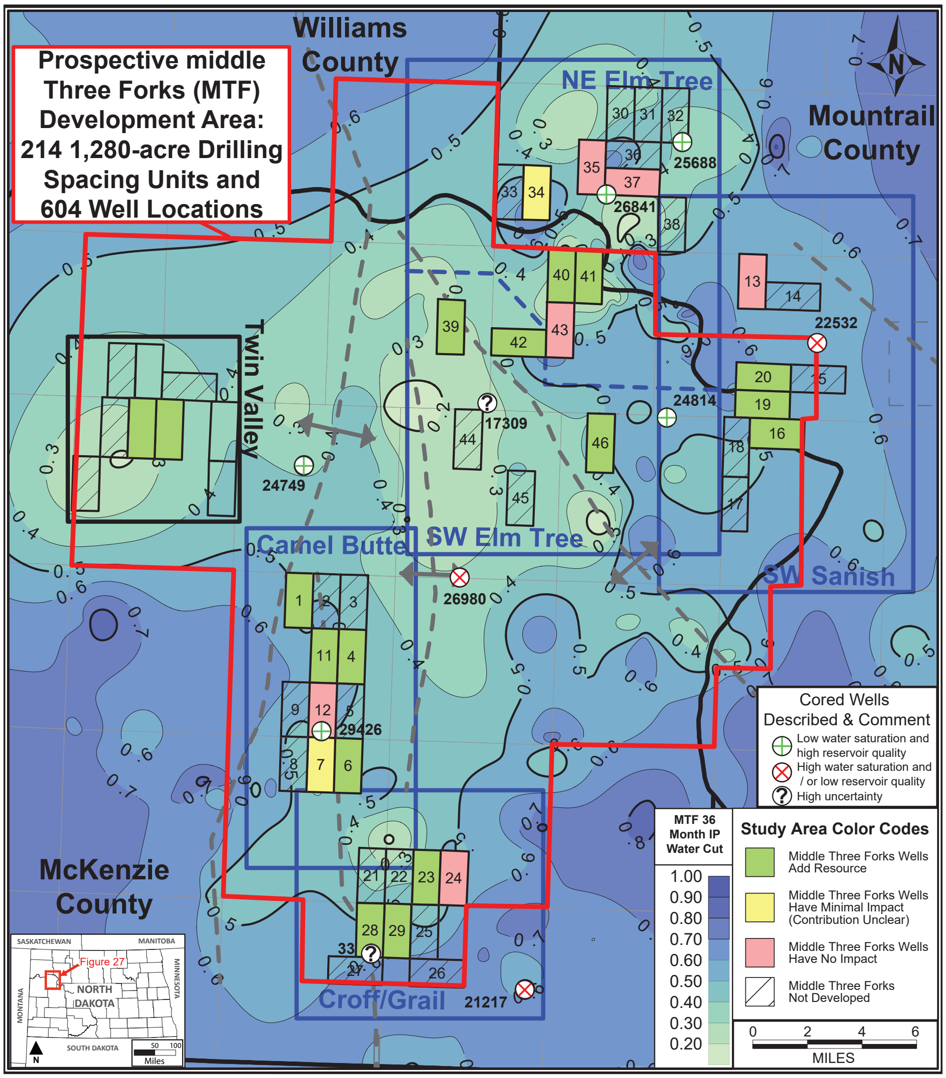
MIDDLE THREE FORKS DEVELOPMENT IMPACT AND RESOURCE POTENTIAL IN NORTHEASTERN MCKENZIE COUNTY, NORTH DAKOTA

by

Edward (Ted) Starns and Timothy O. Nesheim



REPORT OF INVESTIGATION NO. 136
NORTH DAKOTA GEOLOGICAL SURVEY
Edward C. Murphy, State Geologist
Nathan D. Anderson, Director, Dept. of Mineral Resources
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Project summary illustrating an interpretation of results and prospective area for development of the middle Three Forks in northeastern McKenzie County, North Dakota.

SUMMARY

Following the 2006 discovery of the Parshall Field in western North Dakota, oil and gas companies primarily targeted the Middle Member of the Bakken Formation (Middle Bakken) with horizontal wells. As understanding and investment grew in the play, the underlying rock units in the Three Forks Formation were targeted and proven to hold reserves. The upper Member of the Three Forks Formation (upper Three Forks) developed into a second established exploration and development target during 2008-2010. Beginning in 2013, the middle Member of the Three Forks Formation (middle Three Forks) also began to be targeted. A dilemma that has potentially limited development of the middle Three Forks is whether its co-development adds to long-term oil production, or simply accelerates the rate of recovery within the Bakken-Three Forks petroleum system. To evaluate the contribution of the middle Three Forks, 1,280-acre drilling spacing units (DSUs) with Middle Bakken, upper Three Forks, and middle Three Forks wells were compared to DSUs with only Middle Bakken and upper Three Forks wells. Each well within a DSU was analyzed to determine its three-year cumulative oil production and estimated ultimate recovery (EUR). By combining the production data of wells within each drilling spacing unit, a comparison was made between drilling spacing units containing middle Three Forks development wells and adjacent DSUs without middle Three Forks wells. Seventeen of the twenty-five (68%) DSUs with middle Three Forks development showed approximately 1 – 2 MMBO uplift in EUR compared to adjacent DSUs without middle Three Forks development. This study along with Nesheim and Starns (2024) combined to investigate 593 wells in fifty-one 1,280-acre DSUs, and defines a contiguous area of potential development that spans ~275,000 acres. This area holds the potential for 600+ new middle Three Forks development wells with an estimated ultimate recovery between 165 – 410 million barrels of oil. The results of these studies indicate that developing the middle Three Forks in addition to the Middle Bakken and upper Three Forks can increase long-term recovery.

INTRODUCTION

To date, over 360 horizontal wells have been drilled and completed targeting the middle Three Forks and have produced over 92 million barrels of oil and 238 billion cubic feet of gas. While drilling and completion activity in the middle Three Forks has been relatively steady (fig. 1), it has only represented a small fraction of the drilling activity compared to the overlying upper Three Forks and Middle Bakken. The purpose of this investigation is to address the question: Does co-development of the middle Three Forks in areas with Middle Bakken and upper Three Forks development wells add resource?

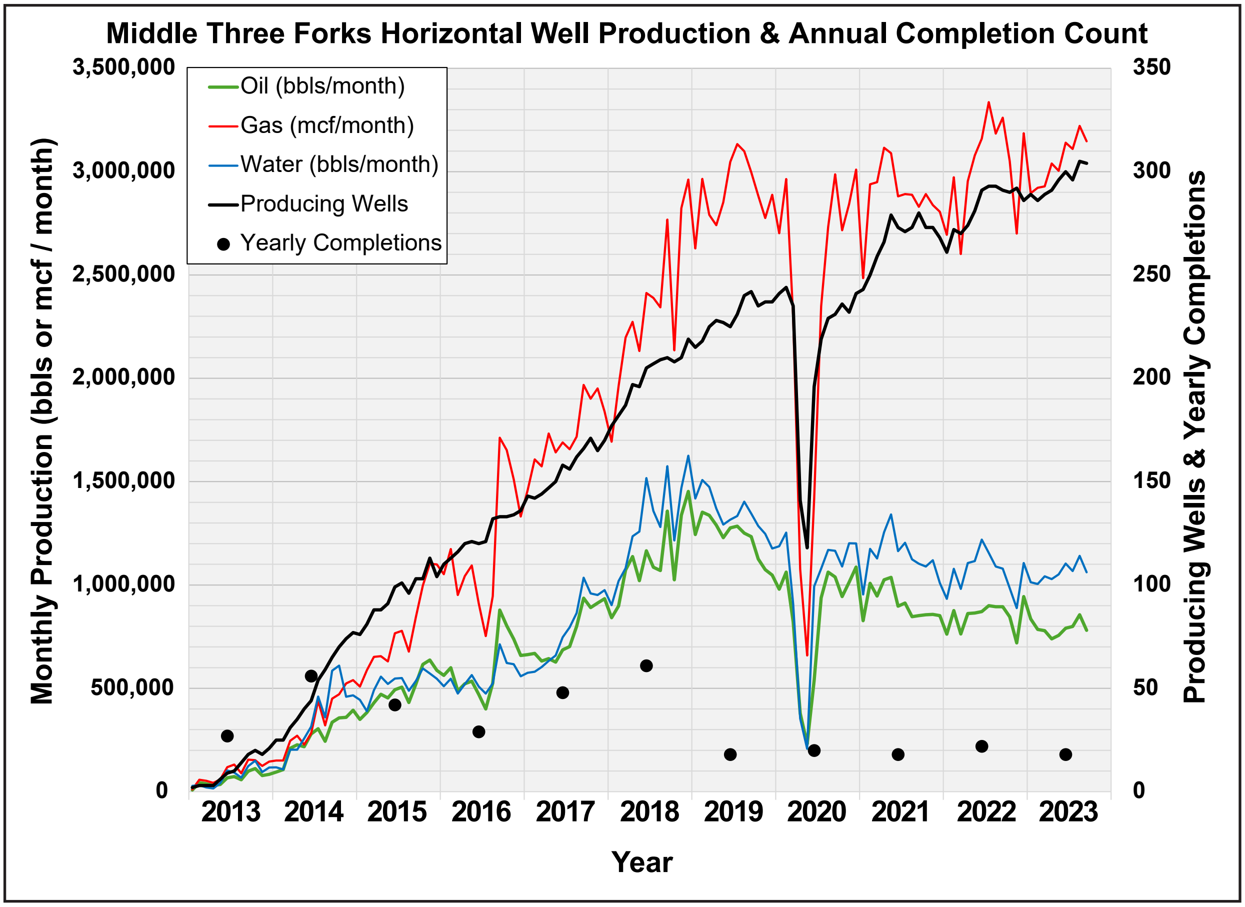

FIGURE 1. Middle Three Forks production and producing well count chart. The middle Three Forks emerged as a drilling target within the Bakken-Three Forks petroleum system in 2013, and from 2013 – 2023 was targeted by 20 – 60 development wells per year. Data from January of calendar year.

This investigation is an extension of RI-135 (Nesheim and Starns, 2024), which demonstrated the viability of middle Three Forks development in the Twin Valley Field study area of McKenzie County, North Dakota. In that study, 61 wells in six DSUs were investigated. Herein, 45 additional 1280-acre DSUs comprising 532 wells in the Middle Bakken, upper Three Forks, middle Three Forks, and lower Three Forks are analyzed for the performance of co-development of the four stacked reservoirs of the Bakken-Three Forks petroleum system in northeastern McKenzie County, North Dakota (Fig 2). The objective of this study was to determine the repeatability, contiguity, and extent of the findings first demonstrated in Nesheim and Starns (2024), which showed that the development of the middle Three Forks in addition to the upper Three Forks and Middle Bakken adds recoverable resource on the level of a 1,280-acre DSU.

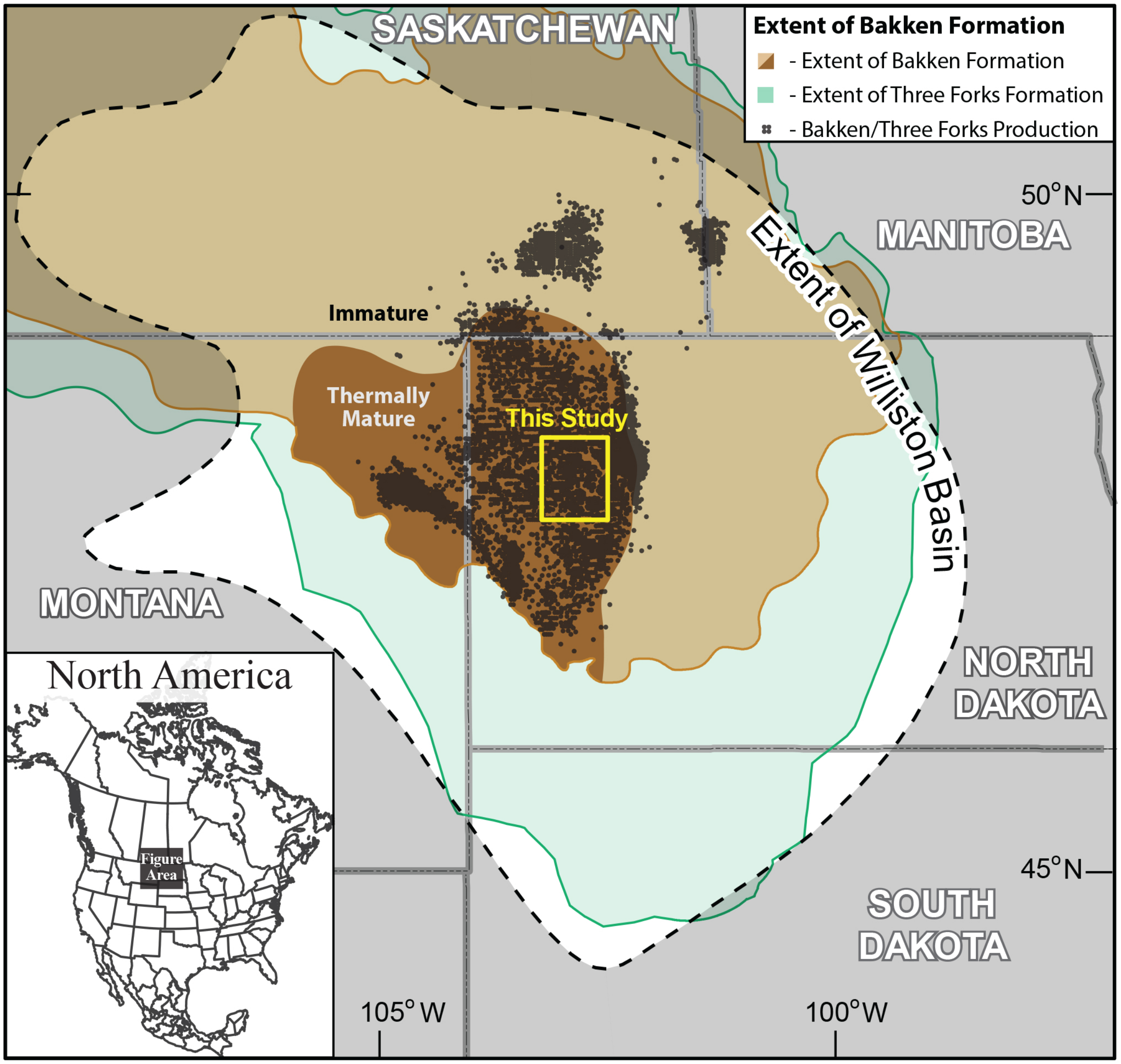

FIGURE 2. Location of the study relative to the Williston Basin, the extent of the Bakken and Three Forks Formations, the area of thermally mature Bakken source rocks, and the location of wells that have produced from the Bakken-Three Forks petroleum system in the region.

GEOLOGIC BACKGROUND

The following section is a slightly modified version of the "Geologic Background" section from Nesheim and Starns (2024) and is included here to provided context within this publication.

The Bakken – Three Forks petroleum system is composed of four reservoirs and two source intervals, all of which have been developed to some extent, going as far back as the 1950s (fig. 3). With a regional extent that covers most of the Williston Basin (fig. 2), the Bakken – Three Forks petroleum system represents the most important oil and gas bearing system in the history of North Dakota, with a cumulative production of 5.2 billion barrels of oil and 10 TCF of gas as of August 2024.

The Three Forks Formation is a mixed carbonate-siliciclastic unit that was deposited during the Late Devonian (Murphy et al., 2009; Droege, 2014; Franklin and Sarg, 2018) (fig. 3). Two competing models for deposition include a storm dominated intrashelf, restricted marine setting (Franklin and Sarg, 2018) versus an arid, hypersaline, lacustrine environment (Garcia-Fresca et al. 2018). The Three Forks mineral assemblage is comprised primarily of fine-grained dolomite with moderate amounts of clay (mostly illite) and silt – to sand-sized quartz with variable amounts of anhydrite primarily in the lower portions of the section (Ashu, 2014; Murphy, 2014). The Three Forks has been sub-divided into different nomenclature systems, including: 1) six sub-units ranging from unit 1 to unit 6 in ascending stratigraphic order (Christopher, 1961; 1963); and 2) an upper, middle, and lower member distinction (Bottjer et al., 2011), which is utilized herein (Fig. 3). Additionally, an informal "bench" terminology system has also been developed by industry, where four reservoir target horizons are referred to as benches one to four in descending stratigraphic order (fig. 3).

The upper Three Forks reservoir (also referred to as the 1st bench) is composed mostly of tan silty laminated dolostone that is, in part, intercalated with grey to green claystone (Bottjer et al., 2011; Franklin and Sarg, 2018). The middle Three Forks reservoir (2nd bench) also contains some laminated to intercalated silty tan – brown dolostone but contains a conglomeratic facies association with re-worked dolostone clasts (Nesheim, 2021). Both reservoir intervals are typically on the order of 30-40 ft (9-12 m) thick and are separated by a 12-14 ft (3-4 m thick) interval primarily composed of poorly laminated silty mudstone that is comprised of relatively equal proportions of quartz-dolomite-clay (Nesheim, 2021).

