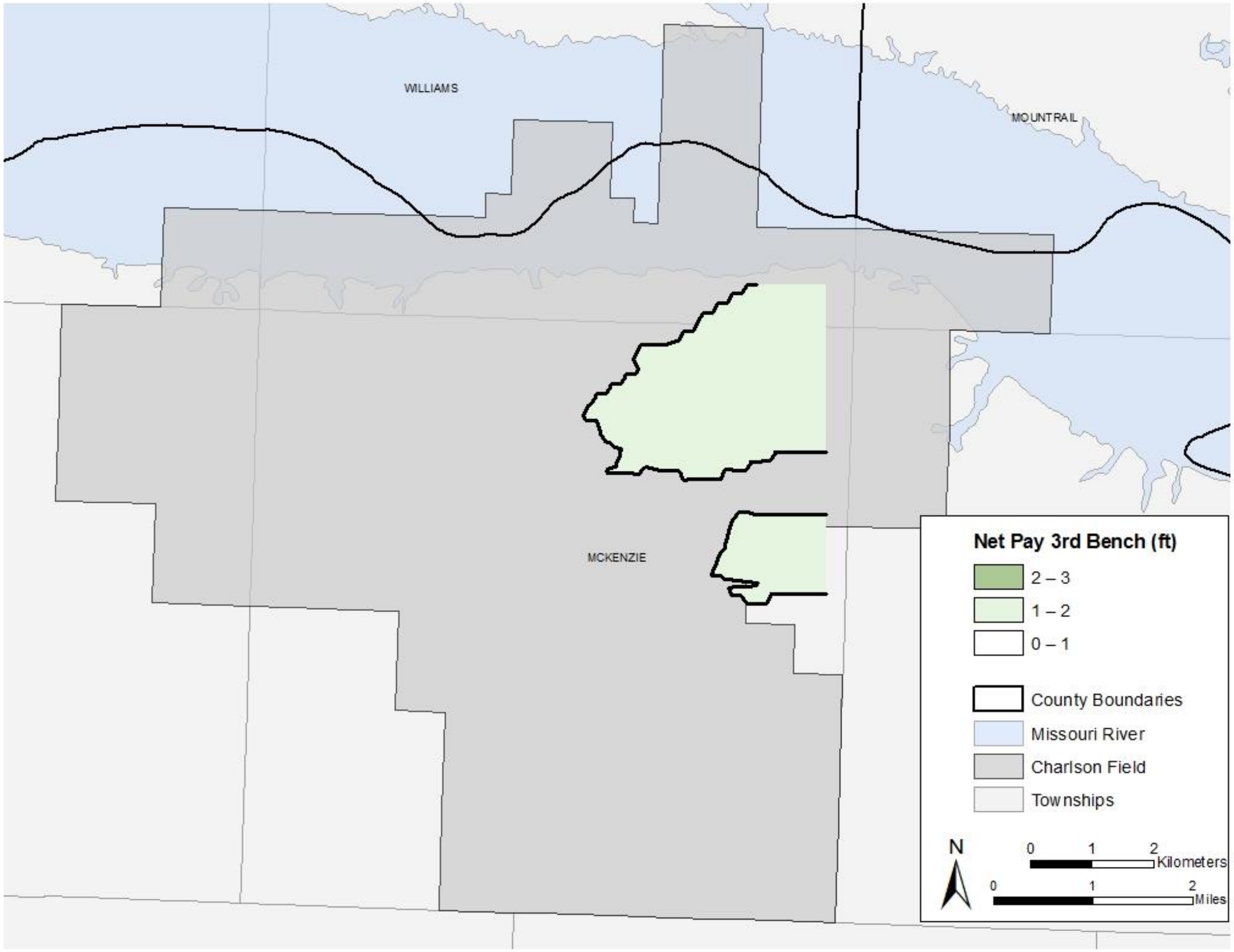

Figure 33. Net pay for third bench Three Forks Formation. The low amount of pay in the 3rd bench is shown here with only a maximum of 2 feet of pay.