The Three Forks is disconformably overlain by the Bakken Formation (Mississippian-Devonian), which is comprised of four members (fig. 3), in descending order: the Upper, Middle, Lower, and Pronghorn (LeFever et al., 2011). The Upper and Lower Members consist of black, slightly calcareous, organic-rich shale while the Middle Member is primarily composed of dolomitic to calcareous siltstone to sandstone (LeFever et al., 2011). The Middle Member siltstones record a history of progradational and retrogradational basin filling parasequences with very low angle geometries (Egenhoff et al., 2011; Egenhoff and Fishman, 2020). The basal Pronghorn Member ranges from siltstone to sandstone (proximal deposits) and silty to sandy mudstone (distal deposits) (LeFever et al., 2011). The proximal deposits of the Pronghorn can serve as a hydrocarbon reservoir and is currently the southernmost reservoir of the petroleum system (Skinner et al., 2015). The distal Pronghorn is overall clay-rich (poor reservoir quality), and, when present and substantially thick, has been interpreted to form a barrier to hydrocarbon charge from the lower Bakken shale to the upper Three Forks (Millard and Brinkerhoff, 2016). Both the distal and proximal deposits of the Pronghorn are discontinuous across western North Dakota and range from absent to reaching combined thicknesses of over 40 feet (12 m) (LeFever et al., 2011).

The Three Forks is a non-self-sourced, tight oil reservoir, containing minimal petroleum source rock based upon visual examination and sampling/analysis (Ashu, 2014). The overlying lower Bakken shale is an excellent quality source rock (TOC values commonly > 10%), originally contained abundant Type II (oil-prone) kerogen, reaches a maximum thickness of 60 ft (18 m), ranges from immature to peak-mature with respect to oil generation in the Williston Basin, and is understood to be the primary source of Three Forks hydrocarbons (Nordeng et al., 2010; Abarghani et al., 2018; Nesheim, 2019a). Three Forks reservoir quality in western North Dakota is low porosity (< 6%) with small pore diameters (1–100 nm) and very low permeability (< 1 millidarcy, mD) (Nordeng et al., 2010; Bottjer et al., 2011; Saidian and Prasad, 2015; Liu et al., 2017). In the area where the lower Bakken shale is at its highest thermal maturity and greatest thickness, a large enough volume of hydrocarbons have been expelled to charge the upper, middle and possibly even the lower Three Forks Formations (localized) (Nesheim, 2019a). This area of highest oil generation is centered in northeastern McKenzie County, and is the location of this study.

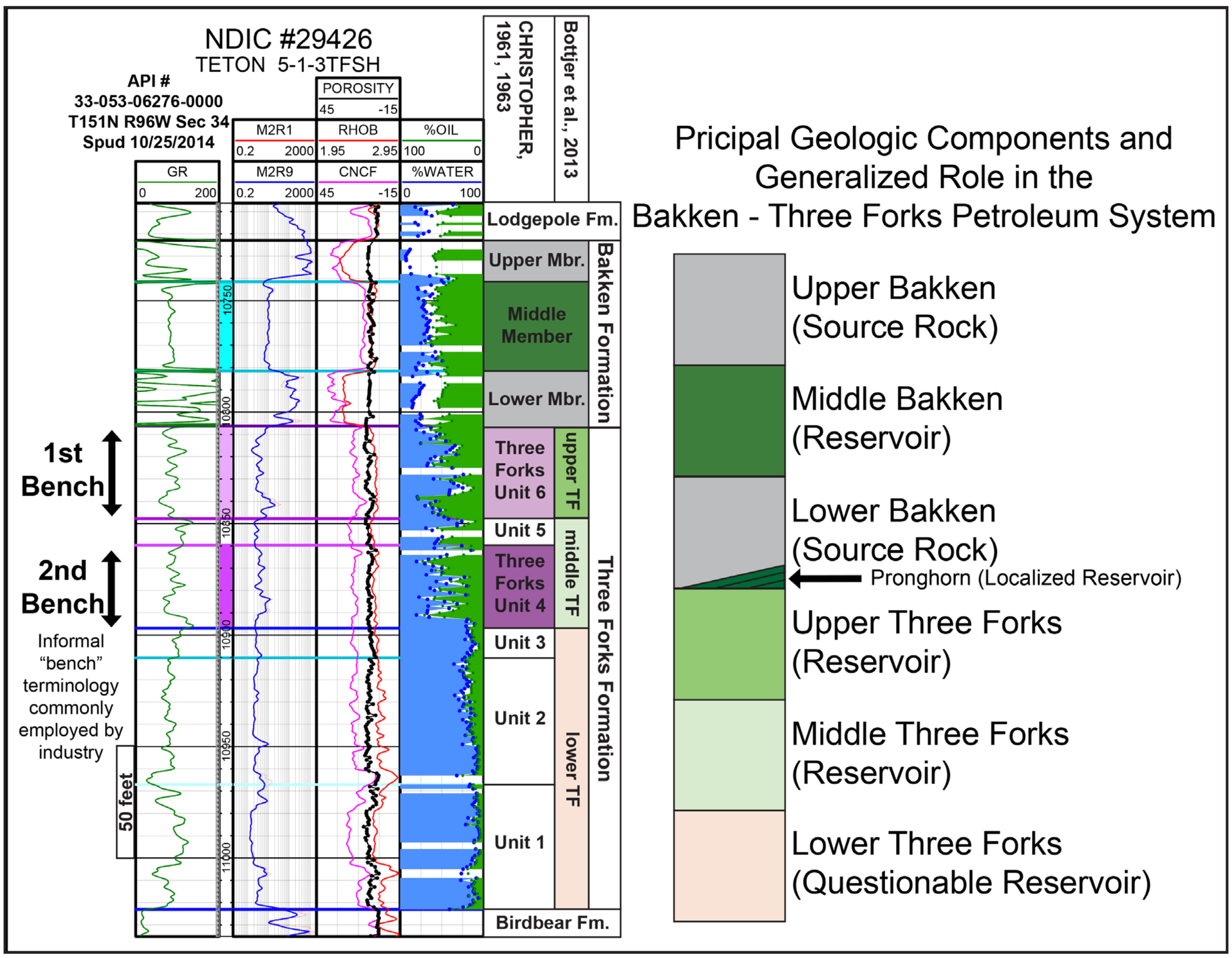

FIGURE 3. Type well with significant log picks of the region and a generalized description of the components of the petroleum system discussed in this study.

METHODS

A methodology was selected to compare the production of similar geologic settings with and without middle Three Forks development. Study areas were selected where 1,280-DSUs with 1 – 4 middle Three Forks development wells in addition to upper Three Forks and Middle Bakken development wells were surrounded by 1280-acre DSUs with only upper Three Forks and Middle Bakken development wells. To maintain consistency of comparison, only 1,280-acre spacing units were analyzed. DSUs within study areas are numbered according to the order in which the analysis was completed and are discussed in following sections in a non-sequential order, by study area, from north to south. A total of 532 wells from 45 DSUs were evaluated in McKenzie and Mountrail Counties, North Dakota (Figure 4). Analysis of the Twin Valley study area can be found in Nesheim, 2024.

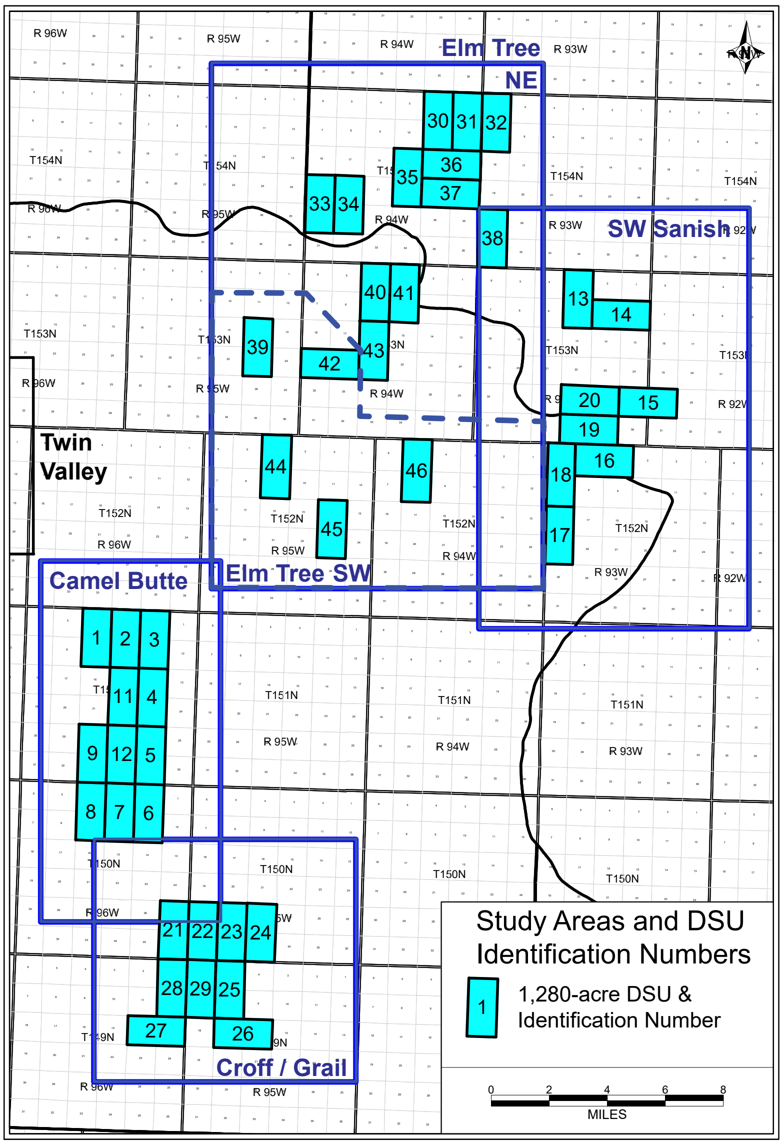

FIGURE 4. Study areas and DSUs presented herein with township-range-section grid and county lines for reference.

Horizontal wells which targeted the middle Three Forks were initially determined from NDGS records and Nesheim, 2020. Upon selection of DSUs for further study, NDIC well files, wellsite geologist reports, interpreted mudlogs, and directional surveys were utilized to determine the formation targeted by each well within a DSU. Individual wells were classified as Middle Bakken, upper Three Forks, middle Three Forks, or lower Three Forks development wells based on landing position in the stratigraphic section and horizontal well placement.

Monthly production data for each well with associated days of production per month was analyzed to determine the cumulative oil production of the first 1,095 days (3 years or 36 months). Where well production had not reached a total of 1,095 days, a decline curve was used to determine a forecast 36-month production value. DSUs where forecasted 36-month production values were included are noted on subsequent charts.

Estimated ultimate recovery (EUR) was determined using the production analysis tool included with the Petra© software package. A single deterministic value was generated for each well. For each well, the final rate to determine EUR was set at 300 barrels of oil (BO) per month (e.g., fig. 5). Where subsequent offset infill drilling well completions or individual well production optimization efforts (e.g., recompletions or artificial lift re-designs) resulted in new production behavior (i.e., increased production and/or shallower decline curves), the most recent trends were used to determine EUR (e.g., fig. 6). In several cases, later infill drilling negatively impacted production in a pre-existing nearby well (e.g., fig. 7). Interactions and optimization efforts such as those exemplified in Figure 6 and Figure 7 were noted where significantly impactful, and several examples are highlighted in the results and discussion section below.

For each 1,280-acre DSU, the 3-year cumulative production and EUR values were segmented by formation target and totaled. This methodology allows for a holistic comparison between DSUs that also highlights the relative contribution and expected performance of each formation (fig. 8). Subsequent charts illustrate the 3-year cumulative oil production, EUR, and total wells per DSU in each study area. Within each column of the histogram, DSUs are split by the relative contribution of each formation and the number of wells that comprise the subtotal. Of note in the indication of wells per formation are partial wells. These indicate that section line wells exist along the edges of the DSU. When section line wells were present, a portion of the 3-year production and EUR indicated by the partial value was allocated to the DSU.

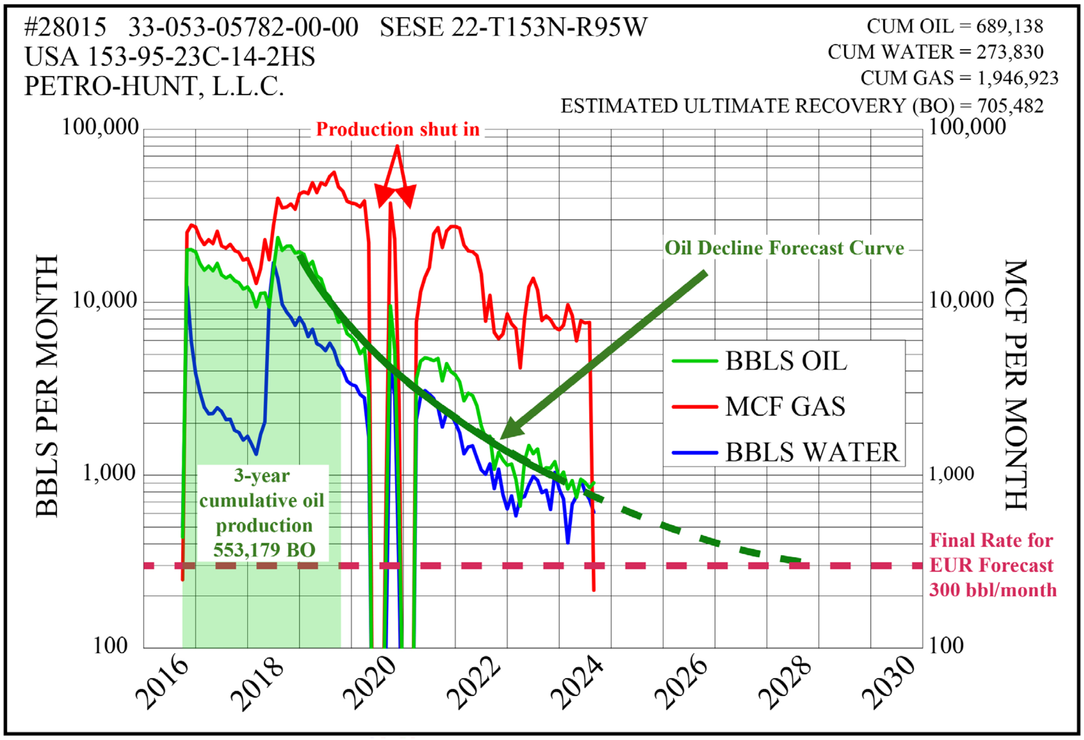

FIGURE 5. Monthly production history and a decline curve generated from the USA 153-95-23C-14-2HS well (NDIC #28015) in the SW Elm Tree study area, illustrating a typical, predictable decline curve for a horizontal well. NDIC #28105 is in the top 10th percentile of middle Three Forks wells analyzed in this study, and was selected to illustrate the potential rates and recovery that the middle Three Forks can yield in McKenzie County.

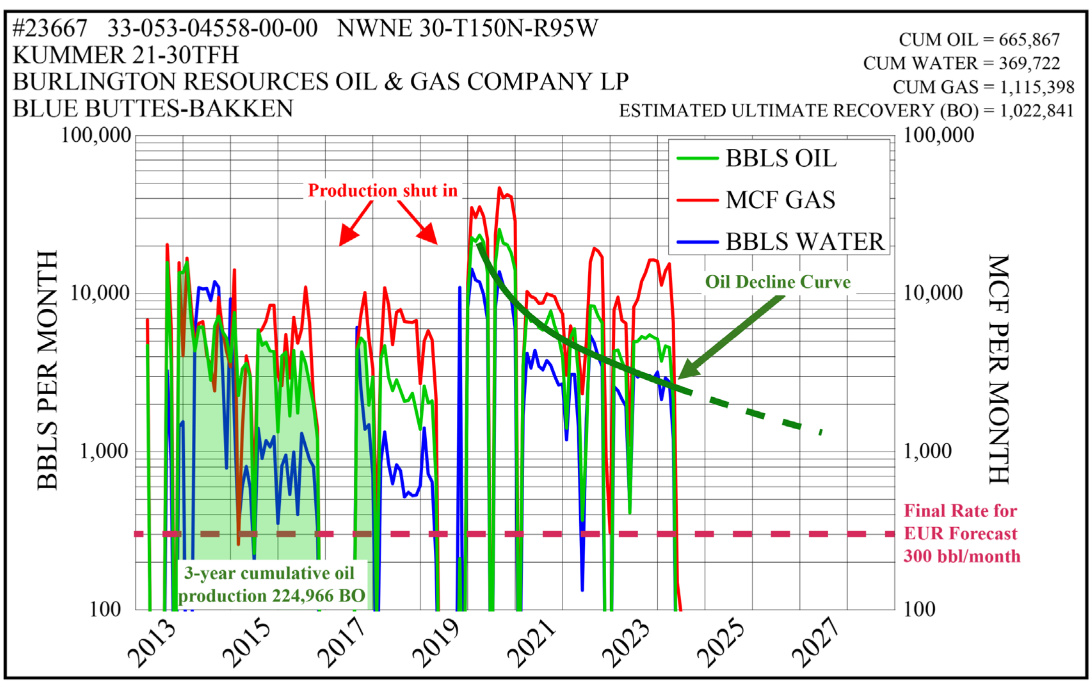

FIGURE 6. Monthly production history and a decline curve generated for the Kummer 21-30TFH well (NDIC #23667) in the Croff & Grail study area, illustrating a revitalization of oil production as a result of a recompletion effort where sliding sleeves were pulled and replaced with a plug and perf completion, and restimulated in 2019.