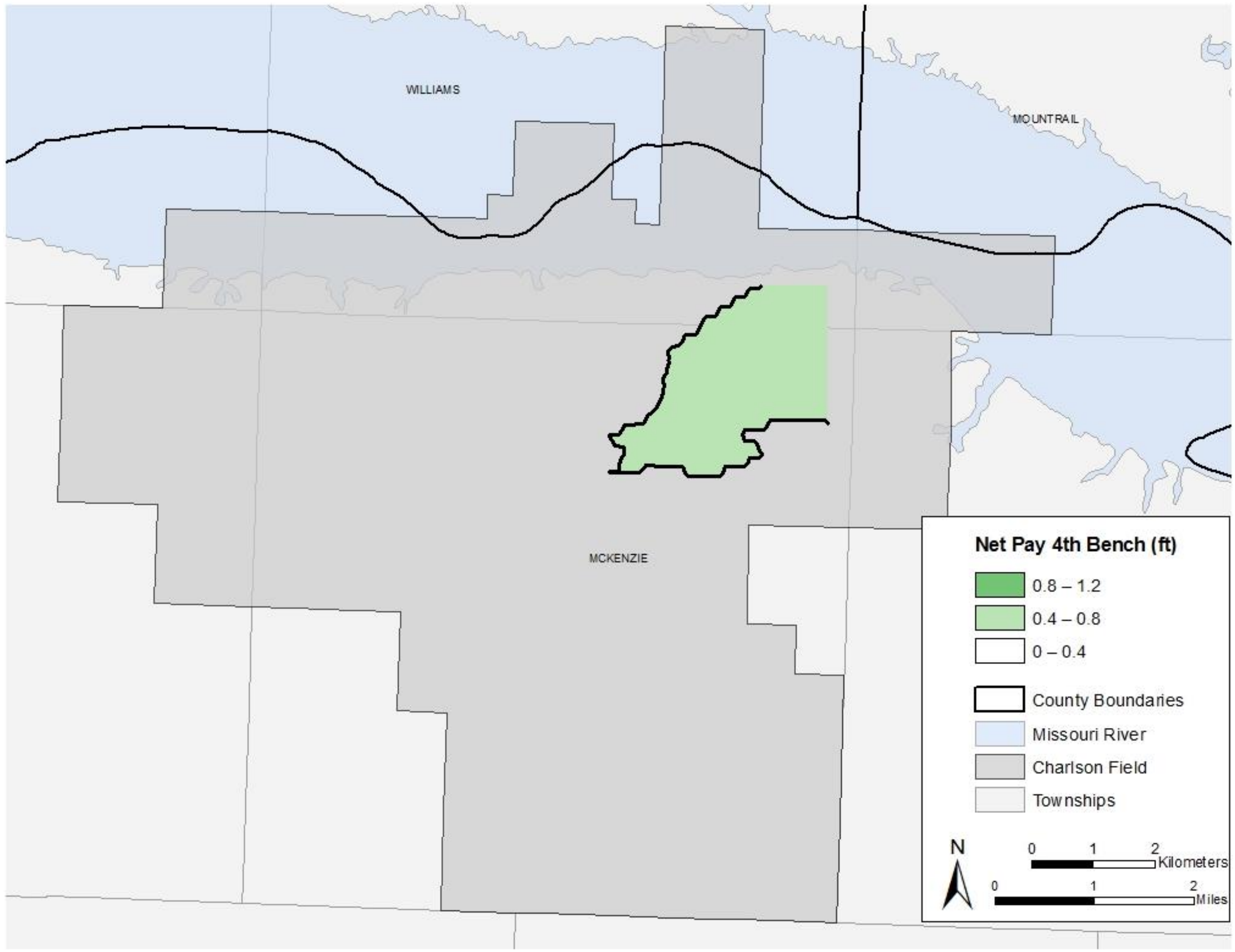

Figure 34. Net pay for the fourth bench Three Forks Formation. The low amount of pay in the 3rd bench is shown here with less than 1 foot of pay.