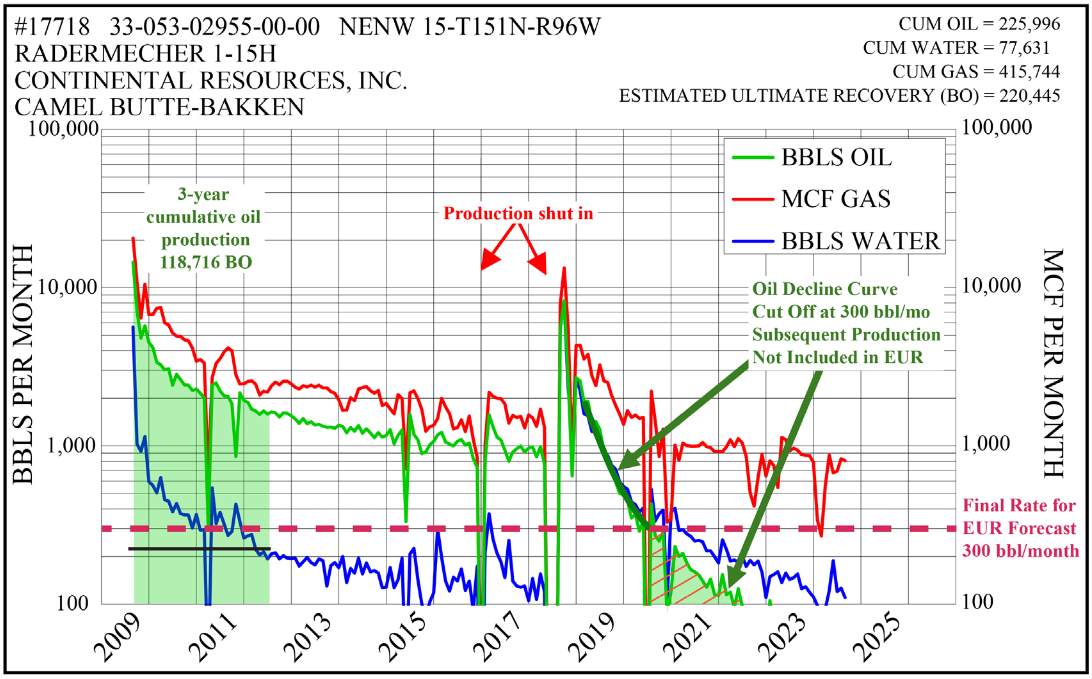

FIGURE 7. Monthly production history and a decline curve generated from the Radermacher 1-15H well (NDIC #17718) in the Camel Butte study area, illustrating an example of a well which had its productivity significantly diminished from infill drilling and completion of four surrounding wells in September – October 2018. The associated decline curve was used to forecast EUR. This is an example where the current oil production rate was below the 300 BO/month cutoff used for EUR forecasting, and as such, production after the well fell below 300 BO/month was not included in EUR comparisons. This is one of the few instances in this study where EUR is lower than the cumulative oil produced.

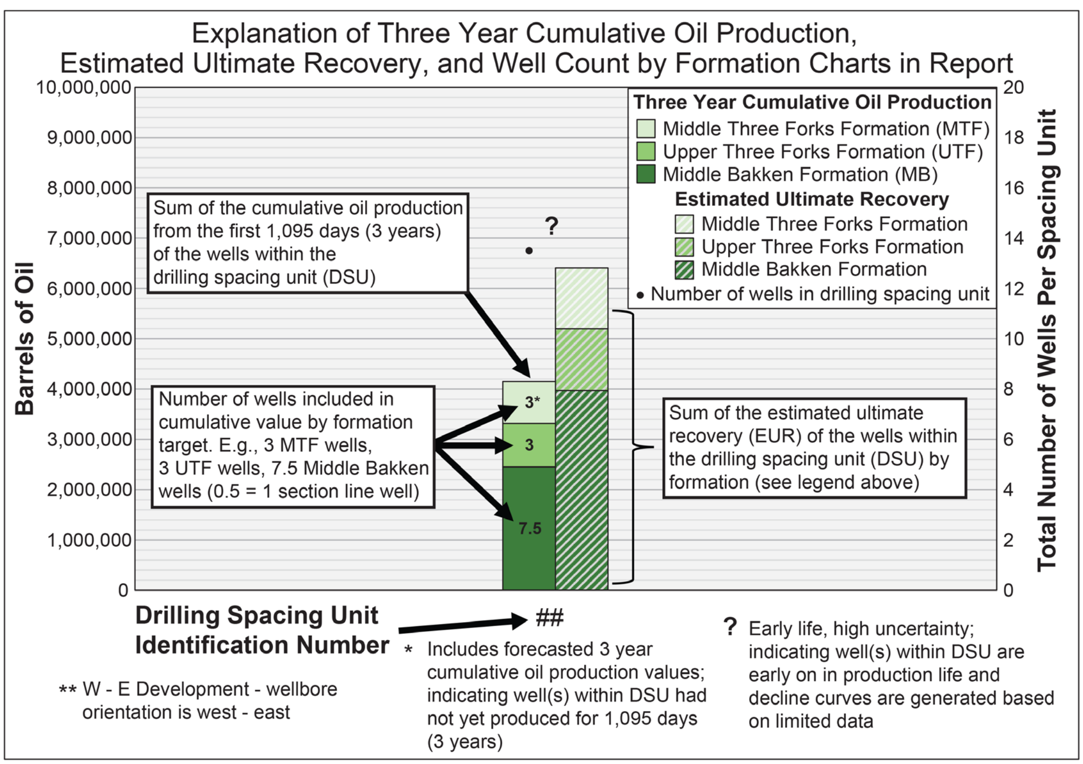

FIGURE 8. Explanation of data displayed in the subsequent histograms of this report.

Completion data for each well was gathered from North Dakota Industrial Commission (NDIC) records to determine if hydraulic fracture stimulation parameters were a significant contributing factor to well performance. Treatment length, volume, proppant weight (pounds) and volume (barrels), number of stages, and maximum treatment pressure and rate were gathered from operator submitted completion reports. Proppant pounds per lateral foot, and pounds per stage were calculated for summary comparison. As all laterals in this study were from 1,280-acre DSUs, lateral lengths were consistently ~10,000 feet (two-mile laterals). Normalization to pounds per foot was used as a comparison metric to investigate differences in the size of the hydraulic fracture stimulation applied to each well. After consultation with an expert in the completion engineering field (Klem, 2024 personal comm.), maximum treatment rate was selected as a second variable to investigate differences in hydraulic fracture stimulation. Maximum treatment pressure was not selected, as this surface measurement can be affected by multiple, complex, down-hole variables not reported in the data sets utilized for this investigation. A discussion of the completion data analyzed can be found in the results section which follows.

Isopach and depth structure mapping was completed for each study area using a combination of vertical and horizontal well penetrations. Bakken Formation and Pronghorn Member picks were made utilizing North Dakota Geological Survey and NDIC convention. Three Forks Formation sub-interval picks were completed utilizing the unit conventions of Christopher, 1961 and Nesheim, 2019 b. (fig. 3). To abbreviate this report, an overview map of the middle Three Forks thickness and top Middle Bakken structure can be found in following sections within the report. Additional maps for reference can be found in Appendix I.

The upper and middle Three Forks were described using ten cores evenly distributed across the study area. This description of 1,348 feet of core employed the facies association methodology introduced by Nesheim (2021). Core selection aimed to provide a spatially representative sample of wells that penetrated at least the upper and middle Three Forks throughout the entire study area (fig. 9). It’s important to note that these ten cores represent only a subset of the available cores in the region; Nesheim (2021) provides additional details.

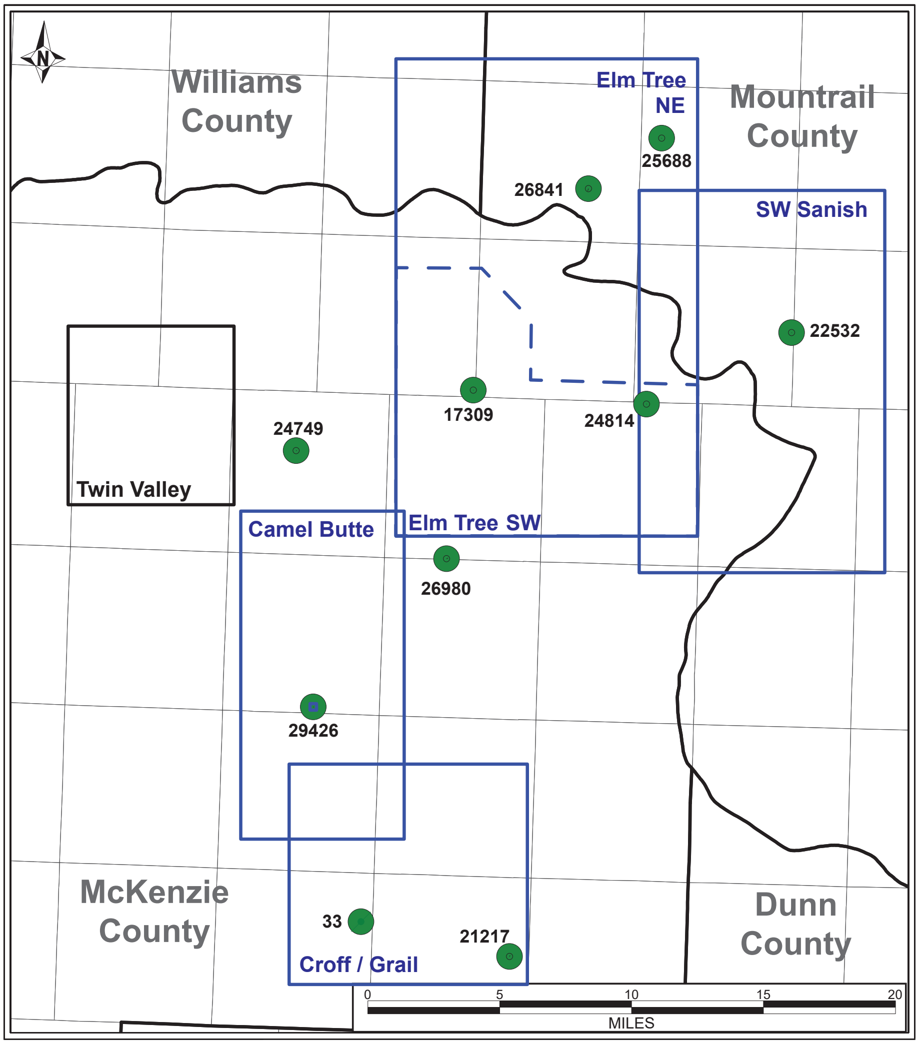

FIGURE 9. NDIC numbers and locations of the ten cores described in this study, the study area boundaries, and the Twin Valley study area detailed in Nesheim and Starns, 2024.

STUDY AREA GEOLOGIC OVERVIEW

Sedimentology and Oil / Water Saturations

Garcia-fresca et. al., (2018) provides an accessible summary of the major rock types of the Three Forks Formation from a basin-wide study. Franklin and Sarg (2018) put forth a more granular study of the intricacies of the sedimentological features of the Three Forks Formation and their implications. Between these two articles there are subtle differences in interpretations of facies associations and terminology, and a distinct difference in depositional models, but general agreement in the rock types. These two recent studies and the previous work cited therein describe the complexities of the Three Forks Formation in great detail on a basin scale. Nesheim, 2021, provides a detailed description of the facies associations within the middle Three Forks. This study further simplifies the rock types of the Three Forks Formation to provide general, reconnaissance-level observations of the rock types at play in the upper and middle Three Forks, the two main Three Forks reservoirs within the study areas.

In the core descriptions which follow, the Three Forks Formation was lumped into three facies: laminated dolostone facies association (FA), conglomeratic FA, and silty mudstone FA. Within the conglomeratic FA, differences in dominant matrix composition (i.e., mud-rich or dolo-siltstone-rich), are indicated with color differences on the following core description cross-sections. Orange indicates dominantly dolo-siltstone matrix, green indicates dominantly clay-rich matrix. Within the silty mudstone FA, oxidized zones are indicated with a red color, and anhydritic mudstone zones in the lower Three Forks are also noted with blue horizontal diamonds. Figure 10 is an example of a core description from the Mangum 5493 44-7 T3 well (NDIC #25688) in the Southwest Sanish study area. This well in the northeastern portion of the study area was selected to illustrate the core description rock types because it contains all categories observed.

Throughout the Three Forks Formation, a visual assessment of net thickness of reservoir in each foot of core was completed and included in the resistivity track and displayed as a percentage. In the upper Three Forks and lower Three Forks, this process is a simple visual estimation of the ratio of planar and ripple laminate dolo-siltstone (reservoir) to mudstone (non-reservoir). In the middle Three Forks, this assessment is more challenging. Where planar and ripple laminated beds were present, the methodology followed the same as with the upper Three Forks. In conglomeratic zones, this visual estimation was derived by abundance and type of clasts and matrix composition. Clay content in the middle Three Forks likely has the most significant influence on reservoir quality, with increasing clay content leading to decreasing hydrocarbon storage potential. Thus, where the clast types were dominantly dolo-siltstone with or without preserved sedimentary structures, estimated values were higher. Also considered was the matrix composition. Where X-ray diffraction data was available, relative proportion of carbonate and quartz content to clay content was used. Where X-ray diffraction data was not available, color and previous observations was used as a proxy for clay content. Figures 11 a, 11b, and 11c are a presentation of simplified descriptions of these ten cored wells, with wireline logs and selected core analysis data (oil and water saturation and porosity).

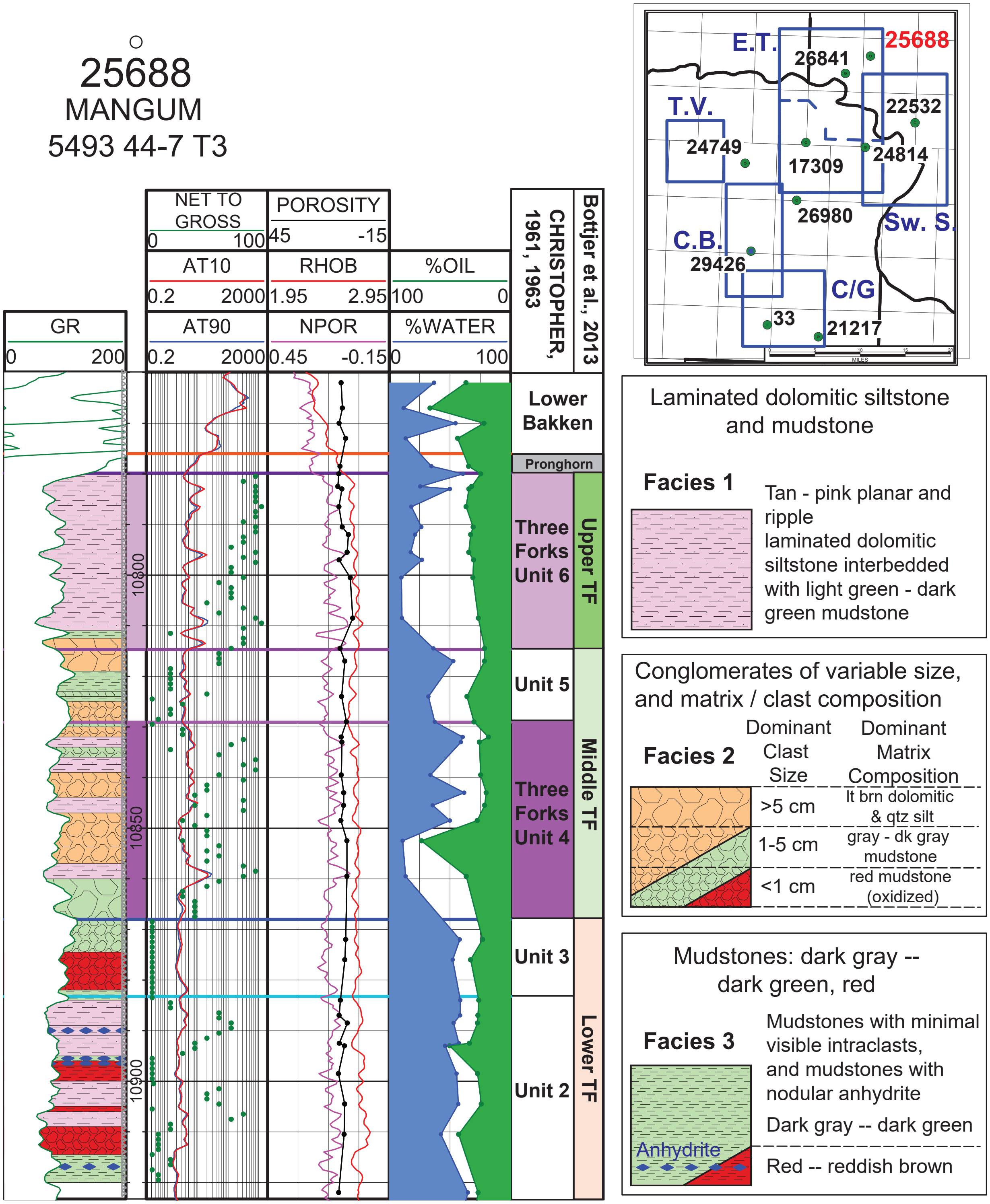

FIGURE 10. Example core description, wireline logs, and presentation of select core analysis data from the Mangum 5493 44-7 T3 well (NDIC #25688) in the Northeast Elm Tree study area.

Lower Three Forks (Unit 2 & Unit 3)

Lower Three Forks Unit 2 is characterized by rock types associated with sub-areal to nearshore deposition in a low topographic gradient, arid depositional environment (Garcia-Fresca et al., 2018; Franklin and Sarg, 2018). The primary lower Three Forks rock types are mudstones and mudstones with anhydrite that can be massive, mosaic, or nodular. Lesser amounts of thinly laminated dolo-siltstone are occasionally present near the upper most section of Unit 2. The lower Three Forks Formation was not a focus of this study, but portions of it were described in certain instances where core was present. Well NDIC #25688 (fig. 10) shows potentially anomalous higher oil saturations and reasonable reservoir quality in the lower Three Forks, but this is an exception. Overall, the lower Three Forks reservoir in the study area is of poor quality, exhibiting high water saturation in core analysis measurements where laminated dolo-siltstone beds are present. The lower Three Forks also exhibits lower resistivity, which follows the increased water saturations. Laminated dolo-siltstone beds within the lower Three forks are also thinner and less abundant than in the overlying Three Forks Formation section, as indicated with net to gross observations. Also of note is the presence of anhydrite and anhydrite nodules within the lower Three forks section which, in addition to the more abundant mudstone beds suggests a more nearshore depositional environment that is less conducive to the deposition of the reservoir facies of the Three Forks Formation.

Lower Three Forks Unit 3 is characterized by dark red – green poorly laminated mudstone and muddy matrix-supported conglomerate. This mud-rich section varies in composition and abundance of intraclasts and is interpreted to be associated with a marine transgression and a mudflat depositional environment (Franklin and Sarg, 2018). In the study area, Unit 3 is a not a prospective reservoir, with high clay content, and consistently high water saturation (with the exception of well NDIC #17309, fig. 11a).

Middle Three Forks (Unit 4 & Unit 5)

Middle Three Forks Unit 4 is the focus of this study and is highly variable in its sedimentology. Nesheim (2021) provides the most focused and thorough description of the middle Three Forks, with a focus on Unit 4, where he categorizes the sedimentology of the middle Three Forks into three facies associations: 1) Laminated dolo-siltstone, 2) conglomeratic, and 3) silty mudstone. These rock types are interpreted to have been deposited at various locations on a continental shelf with low topographic relief, reflecting a progressively shallowing depositional settings from Facies 1 – 3. Unit 4 is dominated by conglomeratic rocks in the study area, which are highly variable in sedimentological characteristics and oil/water saturations. From initial observations, it appears that within conglomeratic facies in Unit 4, conglomeratic rocks dominated by dolostone clasts with low clay content from XRD analysis have the lowest water saturations and are expected to be the best reservoir. Also present within the Unit 4 cores described are 2 – 10-foot-thick packages of laminated dolo-siltstone with planar and ripple laminae, which are often associated with the highest resistivities and oil saturations. Figure 11 (a-c) highlights the variable sedimentology, log responses, and oil / water saturation of the middle Three Forks reservoir (Unit 4) in three cross-sections which transect the study areas, a-c, from north to south.

In the northern portion of the study area, Unit 4 (the main reservoir interval of the middle Three Forks) shows a high variability in the proportion and relative stratigraphic position of Facies 1 and is dominantly composed of Facies 2 (fig. 11a). Facies 2 is also variable, with significant variability in clast size and matrix composition, generally increasing in complexity to the northeast. Well NDIC #24749 shows consistently promising reservoir quality and oil saturation and highlights that T152N, R96W is a highly prospective area for middle Three Forks development. Well NDIC #17309 is a source of uncertainty for prospectivity of the middle Three Forks in the Southwest Elm Tree study area, as core analysis data reports zero oil saturation in the middle Three Forks. Additionally, oil saturations in the upper Three Forks are lower than expected. These data present an issue that may have held back development in the area and warrants a second look.

Unit 4 in the central portion of the study area exhibits similar trends to the northern area, with variable proportions and stratigraphic position of Facies 1 and clast size and matrix variability of Facies 2 (fig. 11b). Wells NDIC #29426 & #24814 are prime examples of prospective middle Three Forks reservoir, with consistently good reservoir quality and oil saturations comparable with the overlying upper Three Forks. Well NDIC # 26980 to the south of the Southwest Elm Tree study area exhibits high water saturation and low oil saturation in the lower portion of Unit 4, suggesting that the oil charge in the middle Three Forks is spatially variable, adding increased risk to this area, which has seen limited middle Three Forks development. Core analysis data from NDIC #22532 on the northeast margin of the Southwest Sanish study area has low oil saturation and low resistivity except for an isolated thin interval of reservoir at the base of Unit 4, suggesting the Southwest Sanish study area lies at or near the eastern margin of prospective middle Three Forks development.

The southern portion of the study area also shows variability in the sedimentology of Unit 4, but with limited degradation of reservoir quality (fig. 11c). Well NDIC #33 was drilled in 1952 and does not have core analysis data, however on visual inspection reservoir quality appears good. The high water saturations in well NDIC #21217 indicates the southeast corner of the Croff/Grail study area is an edge of prospective middle Three Forks reservoir.

Middle Three Forks Unit 5 is composed of variable proportions of thinly laminated mudstones and conglomeratic rocks with rare, thin, planar and ripple laminated dolo-siltstone beds up to two feet thick (Nesheim, 2021). In the study area, Unit 5 is highly variable, ranging from conglomeratic rocks with variable matrix composition to laminated mudstones, with one observed instance of planar and ripple laminated dolo-siltstone (fig. 11b; well NDIC #26980).

Upper Three Forks (Unit 6)

Upper Three Forks Unit 6 is mostly composed of planar and ripple laminated dolo-siltstone beds intercalated with poorly laminated green mudstone (Nesheim, 2021; Garcia-Fresca et. al., 2018; Franklin and Sarg, 2018), with dolo-siltstone clast conglomeratic beds that are commonly found near the base of Unit 6. The upper Three Forks is remarkably consistent within the study area, with only subtle changes in proportion of dolo-siltstone to mudstone. At the base of the upper Three Forks, a conglomeratic zone was present in all cores with thicknesses between 3 – 6 feet. Within Facies 1, the upper Three Forks exhibits classic sedimentary structures that are often described (e.g., Franklin and Sarg, 2018, Garcia-Fresca et al., 2018), including planar laminations, ripple laminations, climbing ripples, ball and pillow structures and other soft sediment deformation and fluid escape related features. Oil and water saturations vary with lithology, with dolo-siltstone beds exhibiting higher oil saturations and resistivities. The upper Three Forks is consistently charged with oil in the study area.

Unit Thickness Variations

Isopach maps for the Upper, Middle, and Lower Members of the Bakken Formation and the six units of the Three Forks Formation were completed for the region which encompasses all study areas using vertical wells only. To abbreviate this report, only the middle Three Forks reservoir (Unit 4) is presented below (fig. 12), and a complete set of isopach maps can be found in Appendix I.

The middle Three Forks reservoir (Unit 4, fig. 12 and Appendix I(f)) shows minor, localized variability in thickness that is mainly a result of facies changes within sub- and suprajacent Unit 3 and Unit 5, partly compounded by questionable log picks in legacy, low quality raster logs. In general, the thickness of the middle Three Forks is consistent both within and between study areas discussed below, ranging from 35 – 50 feet, and is not interpreted to be a driving factor in productivity.

Similarly, the upper Three Forks reservoir (Unit 6) shows only subtle variations in thickness (Appendix I (e)), ranging from 30 – 40 feet. However, there is a subtle thinning present in Unit 6 in northeastern McKenzie County in the region of convergence of major regional anticlinal structures (see Structures section below), that suggests tectonic activity and associated changes in accommodation may have been present in late Devonian time.

Late Devonian time was evidently a period of structural activity for the Antelope anticline, as evidenced by the dramatic thinning of the Lower Bakken from 50 – 25 feet over the crest and to the west of this major structural feature (fig.13, Appendix I (g)). Appendix I (c) is a gross thickness map of the Lower Bakken, illustrating the ~25′ of thinning coincident with ~500′ of relief on the top Middle Bakken on the northeast flank of the Antelope anticline. This trend of thinning over the crest of the Antelope anticline continued into the time of Middle Bakken deposition (Appendix I (b)) with a thinning of 65 – 40 feet, with an apparent hiatus during the time of Upper Bakken (Appendix I (a)).

However, deformation must have continued thereafter given that thickness increases in the Upper and Middle Bakken are an order of magnitude lower than the relief of the structure, and the Middle Bakken is clearly deformed.

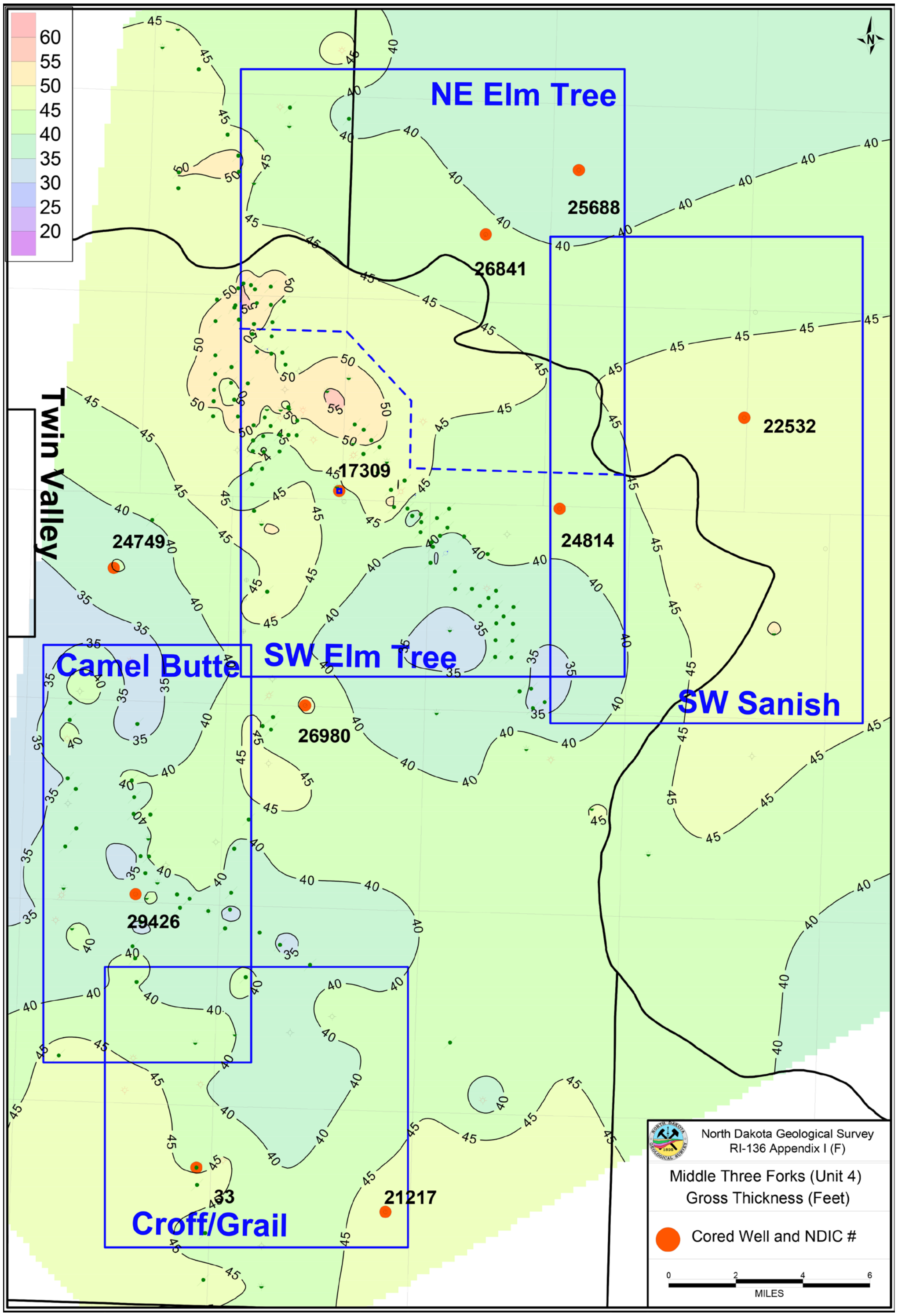

FIGURE 12. Middle Three Forks Isopach illustrating study areas and cored wells described herein. See Appendix I (f) for a full-size version.

Structures

The study areas discussed herein are bisected by two major structures: the composite Nesson anticline and the Antelope anticline (fig. 13). The Nesson anticline is a composite feature of multiple anticlinal structures mappable on various formations (Gerhard, 1990; Laird and Folsom, 1952), and the Nesson anticline splits into three anticlinal features present in the Camel Butte and Croff/Grail study areas (fig. 13). The composite Nesson anticlinal structures show subtle relief on the top Middle Bakken in the area and exhibit limited influence on the thickness of the formations and members of the Bakken-Three Forks petroleum system (Appendix I, a-f). In contrast to the composite Nesson Anticlinal system, the Antelope anticline exhibits ~500′ of relief on its northeastern limb and the Lower and Middle Bakken show dramatic thinning onto the structure (Appendix I, b&c)

Given the manifestation of the regional structures on the top Middle Bakken, particularly on the Antelope anticline, it is inferred that natural fractures are more likely in study areas near structural features. These inferred natural fractures likely have a positive influence on both productivity and charge potential of the middle Three Forks, and higher productivity of middle Three Forks wells is expected in study areas proximal to these structures. In the selection of the following study areas, an effort was made to separate them into areas proximal to major structures, and those with limited spatial relation to known structures. The Southwest Elm Tree Study area was separated from the Northeast Elm Tree study area because it is located near the crest of the Antelope anticline. Figure 13 highlights the axial traces of the major features of the area overlain on a depth structure map on the top of the Middle Bakken, and illustrates that Southwest Elm Tree, Camel Butte, and Croff/Grail study areas are inferred to be in regions with a higher likelihood of natural fracture systems, while Northeast Elm Tree and Southwest Sanish are not.

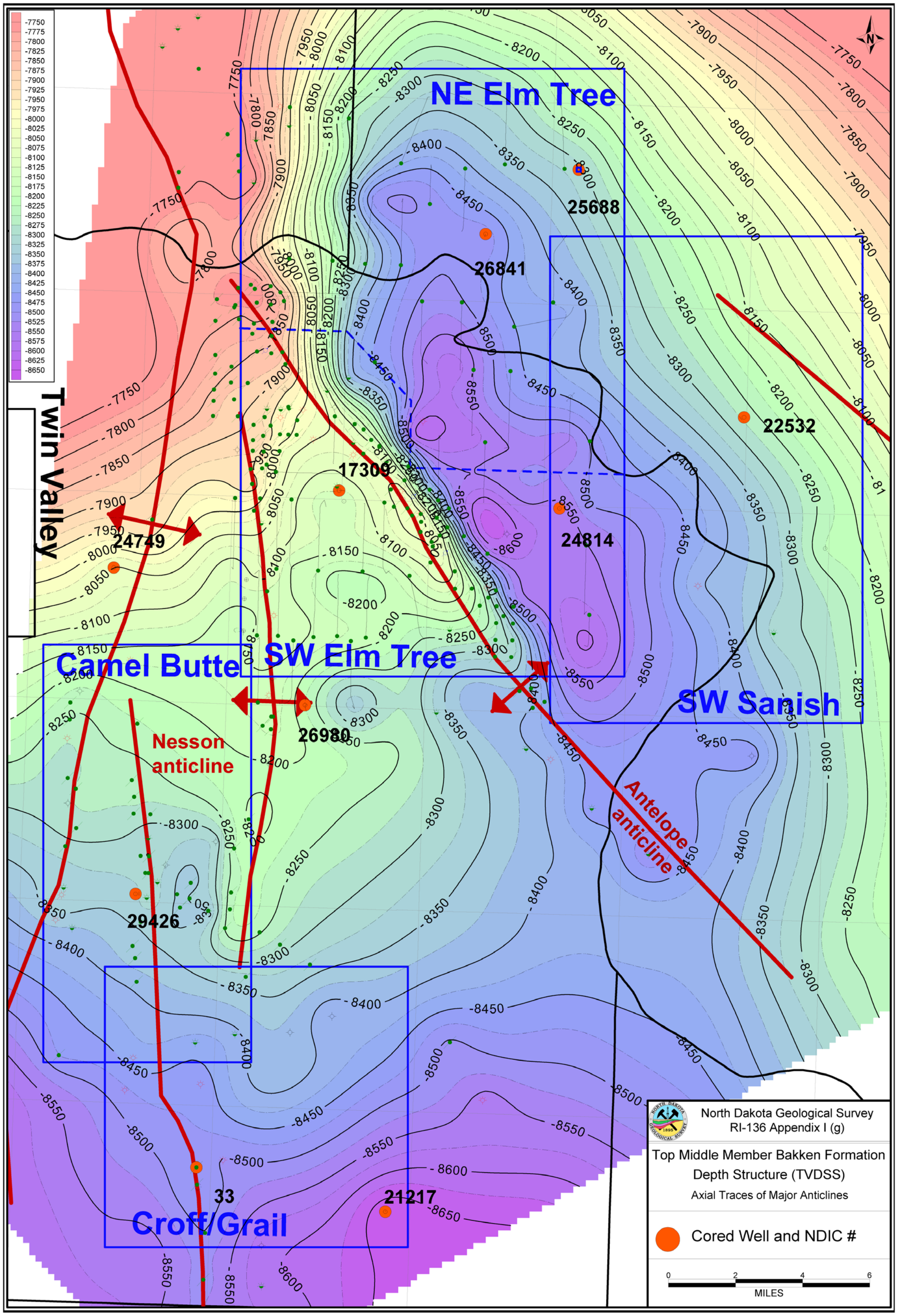

FIGURE 13. A depth structure map of the top of the Middle Member of the Bakken Formation. Contour interval 25 feet, bold every 50 feet. See Appendix I (g) for a full-size version.