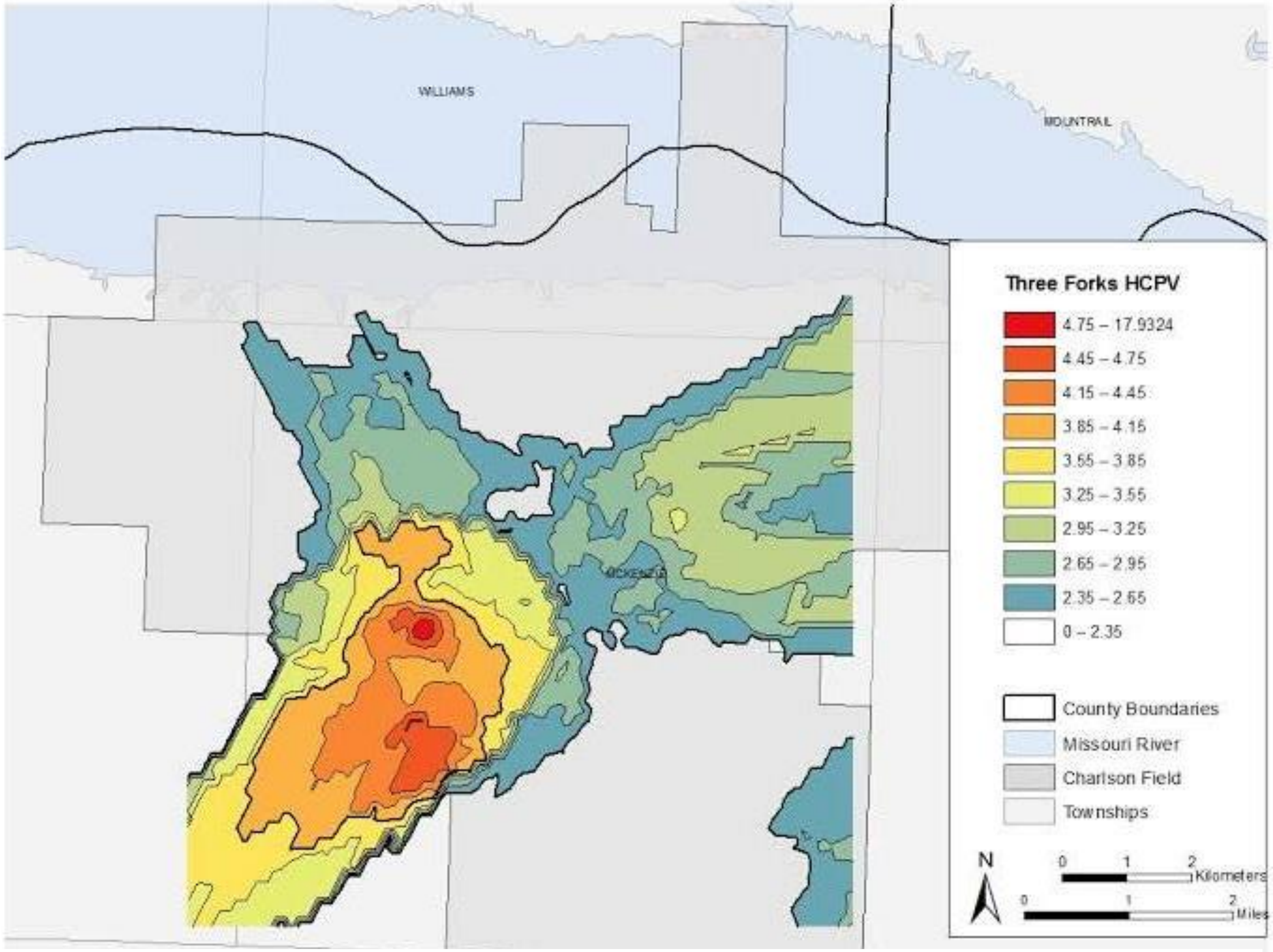

Figure 35. HCPV map for the Three Forks Formation. This map represents the areas that have a HCPV higher than 2.358.

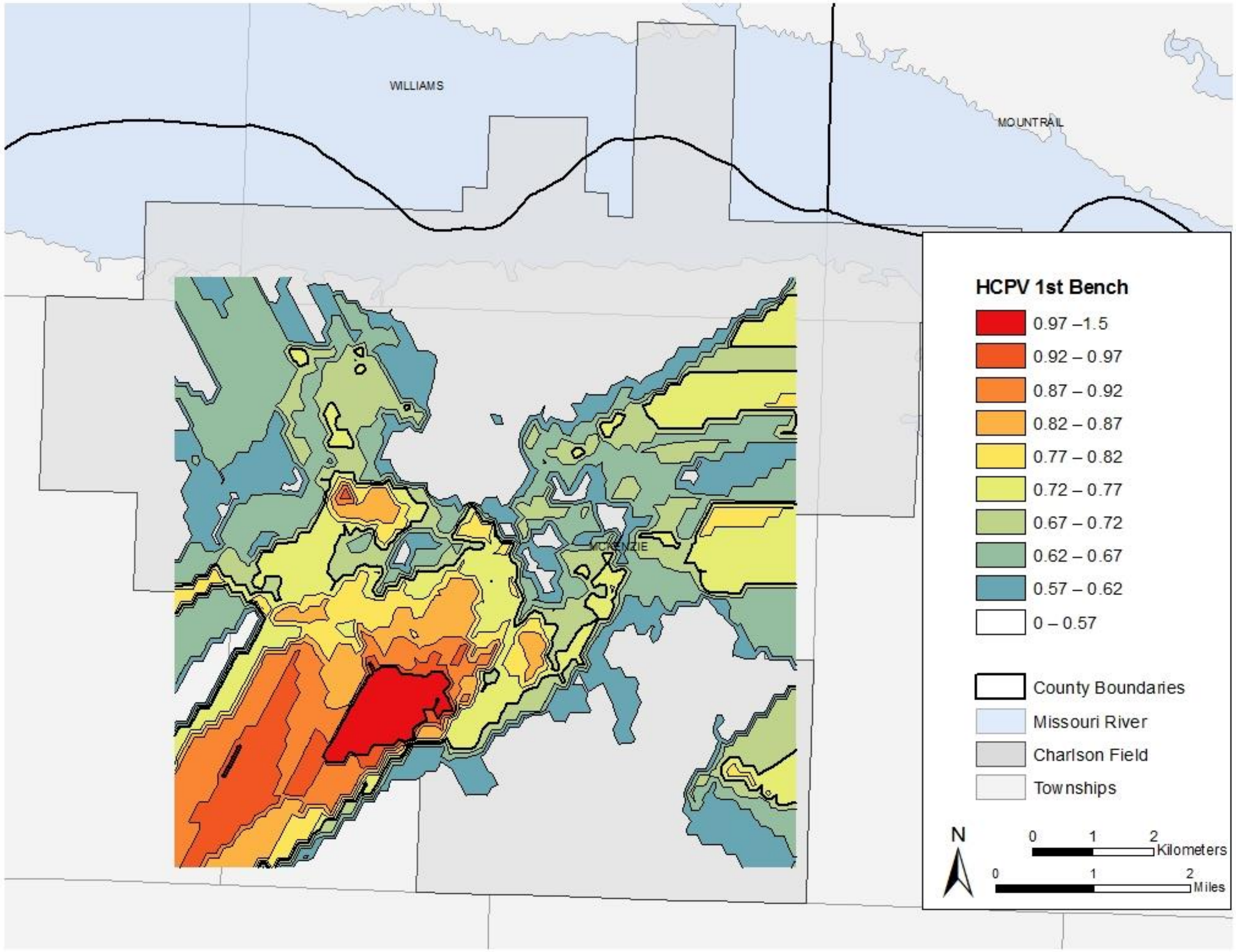

Figure 36. HCPV map for the Three Forks Formation first bench. This map represents the areas that have a HCPV higher than .5745.

CHAPTER IV

CONCLUSION

The porosity, water saturation, and net pay maps, were combined to create the HCPV maps. These variables were used as a parameter for that map and indicate where the potential productive zones could be in the Three Forks Formation and benches. From the results it can be determined that the first and second bench are the productive units in the Three Forks Formation. The first bench is the primary unit that is targeted and produced from, and for future drilling it should be continued to be the main target for Charlson Field.

The second bench also has potential, but more data is needed to determine the cut offs for the formation. In current drilling practices when the well drilled targets the first bench, and it is stimulated, the fractures may be penetrating the second bench of the formation and producing from both intervals. No wells have been drilled to specifically target the second bench,

The third and fourth bench of the Three Forks are not productive units in Charlson field. Based on the data they had minimal pay and are not viable options for future drilling. The third and fourth bench are also fully saturated with water, so if a well is drilled in the lower portion of the Three Forks Formation in Charlson Field, the well will only produce water.

Recommendations

Future work should be completed regarding the porosity of the formation due to its clay content. NMR should be run on core and on wells to gain more detailed information on the formation. Lithology determinations should be completed to classify the clay content and type for the formation as well. The data gained from this analysis could lead to the development of a more accurate estimation for the Three Forks.

The completed wells for the field also need further analysis. The production alone can be misleading as different companies have drilled different wells in the field, their completions methods may vary. This potentially affects the total production. The factors that vary in completing the well are, lateral length, proppant type, frac fluid, frac design, orientation of the lateral, etc. Additional information should be gained and statistical testing should be performed in order to better define the relationship between production and the completion methods.