COMPLETION DATA

Cross-plots of EUR vs maximum treatment rate and pounds of proppant per lateral foot showed no clear correlation between variability in selected fracture stimulation parameters and EUR. Appendix II contains all production and completion data utilized in this study, and plots for each study area with wells separated by reservoir target. The clearest example, from the Southwest Sanish study area (fig. 14) illustrates a weak positive correlation between EUR and pounds per foot up to ~500 pounds per foot. Beyond that, the correlation is unclear. Southwest Sanish has the best correlation of any of the study areas.

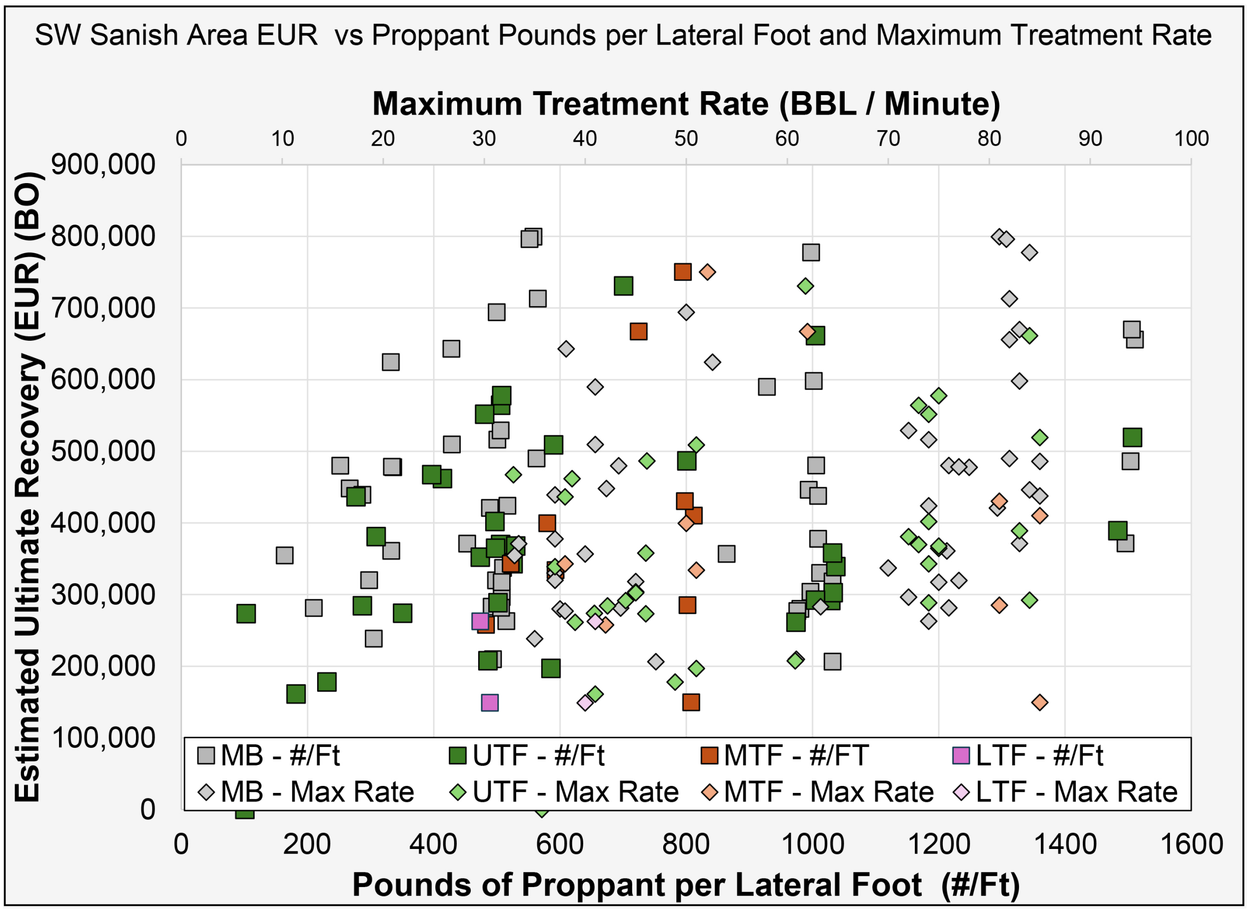

FIGURE 14. Example of one of the correlations of EUR vs completion parameters. This is the clearest correlation between variables seen in this study, and it is weak at best. See Appendix II for a complete set of charts and the source data.

PRODUCTION ANALYSIS

Production data from the first 36 months for middle Three Forks wells within the study areas and surrounding region were used to map water cut (fig. 15). Additionally, cumulative oil production from the same 36-month period was plotted at bottom hole location. The range of water cut for the 291 middle Three Forks wells with three calendar years' production at the time of this report was large, from .17 to .92, with a weakly positive correlation between water cut and 36-month initial production cumulative oil (R2 value of 0.2). Many of the higher water cut wells are located away from the study area, in the broader region of the Bakken – Three Forks petroleum system. The region of northeastern McKenzie County in which the study areas are located is that in which the middle Three Forks wells have the lowest water cuts and the highest initial production volumes. This follows with the model put forth in Nesheim, (2019a), that the area of highest prospectivity for middle Three Forks development is that in which the Lower Bakken shale is thickest, and at its highest thermal maturity.

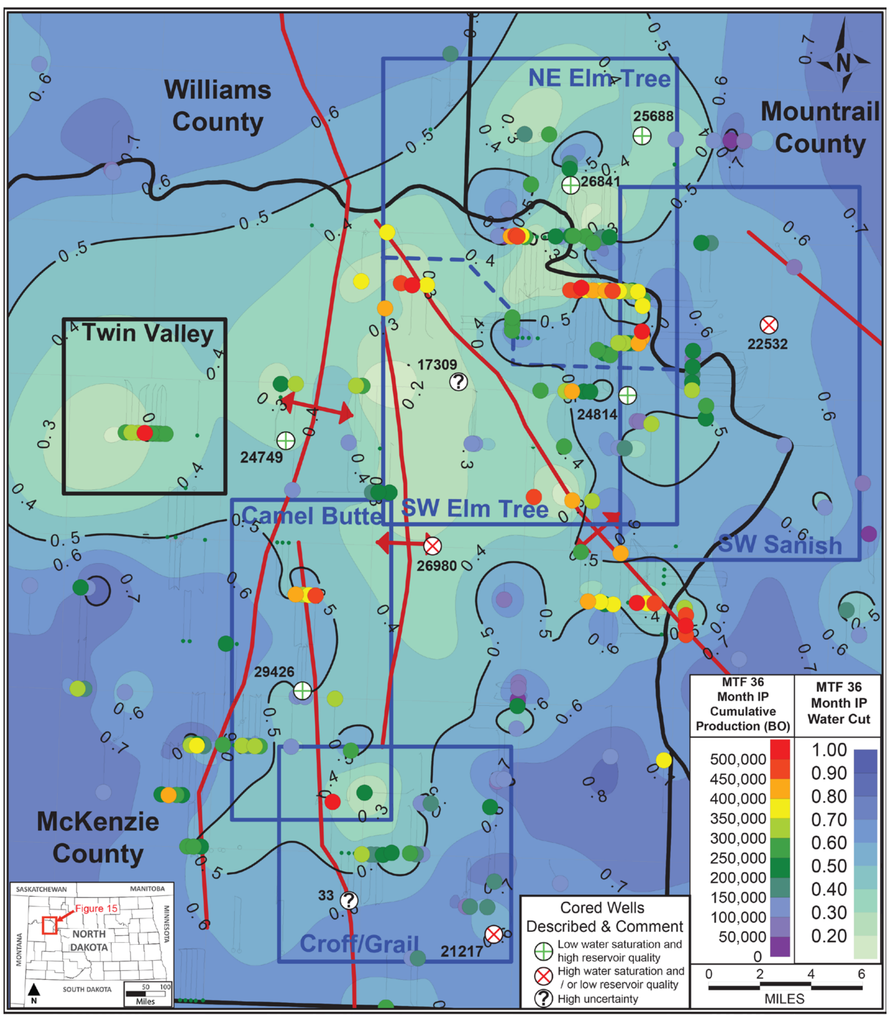

FIGURE 15. First 36 months' cumulative oil production and water cut for middle Three Forks wells in northeastern McKenzie County and surrounding area, also showing cored wells from Figure 11 a-c with a summary of the quality of the middle Three Forks reservoir from core description and core analysis data.

STUDY AREA DISCUSSIONS

The following sections highlight the details of the analysis and selected observations for the five study areas presented herein. DSUs were numbered 1-46, in the order they were evaluated. Results are presented north to south, which does not follow the sequential order.

Northeast Elm Tree

The Northeast Elm Tree study area is named after the Elm Tree field and is in T154N, R94W and the western portion of T154N, R93W in Mountrail County, and the central portion of T153N, R94W in McKenzie County (fig. 4). Twelve 1,280-acre DSUs were selected for comparison. In contrast to other areas presented in this study, the contribution of the middle Three Forks horizontals to the overall productivity of the DSUs is inconsistent (fig. 16).

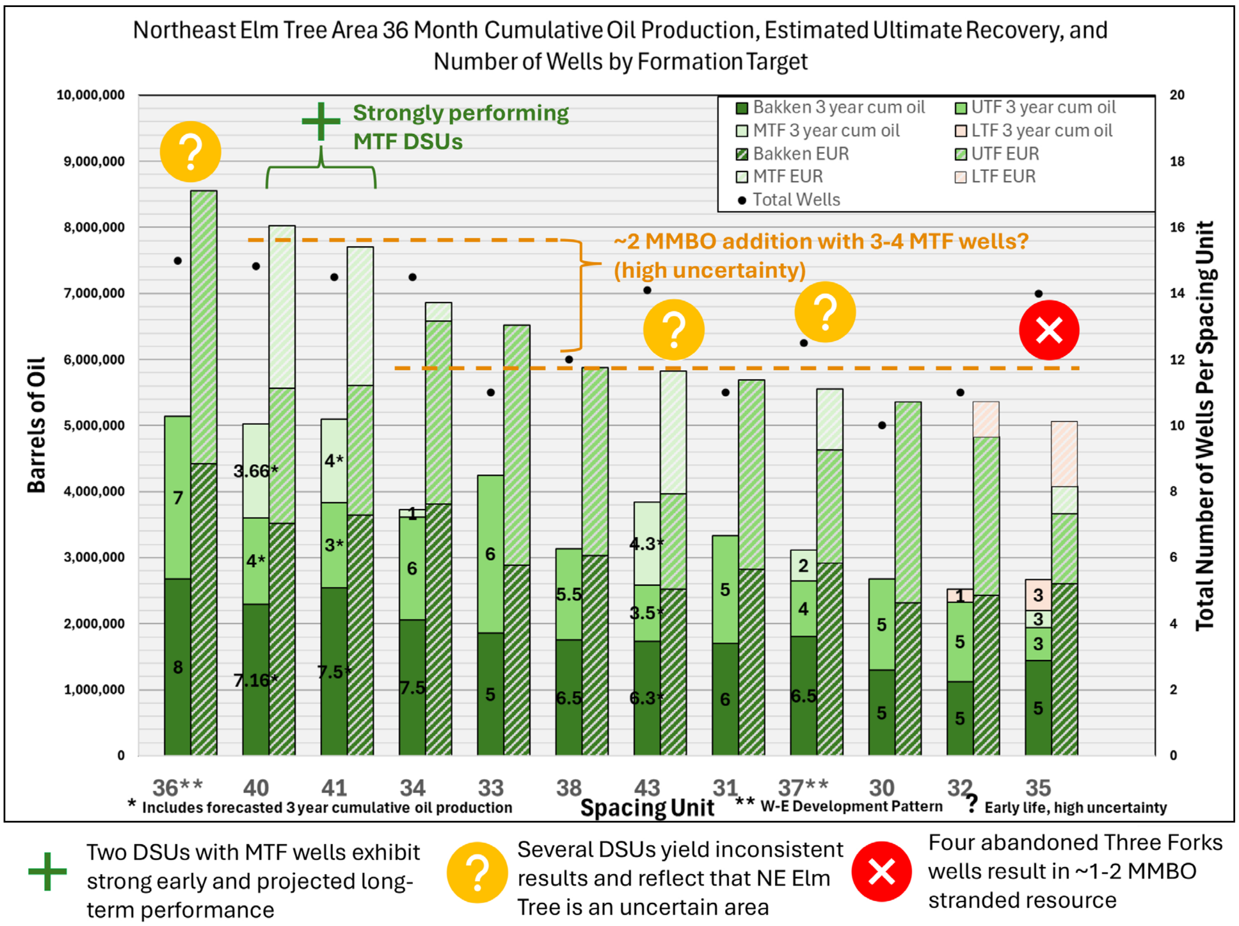

FIGURE 16. Northeast Elm Tree DSU cumulative production and EUR plots. Note the inconsistency in results highlighted with orange question marks. Northeast Elm Tree is interpreted to be an area of high uncertainty for middle Three Forks deliverability and is considered to be on the edge of middle Three Forks resource potential in this study.

The twelve DSUs in the Northeast Elm Tree study area are located off major structures in an area with structural dip to the southwest or east and consistent thickness of the middle Three Forks (figs. 11,12, and 17). With distance to the northeast from the Antelope anticline, the productivity of DSUs with MTF wells decreases, suggesting that an edge of productive middle Three Forks reservoir runs through the Northeast Elm Tree study area.

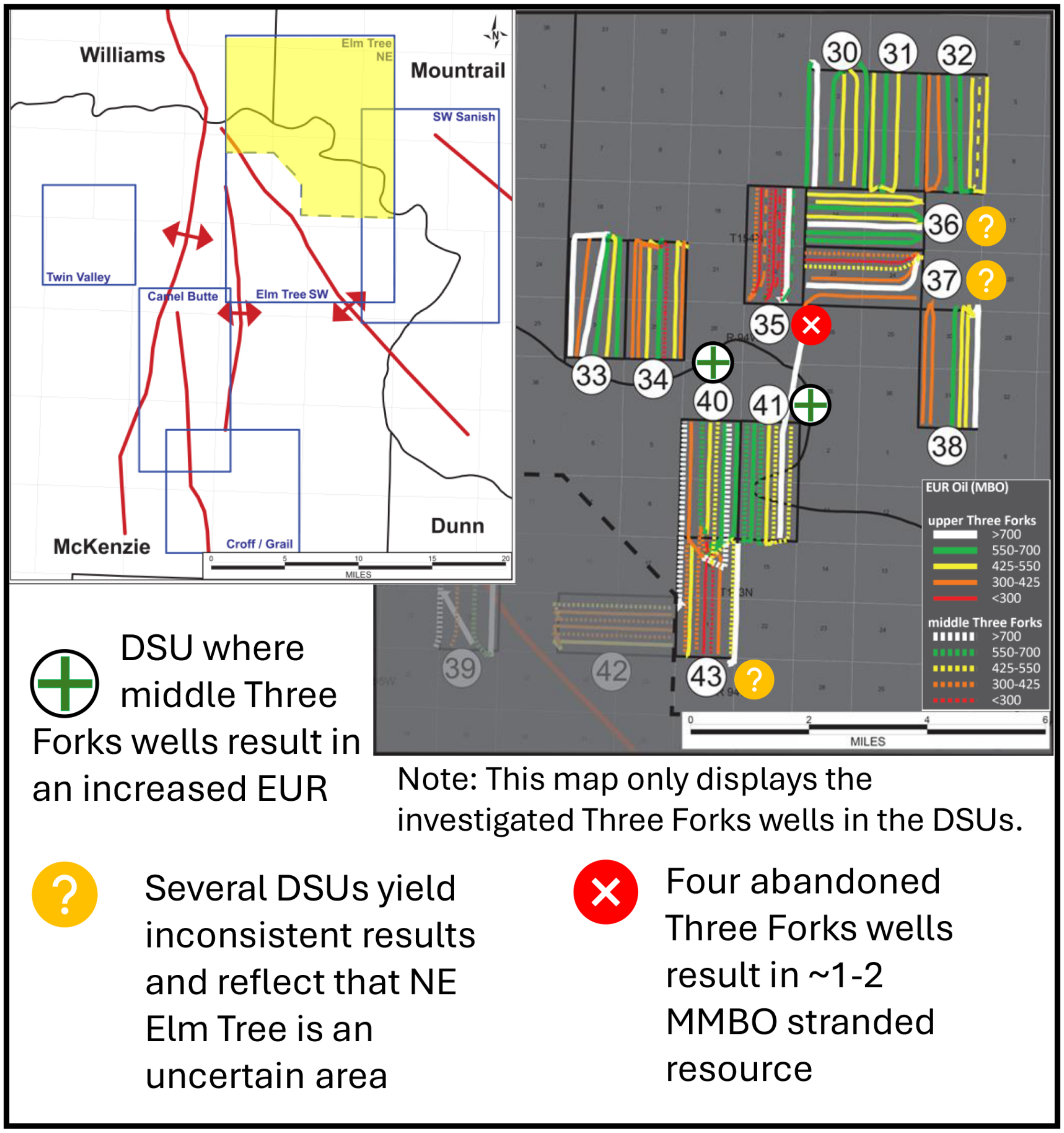

FIGURE 17. Map view and summary of the Northeast Elm Tree study area, illustrating upper Three Forks Formation well bores (solid), middle Three Forks well bores (dashed) and lower Three Forks well bores (long dash), well paths color coded by EUR.