APPENDIX

Appendix A
Well Data

File No	API	Well Status	Status Date	DTD	Location	Operator	Well Name
3804	3305300531	A	12/2/1990	13800	NWSW 23-153-95	FILCO INCORPORATED	RALPH SLAATEN 23-1
5348	3305300620	PA	10/14/1997	10890	SWNE 4-153-95	PETRO-HUNT, L.L.C.	DEVONIAN 6-1
5663	3305300648	A	1/21/1976	10790	NWSE 6-153-95	XTO ENERGY INC.	DEVONIAN UNIT 9
5727	3305300649	A	12/26/1975	10525	S2SE 33-154-95	XTO ENERGY INC.	FEDERAL 33-1
5742	3305300650	PA	5/27/1999	10843	SWSW 4-153-95	PETRO-HUNT, L.L.C.	CMNU D-104
5801	3305300655	A	12/11/1995	11000	NESE 33-154-95	PHILLIP D. ARMSTRONG	USA-YTTREDAHL BAKKEN 33-43
6107	3305300686	DRY	10/15/1977	12600	W2NW 25-153-95	TIGER OIL COMPANY	SIGUARDSON TRUST 1-25
6112	3305300688	DRY	6/26/1991	14760	SENW 23-153-95	DEVRAN PETROLEUM LTD.	DINWOODIE 22-23
6137	3305300697	DRY	8/17/1977	12550	SWNE 22-153-95	TIGER OIL COMPANY	B. J. WESTDAL 32-22
6178	3305300706	PA	10/3/1997	12324	SESE 22-153-95	PETRO-HUNT, L.L.C.	P.S. THORLACKSON 2
6207	3305300708	PA	11/9/1982	12300	NWNE 27-153-95	PROSPER ENERGY CORP.	HAUGEN 1
6213	3305300710	PA	8/28/2014	12600	NENW 26-153-95	XTO ENERGY INC.	THORLACKSON 21-26
6366	3305300729	A	12/2/1991	12240	SENW 27-153-95	PETRO-HUNT, L.L.C.	CMSU B-227A
6433	3305300743	PA	10/28/1989	12590	NWSE 23-153-95	SAMUEL GARY JR. & ASSOCIATES, INC.	SIGUARDSON TRUST 33-23
6479	3305300754	PA	8/14/1997	12268	SESW 22-153-95	PETRO-HUNT, L.L.C.	SILURIAN 2-1
6488	3305300755	PA	5/9/1979	12560	SENE 23-153-95	TIGER OIL COMPANY	SIGUARDSON 42-23

6514	3305300761	PA	1/31/1983	12310	NWSE 27-153-95	PROSPER ENERGY CORP.	SHERVEN 27-1
6539	3305300769	AB	12/24/1986	12200	NWNE 34-153-95	CONTINENTAL RESOURCES, INC.	SUGAR BUTTE 1
6558	3305300778	PA	7/3/1979	12300	NWNW 26-153-95	TIGER OIL COMPANY	THORLACKSON 11-26
6592	3305300785	PA	8/26/1997	12225	NESW 27-153-95	PETRO-HUNT, L.L.C.	JENS ROBERTSON 11-27
6617	3305300798	DRY	9/1/1979	12401	NESE 36-153-95	ENERGETICS OPERATING CO.	STATE 43-36
6793	3305300844	DRY	2/2/1979	12237	NESE 28-153-95	GETTY OIL CO.	E. O. AND G. 28-9
7001	3305300900	PA	11/7/1997	13845	NWSW 34-154-95	PETRO-HUNT, L.L.C.	CMNU C-134
7002	3305300901	A	2/6/1980	13736	SESW 3-153-95	PETRO-HUNT, L.L.C.	SILURIAN 6-1
7066	3305300910	PA	12/5/2001	12226	NWSE 34-154-95	PETRO-HUNT, L.L.C.	SILURIAN 8-1
7072	3305300912	PA	10/27/1997	12180	NESE 4-153-95	PETRO-HUNT, L.L.C.	CMNU C-404
7073	3305300913	PA	11/18/1996	12166	NWNW 10-153-95	PETRO-HUNT, L.L.C.	SILURIAN 10-1
7216	3305300953	PA	9/12/2013	13850	NENW 34-153-95	CONTINENTAL RESOURCES, INC.	SWENSON 1-34
7587	3305301061	PA	12/21/2012	11829	NWSW 34-154-95	PETRO-HUNT, L.L.C.	CMNU C134X
7607	3305301066	PA	6/27/1991	14230	SESE 33-154-95	AMERADA HESS CORPORATION	FEDERAL 33 3
7747	3305301107	PA	11/29/1997	12839	NESE 33-154-95	PHILLIP D. ARMSTRONG	YTTREDAHL MINNELUSA 33-43
7780	3305301121	PA	10/12/2000	12145	SWNE 4-153-95	PETRO-HUNT, L.L.C.	CMNU B-304
7825	3305301135	PA	10/24/1997	12003	NWNW 4-153-95	PETRO-HUNT, L.L.C.	DEVONIAN 2-2
7979	3305301166	A	1/4/1983	12207	NESE 10-153-95	PETRO-HUNT, L.L.C.	SILURIAN 14-1

8932	3305301395	PA	9/16/2014	12590	NWSW 15-153-95	XTO ENERGY INC.	TIPCO 1-15
9039	3305301426	DRY	10/14/1997	12202	NWSE 22-153-95	PETRO-HUNT, L.L.C.	P.S. THORLACKSON 3
9393	3305301496	TA	10/15/2014	13469	NENW 3-153-95	PETRO-HUNT, L.L.C.	CHARLSON (DEEP) UNIT 2
9875	3305301617	PA	10/15/1997	13400	SWNE 6-153-95	PETRO-HUNT, L.L.C.	CMNU B-306X
10224	3305301706	PA	6/8/2015	12180	SWSE 17-153-95	PETRO-HUNT, L.L.C.	DEVONIAN 10-1
10297	3305301724	PA	6/9/2000	12265	NWNE 20-153-95	TIPPERARY OIL & GAS CORPORATION	ALMA 1-20
10426	3305301753	PA	10/29/1997	12193	S2SW 17-153-95	PETRO-HUNT, L.L.C.	SILURIAN 22-1
10438	3305301757	PA	9/9/1997	12210	SESW 18-153-95	PETRO-HUNT, L.L.C.	SILURIAN 23-1
10448	3305301760	A	4/24/1984	12175	NWSW 11-153-95	PETRO-HUNT, L.L.C.	SILURIAN 19-1
10459	3305301763	PA	9/9/1997	12225	NESW 10-153-95	PETRO-HUNT, L.L.C.	SILURIAN 18-1
10498	3305301772	A	9/3/1993	12320	SWSE 8-153-95	PHILLIP D. ARMSTRONG	I. THOMPSON 8-34
10499	3305301773	PA	7/14/1998	12300	SWNE 17-153-95	BERCO RESOURCES, LLC	FEDERAL 17-32
10548	3305301783	DRY	2/2/1985	12130	NWNE 14-153-95	TEXACO INC.	SILURIAN UNIT 28-1
10728	3305301826	PA	11/14/1991	12240	SWNW 17-153-95	AMERADA HESS CORPORATION	DORIS SLAATEN 17-12
10771	3305301836	DRY	7/18/1984	12225	SWSE 27-153-95	AMERADA HESS CORPORATION	SHERVEN 27-34
10802	3305301843	PA	10/5/2000	12225	NWNW 21-153-95	PETRO-HUNT, L.L.C.	SILURIAN 30-1
10965	3305301895	AB	5/20/2015	12231	SWSW 16-153-95	XTO ENERGY INC.	STATE 16-14
10991	3305301903	PA	10/29/1997	12274	NWSW 21-153-95	PETRO-HUNT, L.L.C.	SILURIAN 38-1
11001	3305301906	A	2/23/1985	12156	NWNW 14-153-	PETRO-HUNT, L.L.C.	SILURIAN 26-1