While DSUs #40 and #41 are strong performers with middle Three Forks horizontal wells and the core in the area (NDIC #25688, fig. 10a) shows reasonably low water saturations, DSUs #43 and #37 show no obvious benefit to EUR from drilling middle Three Forks wells. When compared to area DSUs where the upper Three Forks and

Middle Bakken only were drilled with horizontal wells (particularly the outstanding performance of DSU #36), the additional benefit of middle Three Forks wells in this area is uncertain. As such, this area is considered to have marginal potential for middle Three Forks infill development.

Of note in this area is DSU #35. Located in T154N, R94W, sections 15 & 22, this 1,280-acre DSU is underperforming its neighbors by ~1MMBO in 36-month initial production and is expected to underperform area peers by 1 – 2 MMBO in EUR. This underperformance is the result of four Three Forks Formation horizontals being abandoned after casing breaches occurred during hydraulic fracture stimulation operations.

Southwest Elm Tree

The Southwest Elm Tree study area is named after the Elm Tree Field and is in T153N, R95W, T153N, R94W, T152N, R95W, and T152N, R94W in northeastern McKenzie County (fig. 4). Five 1,280-acre DSUs were selected for comparison, separated from the DSUs of the Northeast Elm Tree study area because of their location proximal to the crest of the Antelope anticline (figs. 13, 19). Southwest Elm Tree study area represents one of the clearest examples of the increased productivity of a DSU when middle Three Forks horizontal wells are drilled (fig. 18).

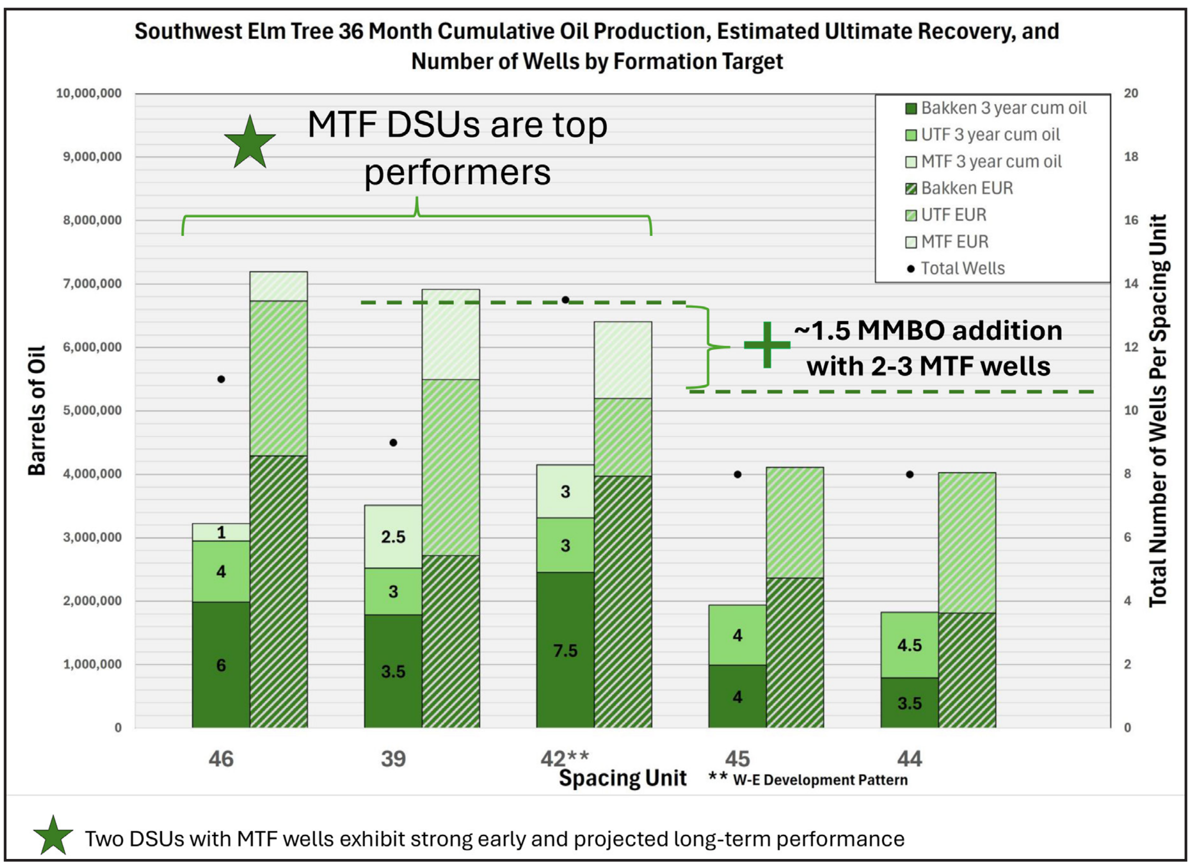

FIGURE 18. A comparison of the production and EUR from the five DSUs of the Southwest Elm Tree study area illustrates the increased productivity of DSUs with middle Three Forks well compared to those without.

The five DSUs in the Southwest Elm Tree study area are in areas of high relief structure on the top Middle Bakken (fig. 13), and natural fractures are assumed to be present, likely enhancing reservoir productivity. DSU #39 (T153N, R95W, Sec 14 & 23) is a standout performer, which was completed with even well spacing between horizontals and an even distribution of wells between the three reservoir targets. DSU #39 is also a prime example of the beneficial interactions from infill drilling, with wells NDIC #16452 & NDIC #17799 seeing significant production bumps and prolonged lives from offset completions in 2018. While the core analysis data from NDIC #17309 (fig. 11b) indicates zero oil saturation in the middle Three Forks, the ~40-50% water saturation from core analysis data suggests promising oil charge not measured. The consistent, high performance of middle Three Forks wells in DSUs 39 & 42 (fig. 19) coupled with the low water cut from wells in the area (fig. 15) suggest that the Antelope anticline, and by extension other areas with regional anticlinal structures, are prospective for middle Three Forks development.

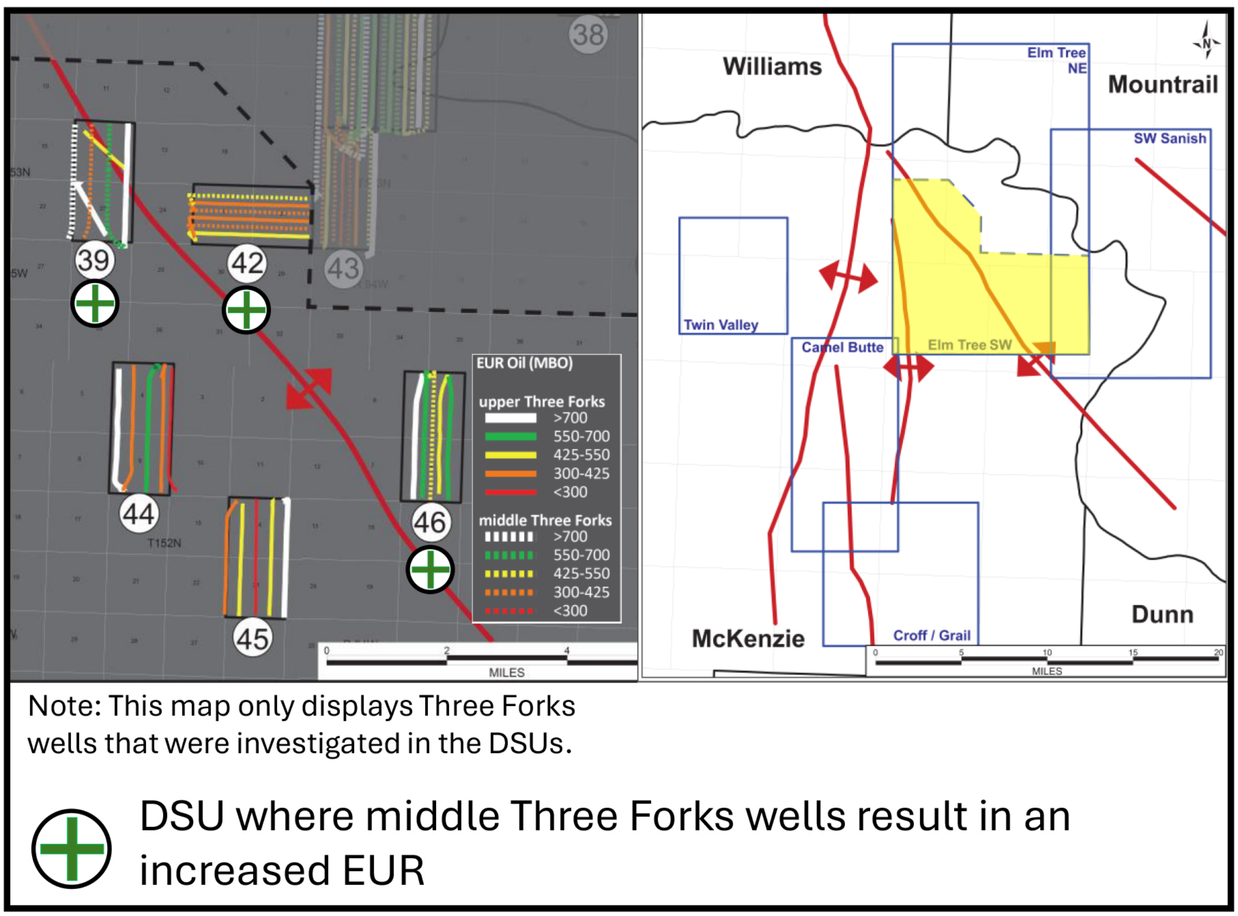

FIGURE 19. Map view and summary of the Southwest Elm Tree study area, illustrating upper Three Forks well bores (solid) and middle Three Forks well bores (dashed), with well paths color coded to EUR. The axial trace of the Antelope anticline is indicated with a red line.

Southwest Sanish

The Southwest Sanish study area is named after the Sanish field and is in T153N R93W and T152N R93W in Mountrail and McKenzie counties. Eight 1,280-acre DSUs were selected for comparison. The Southwest Sanish study area is unique in that seven of the eight DSUs compared have a similar number of wells drilled (12-13), but with a different distribution between the three reservoirs (fig. 20).

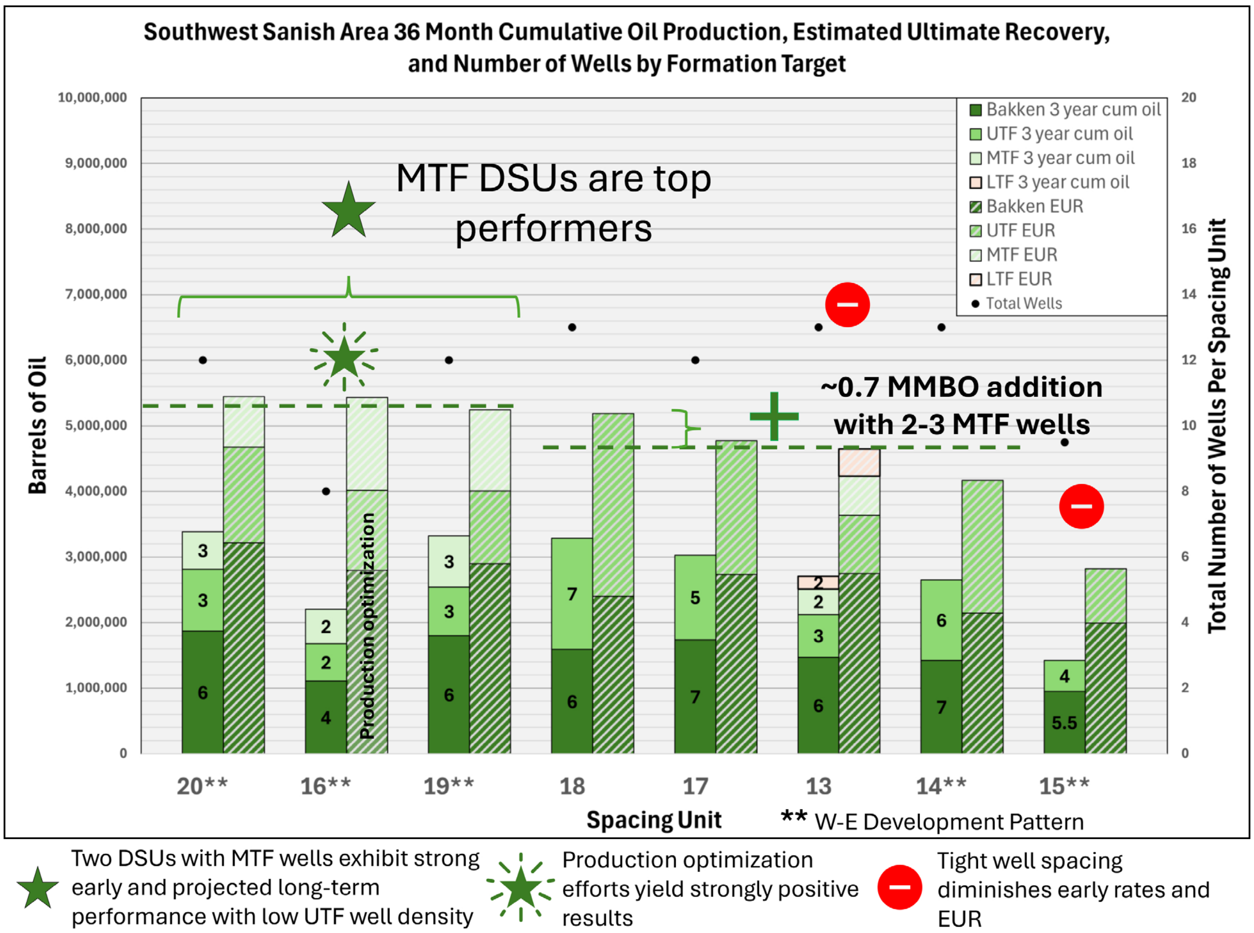

FIGURE 20. A comparison of the production and EUR from the eight DSUs of the Southwest Sanish study area illustrates that between DSUs with similar well density, DSUs with middle Three Forks wells are expected to be stronger performers.

The increase in early rate and EUR is less dramatic in the Southwest Sanish area compared to other study areas discussed here, but the equal to slight increase in recovery of DSUs with middle Three Forks wells compared to those without, coupled with the similar well density, suggests that the middle Three Forks contributes to the overall productivity of the DSU. Furthermore, DSUs in the Southwest Sanish study area that have middle Three Forks wells have a lower density of Middle Bakken and Upper Three Forks wells, indicating that infill drilling potential remains in the area. Given that DSUs in the Southwest Sanish area show a less pronounced benefit from the addition of middle Three Forks wells (figs. 20, 21), that middle Three Forks horizontal well water cut increases to the east from the study area (fig. 15), and that well NDIC #22532 shows high water saturations in core analysis, an edge of prospective middle Three Forks reservoir is interpreted to lie within the Southwest Sanish study area.

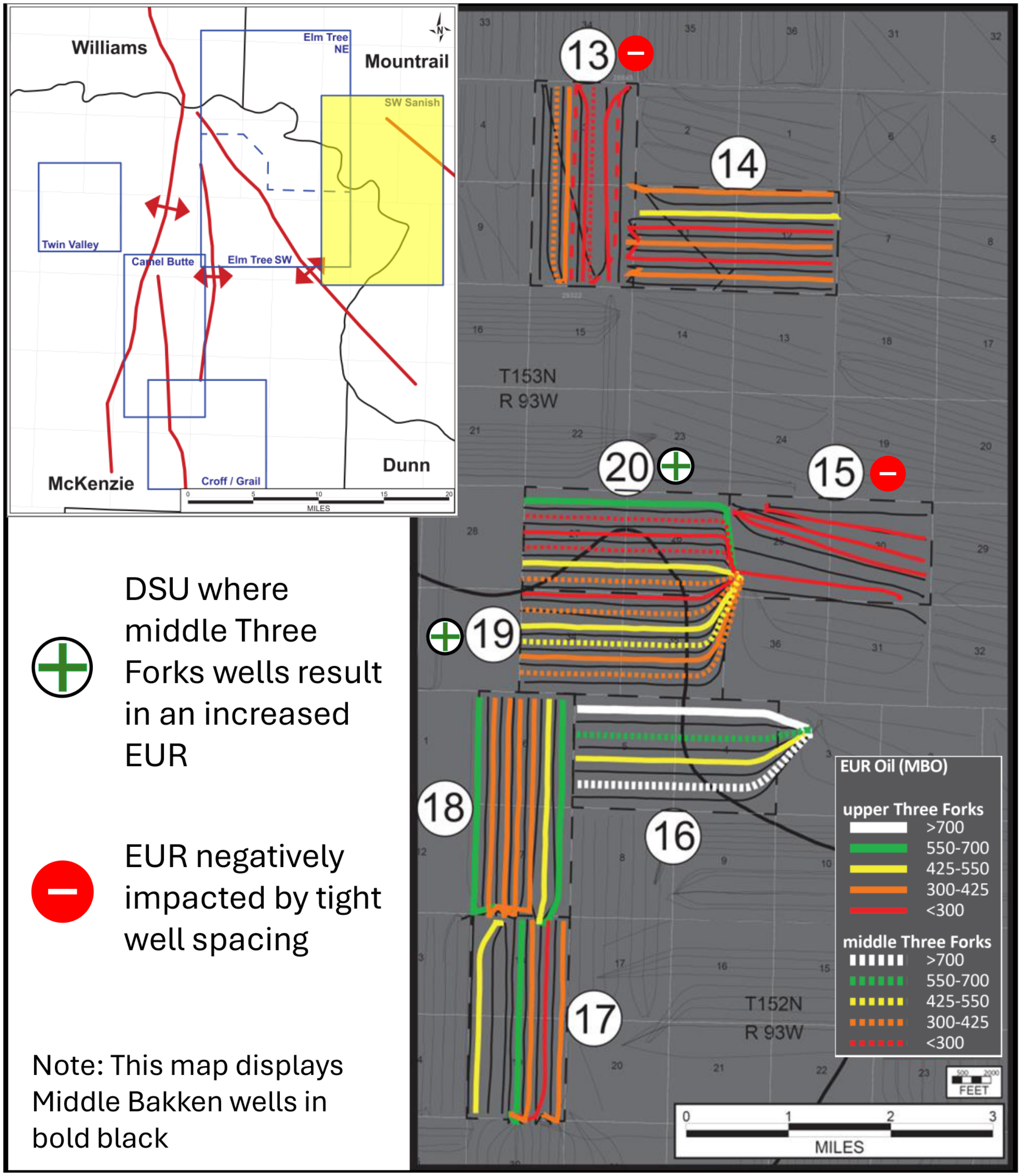

FIGURE 21. Map view and summary of the Southwest Sanish study area, illustrating upper Three Forks well bores (solid), middle Three Forks well bores (dashed) and lower Three Forks well bores (long dash), with well paths color coded to EUR. Middle Bakken horizontals are shown on this chart in black, to illustrate areas with tight well spacing.

Two other noteworthy observations from this study are exemplified in the Southwest Sanish study area. First, two DSUs (#13 & #15) were developed with tight well spacing (i.e., wellbores are in close proximity). These two DSUs show a diminished performance relative to area peers and it is interpreted to be a symptom of placing wells immediately below or above other wells. Second, this area illustrates an example of uplift/stabilization from production optimization efforts in DSU #16. Four horizontal wells in DSU#16 (T152N, R93W, Sec 4 & 5) were initially produced with gas lift, but switched to rod pump in 2017. This change is expected to have a dramatic, positive impact on EUR (fig. 20), with DSU #16 projected to be a top producing unit in the study area with the lowest well count and stacked laterals in the middle Three Forks, upper Three Forks, and Middle Bakken.

Camel Butte

The Camel Butte study area is named after the Camel Butte field and is in the eastern half of T151N, R96W and the northeast portion of T150N, R96W, in McKenzie County. Eleven closely spaced 1,280-acre DSUs were selected for comparison. When DSU #12 is excluded (due to tight well spacing driving under-performance), DSUs with middle Three Forks wells outperform those without by ~1.5 MMBO in EUR (fig. 22).

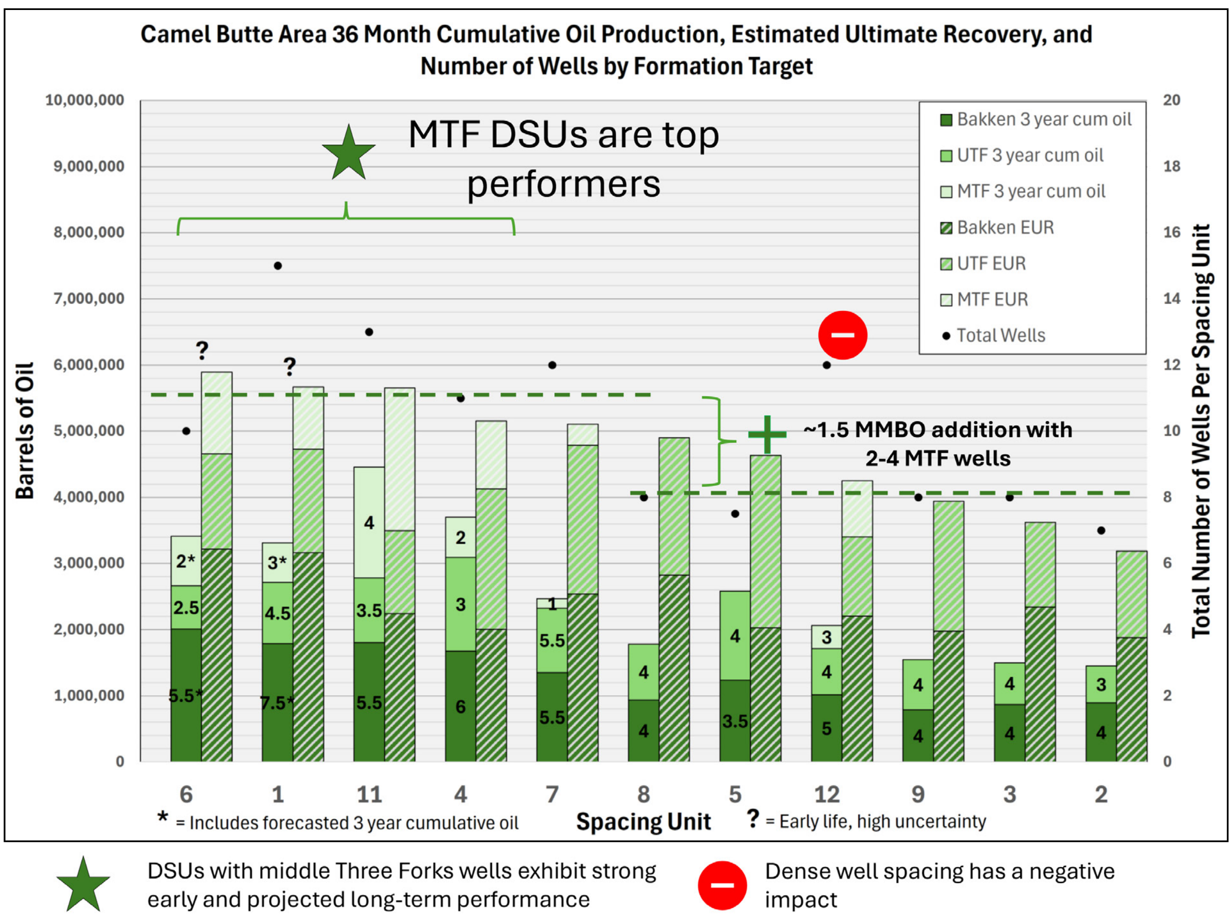

FIGURE 22. A comparison of the production and EUR from the eleven DSUs of the Camel Butte study area illustrates that the four DSUs with two or more middle Three Forks wells outperform comparison area DSUs in both three-year cumulative oil production and EUR.

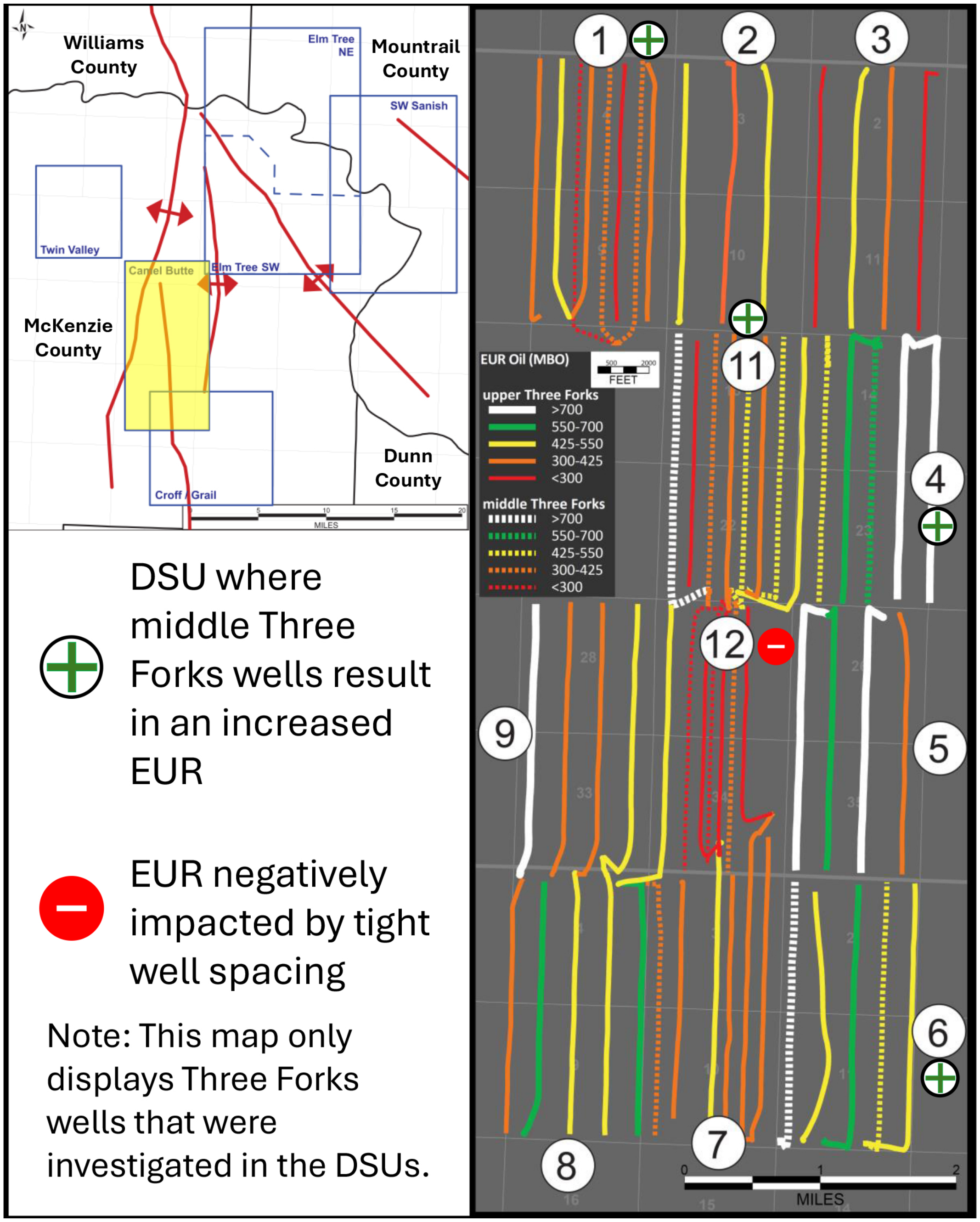

FIGURE 23. Map view and summary of the Camel Butte study area, illustrating upper Three Forks well bores (solid) and middle Three Forks well bores (dashed), with well paths color coded to EUR.

The Camel Butte study area is interpreted to be in the heart of productive middle Three forks acreage as illustrated by consistently strong middle Three Forks wells and the resultant outperformance of DSUs with middle Three Forks development relative to their area peers (figs. 22, 23). Like observations from the Southwest Sanish study area, tight well spacing appears to be a significant detractor to short-term and long-term performance of a DSU (e.g., DSU#12). As a result, DSU #12 was removed from the comparison set for calculating average uplift (fig. 22).

Croff / Grail

The Croff / Grail study area is named after the Croff and Grail fields and is in T150N R96W, T150N R95W, T149N R96W, and T149N R95W in McKenzie County (fig. 4). Nine closely spaced 1,280-acre DSUs were selected for comparison. Like the results of the Southwest Elm Tree and Camel Butte study areas, the Croff / Grail study area shows a consistent uplift from additional middle Three forks infill drilling. It also hosts an example where infill drilling in the middle Three Forks in 2022 shows strong early results and expected long term performance.

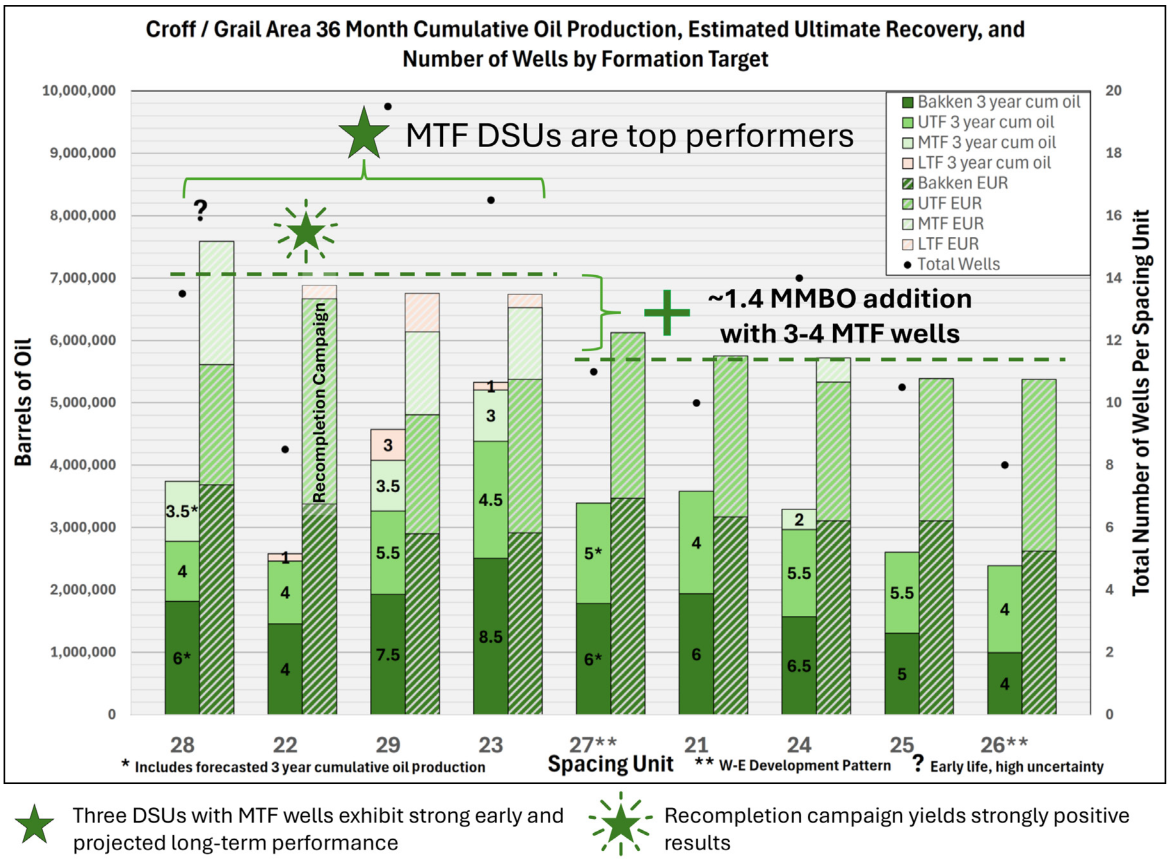

FIGURE 24. A comparison of the production and EUR from the nine DSUs of the Croff / Grail study area illustrates that the three DSUs with four or more middle Three Forks wells outperform comparison area DSUs in both three-year cumulative oil production and EUR.

DSUs #28, 29, and 23 exhibit strong performance of the middle Three Forks, but DSU #24 does not. Eight of the wells in DSU #24 were completed in close areal proximity, either above or below one another (tight well spacing), and show rapid declines. The development style may have impacted the performance of DSU #24, but this poor performance of the middle Three Forks, coupled with the high water saturations in cored well NDIC #21217 (fig. 11c) and the increased water cut in middle Three Forks production to the east and southeast of the Croff/Grail study area (fig. 15), suggest the eastern margin of the Croff/Grail study area is nearby the boundary for prospective middle Three Forks development.