					95		
11017	3305301908	PA	9/23/1997	12154	SENE 18-153-95	PETRO-HUNT, L.L.C.	DEVONIAN 11-1
11063	3305301919	A	11/5/1992	12170	SESE 7-153-95	PETRO-HUNT, L.L.C.	CMNU D-407X
11064	3305301920	PA	11/20/2001	12250	NESE 21-153-95	PETRO-HUNT, L.L.C.	CMSU C-421
11103	3305301933	PA	5/12/1999	12235	SESW 8-153-95	PETRO-HUNT, L.L.C.	CMNU D-208X
11194	3305301958	PA	5/12/1999	12107	NENW 18-153-95	PETRO-HUNT, L.L.C.	SILURIAN 37-1
11352	3305302007	PA	10/15/1997	11870	SENE 8-153-95	WILLIAM HERBERT HUNT TRUST ESTATE	SILURIAN 41-1
11353	3305302008	A	8/4/1985	12135	SESW 7-153-95	PETRO-HUNT, L.L.C.	SILURIAN 39-1
11367	3305302012	AB	5/20/2015	12300	SWNW 16-153-95	XTO ENERGY INC.	STATE 16-12
11429	3305302027	PA	9/8/2014	12299	NWNE 26-153-95	XTO ENERGY INC.	SLAATEN 26-1
11553	3305302063	TA	4/7/2014	13810	NENW 26-153-95	XTO ENERGY INC.	THORLACKSON 26-3
11647	3305302082	PA	3/5/1993	12157	SENE 13-153-96	TEXACO EXPLORATION & PRODUCTION INC.	SILURIAN UNIT 44-1
11687	3305302088	DRY	4/20/1995	12185	SESE 12-153-96	TEXACO EXPLORATION & PRODUCTION INC.	SILURIAN UNIT 40-1
11785	3305302111	IA	11/11/2011	12212	NESE 13-153-96	PETRO-HUNT, L.L.C.	CHARLSON FEDERAL 13D-1-1SWD
11802	3305302113	A	2/21/1991	13776	CNE 27-153-95	FILCO INCORPORATED	TEMPLE-HAUGEN 27-2
11853	3305302129	A	6/20/2012	12248	NWSE 16-153-95	XTO ENERGY INC.	SILURIAN UNIT 56-1
11887	3305302140	A	11/17/1993	12120	NWNW 7-153-95	PETRO-HUNT, L.L.C.	MCKENZIE COUNTY 5-SWD
11895	3305302143	IA	2/23/1986	12357	NWNE 16-153-95	XTO ENERGY INC.	STATE 16-31
11897	3305302144	A	3/31/1992	12135	SWNW 8-153-95	PETRO-HUNT, L.L.C.	CMNU B-108
11948	3305302151	PA	10/10/1988	12300	SWSW 9-153-95	PROSPER ENERGY CORP.	PROSPER-ISAACSON 1

11983	3305302157	A	3/30/2008	14790	SESE 5-153-95	PETRO-HUNT, L.L.C.	USA 5D-4-4HR
12022	3305302164	PA	6/19/1991	12763	NENW 16-153-95	TEXACO EXPLORATION & PRODUCTION INC.	SILURIAN UNIT 53-1
12026	3305302166	DRY	1/22/1987	13653	NENW 13-153-96	WILLIAM HERBERT HUNT	W.H. HUNT SILURIAN 1-13
12031	3305302167	A	5/9/1987	12247	SWNW 9-153-95	PETRO-HUNT, L.L.C.	SILURIAN 54-1
12148	3305302186	PA	8/16/2013	12268	NWNE 21-153-95	PETRO-HUNT, L.L.C.	CMSU A-421
12707	3305302295	DRY	9/15/1989	11120	SWSW 14-153-95	TEXACO EXPLORATION & PRODUCTION INC.	GILBERTSON NCT-2 1
13429	3305302407	PA	10/17/1997	13620	NWSE 7-153-95	BERCO RESOURCES, INC.	G. L. THOMPSON 7-33
14854	3305302524	IA	10/2/2000	11904	NWNW 2-153-95	PETRO-HUNT, L.L.C.	CHARLSON USA 2B-2-2
21668	3305303819	DRY	4/13/2012	10649	SENW 34-153-95	BURLINGTON RESOURCES OIL & GAS COMPANY LP	UBERWACHEN 22-34

API	Top of Second Bakken	Three Forks top	first bench base	second bench top	second bench base	third bench top	third bench base/fourth bench bop	Top of Birdbear
3305300531	10356	10387	10423	10436	10484	10498	10554	10598
3305300620	10105	10135	10167	10177	10229	10243	10289	10344
3305300648	9977	10007	10040	10052	10107	10121	10178	10223
3305300649	9726	9759	9790	9801	9850	9865	9914	9964
3305300650	10062	10095	10126	10135	10189	10201	10254	10309
3305300655	10096	10133	10167	10177	10235	10252	10302	10363
3305300686	10393	10419	10452	10463	10511	10526	10574	10624
3305300688	10390	10421	10454	10465	10513	10524	10587	10630
3305300697	10330	10359	10394	10410	10455	10469	10527	10572
3305300706	10377	10404	10440	10451	10500	10516	10571	10613
3305300708	10355	10379	10417	10427	10474	10486	10546	10588
3305300710	10379	10407	10442	10452	10497	10511	10563	10614
3305300729	10306	10333	10370	10382	10430	10441	10497	10542
3305300743	10392	10423	10455	10470	10515	10526	10593	10633
3305300754	10327	10359	10394	10406	10457	10471	10529	10575
3305300755	10357	10386	10418	10430	10479	10492	10550	10596

3305300761	10340	10369	10406	10416	10458	10475	10530	10573
3305300769	10311	10335	10368	10380	10420	10439	10496	10543
3305300778	10385	10412	10446	10461	10503	10519	10576	10616
3305300785	10284	10314	10354	10367	10408	10424	10482	10525
3305300798	10529	10555	10588	10602	10642	10656	10713	10751
3305300844	10299	10330	10367	10379	10425	10440	10497	10543
3305300900	9957	9994	10030	10041	10098	10113	10168	10222
3305300901	10119	10152	10181	10195	10243	10252	10310	10362
3305300910	9764	9796	9828	9839	9890	9906	9954	10008
3305300912	10167	10199	10229	10239	10289	10299	10356	10410
3305300913	10178	10211	10242	10254	10301	10313	10373	10416
3305300953	10282	10310	10347	10359	10406	10420	10476	10517
3305301061	9690	9723	9751	9763	9815	9831	9878	9930
3305301066	9783	9815	9848	9858	9908	9924	9975	10027
3305301107	9957	9993	10027	10039	10097	10114	10166	10223
3305301121	10098	10128	10160	10171	10222	10236	10288	10344
3305301135	9859	9887	9921	9933	9982	9998	10054	10098
3305301166	10310	10339	10370	10380	10429	10439	10493	10546
3305301395	10311	10348	10379	10391	10439	10459	10517	10562
3305301426	10345	10373	10409	10420	10472	10485	10541	10583
3305301496	10005	10037	10071	10081	10135	10148	10195	10250
3305301617	9927	9960	9996	10007	10059	10073	10195	10177
3305301706	10214	10239	10272	10286	10334	10349	10195	10452
3305301724	10273	10300	10330	10345	10385	10406	10195	10504
3305301753	10215	10241	10276	10287	10331	10353	10195	10458
3305301757	10225	10252	10285	10298	10343	10364	10195	10467
3305301760	10268	10301	10331	10343	10389	10400	10195	10504
3305301763	10310	10346	10378	10391	10439	10450	10195	10563
3305301772	10262	10290	10326	10337	10387	10402	10195	10505
3305301773	10255	10286	10314	10326	10375	10392	10195	10494
3305301783	10220	10251	10283	10295	10344	10358	10195	10456
3305301826	10176	10205	10237	10249	10289	10313	10195	10415
3305301836	10316	10342	10379	10389	10433	10452	10195	10552
3305301843	10271	10301	10332	10344	10391	10406	10195	10506
3305301895	10244	10274	10305	10318	10368	10388	10195	10486
3305301903	10295	10322	10355	10368	10415	10434	10195	10530
3305301906	10228	10261	10292	10306	10349	10359	10195	10467
3305301908	10138	10166	10196	10211	10253	10275	10195	10380
3305301919	10171	10198	10233	10243	10292	10312	10195	10418
3305301920	10299	10330	10367	10379	10427	10444	10195	10548

3305301933	10234	10266	10295	10307	10358	10374	10195	10478
3305301958	10123	10149	10188	10202	10253	10265	10195	10369
3305302007	9910	9935	9972	9986	10035	10050	10195	10148
3305302008	10131	10162	10197	10211	10260	10274	10195	10379
3305302012	10310	10338	10369	10381	10429	10447	10195	10550
3305302027	10374	10400	10433	10445	10492	10510	10195	10608
3305302063	10390	10417	10453	10464	10505	10519	10195	10626
3305302082	10117	10146	10179	10192	10242	10255	10195	10365
3305302088	10144	10176	10213	10224	10270	10285	10195	10394
3305302111	10188	10216	10254	10265	10314	10327	10195	10434
3305302113	10348	10374	10409	10422	10464	10479	10195	10583
3305302129	10271	10300	10334	10347	10395	10412	10195	10514
3305302140	10089	10121	10157	10169	10218	10234	10195	10342
3305302143	10358	10388	10421	10431	10482	10495	10195	10600
3305302144	10109	10139	10176	10189	10232	10252	10195	10354
3305302151	10249	10276	10309	10321	10370	10387	10195	10493
3305302157	9968	9997	10030	10042	10092	10109	10195	10216
3305302164	10581	10620	10652	10666	10720	10739	10195	10857
3305302166	10111	10145	10181	10190	10239	10251	10195	10364
3305302167	10087	10116	10146	10159	10211	10228	10195	10333
3305302186	10284	10316	10354	10365	10412	10426	10195	10530
3305302295	10348	10377	10412	10423	10475	10488	10195	10586
3305302407	10133	10159	10196	10209	10249	10283	10195	10374
3305302524	9945	9977	10005	10018	10065	10076	10195	10180
3305303819	10298	10324	10361	10374	10415	10430	10195	10530

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