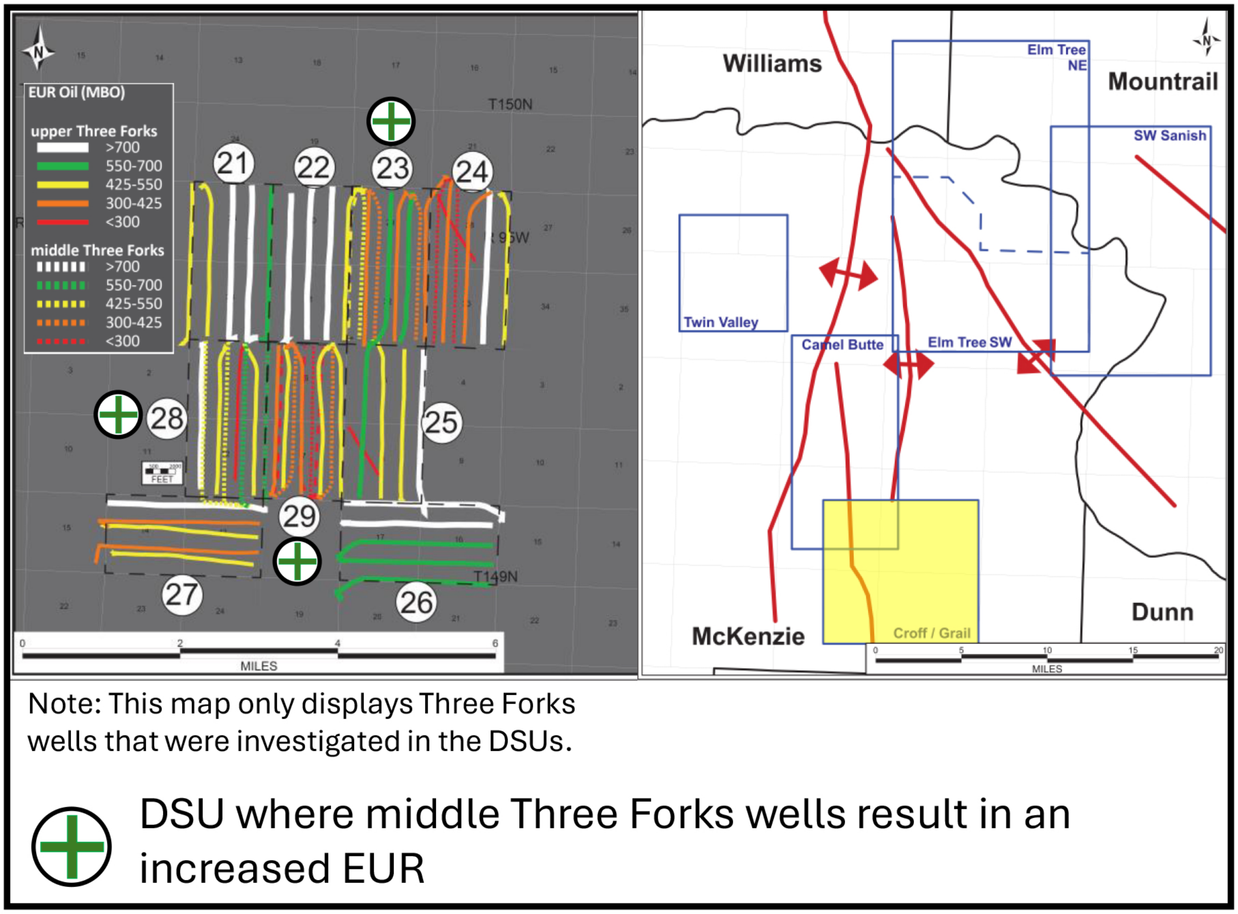

FIGURE 25. Map view and summary of the Croff/Grail study area, illustrating upper Three Forks Formation well bores (solid), middle Three Forks Formation well bores (dashed) and lower Three Forks Formation well bores (long dash), with well paths colored by EUR.

DSU #22 (T150N, R95W, Sec 30 & 31) is an interesting example of the benefits of recompletion efforts (fig. 6). In 2019, three horizontal wells in the DSU were worked over, removing the initially installed sliding sleeve completions to be re-stimulated using a plug-and-perf completion style. The uplift generated from this campaign transformed the DSU to make it one of the highest expected producing units in the study area.

The most noteworthy DSU in the Croff/Grail area is #28 (T149N, R96W Sec 1 & 2), in which three middle Three Forks wells were completed in 2022, nine to twelve years after existing horizontals had been completed in the upper Three Forks (fig. 26). These wells are strong performers relative to other middle Three Forks wells analyzed in this study, and their completions either had no obvious negative impact on existing production, or in some cases provided short-lived incremental production bumps to overlying wells. This observation, coupled with the increased performance of DSUs with middle Three Forks development wells, bodes well for the future infill drilling potential of the middle Three Forks in northeastern McKenzie County.

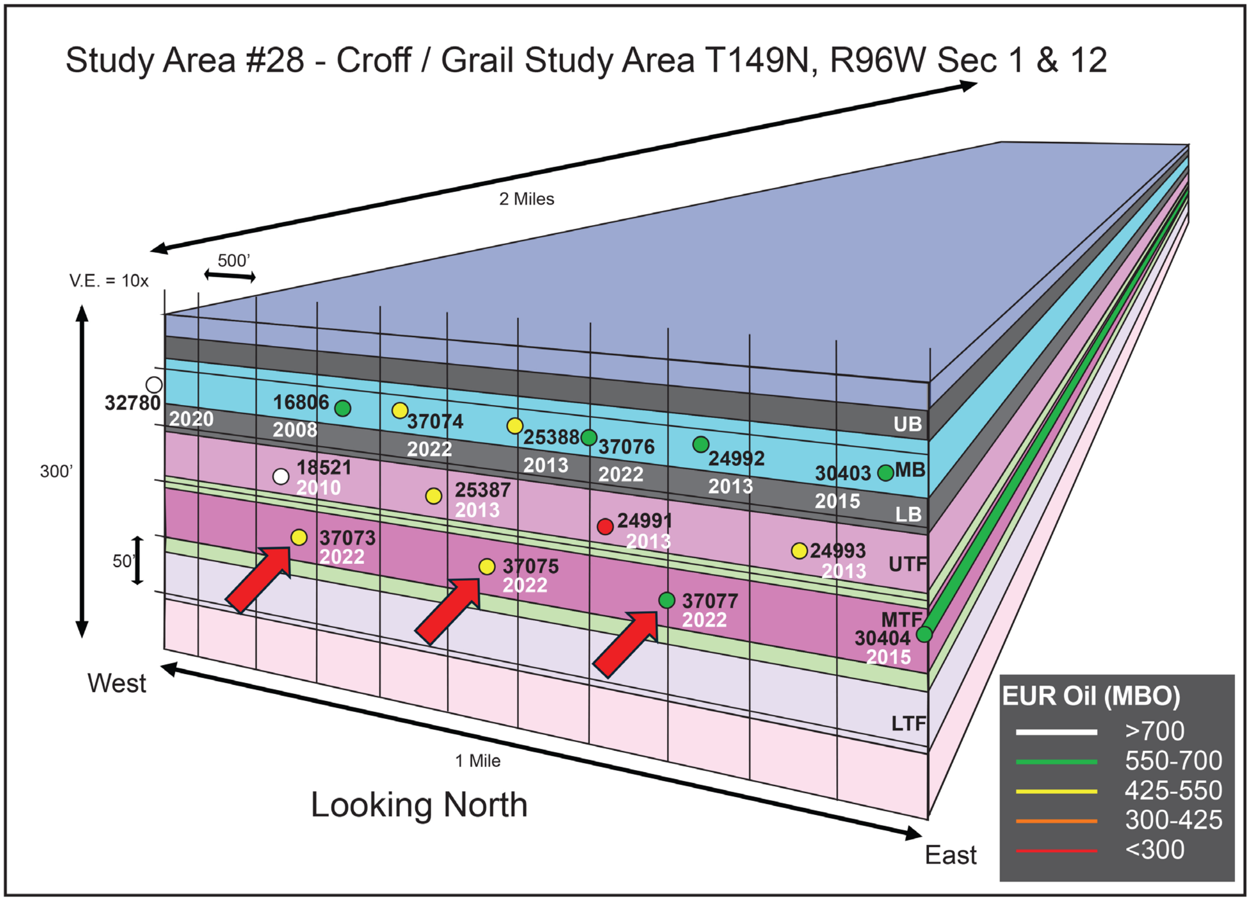

FIGURE 26. Block model of DSU #28 with well bores color coded to EUR, highlighting a middle Three Forks infill drilling program implemented in 2022. Well bores are labeled with NDIC# in black text and completion year in white.

INTERPRETATIONS

This study investigated 25 DSUs with middle Three Forks horizontal wells compared to 26 DSUs without middle Three Forks wells. Of those 25 DSUs with middle Three Forks wells, 17 exhibited a clear volumetric addition of oil produced with the development of the middle Three Forks (68%), six did not (24%), and in two (8%), the contribution was unclear (fig. 27). The results of this study indicate that developing the middle Three Forks, in addition to the Middle Bakken and the upper Three Forks, adds to long-term oil recovery on the order of 1 – 2 million of barrels per 1,280-acre DSU. The results of this study, in combination with Nesheim and Starns (2024), outline a contiguous area of potential middle Three Forks development that spans 19 townships and ~275,000 acres in northeast McKenzie County (fig. 27). Not counting existing middle Three Forks wells, and assuming three middle Three Forks wells can be drilled in each 1280-acre DSU, 604 middle Three Forks wells could be drilled within the immediate prospective area.

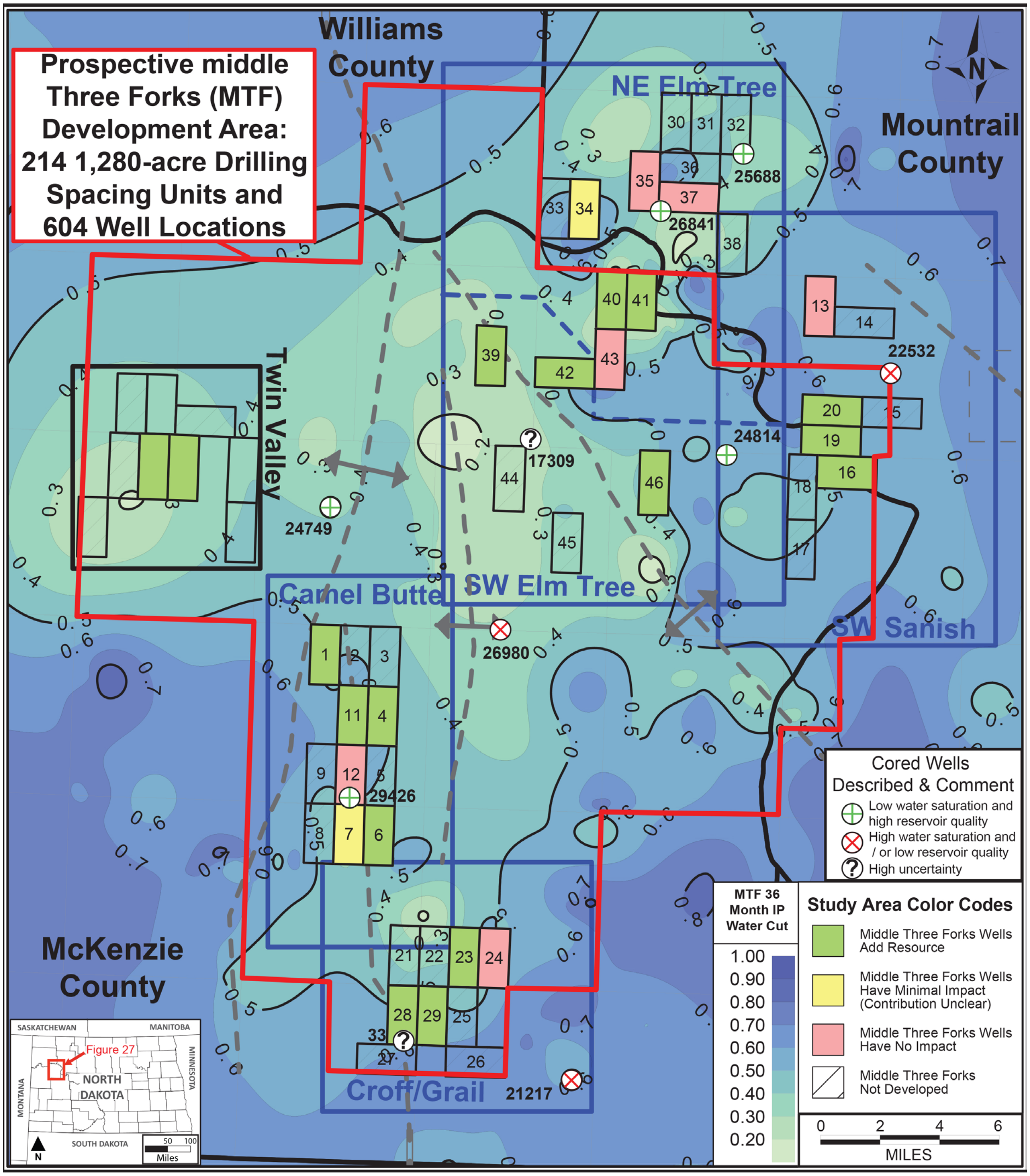

FIGURE 27. Project summary illustrating an interpretation of results and prospective area for development of the middle Three Forks in northeastern McKenzie County, North Dakota.

Table 1 contains a sample of the distribution of EURs from middle Three Forks wells in this study and Nesheim and Starns (2024). A simplistic resource assessment calculation using the 10th to 90th percentile EUR of middle Three Forks wells analyzed here, multiplied by the 604 potential drilling locations, suggests that 160 – 410 million barrels of recoverable oil are remaining to be developed in northeastern McKenzie County, with the possibility of an expansion of the area with further development.

TABLE 1. An assessment of potential remaining oil in the middle Three Forks of northeastern McKenzie County, using the data presented here and in Nesheim and Starns (2024).

Wells in Data Set	Middle Three Forks Estimated Ultimate Recovery (EUR)		
	10th Percentile	50th Percentile	90th Percentile
70	274,111	430,262	682,608
Potential Remaining Drilling Locations	Prospective Area* middle Three Forks EUR		
	10th Percentile	50th Percentile	90th Percentile
600	164,466,600	258,157,200	409,564,800
~165 - 410 Million Barrels of Recoverable Oil			

*See Figure 27 for prospective area

A comparison of EURs of the wells within this study and in Nesheim and Starns (2024) illustrates that the middle Three Forks wells have a similar distribution of expected performance to the overlying upper Three Forks and Middle Bakken (fig. 28). While the middle Three Forks wells in northeastern McKenzie County show greater variability than the overlying upper Three Forks and Middle Bakken, the 50th percentile EUR of middle Three Forks wells is in line with the much larger data set of upper Three Forks and Middle Bakken wells (Table 2).

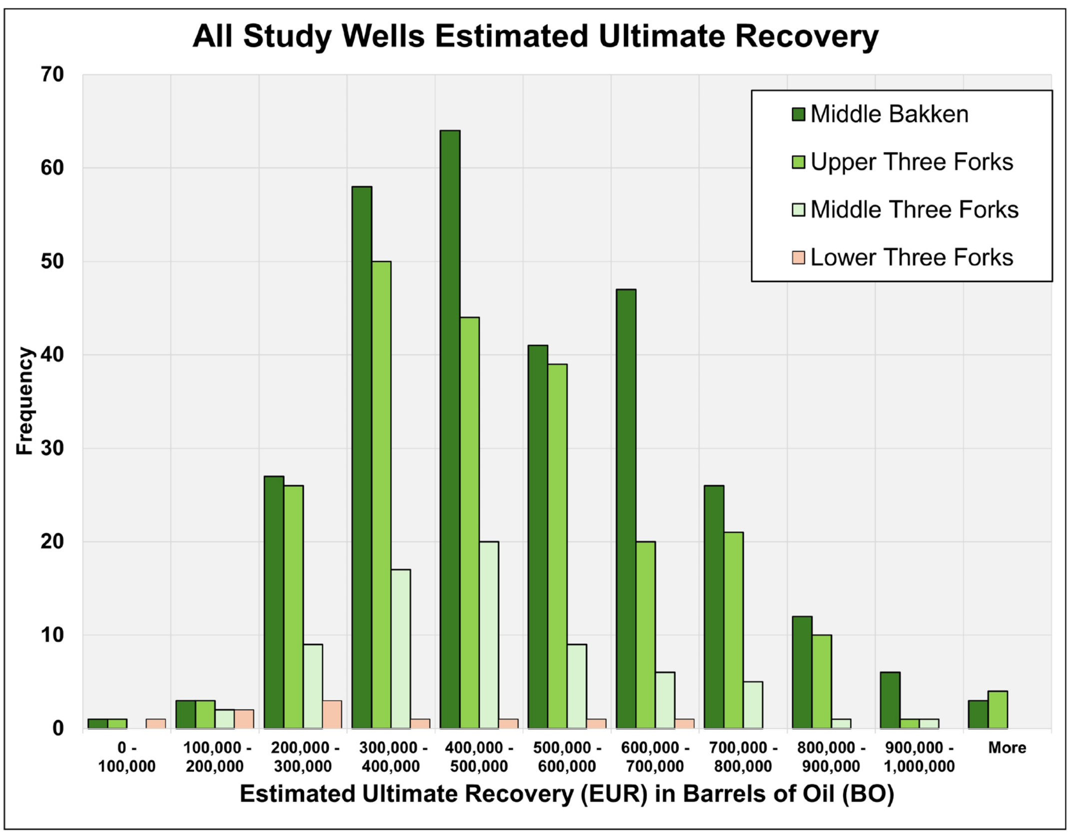

FIGURE 28. A comparison of the distribution of EUR for individual wells by formation target, displaying all the wells analyzed in this study and in Nesheim and Starns (2024).

TABLE 2. A comparison of the 10th, 50th, and 90th percentile values of EUR (in barrels of oil) by formation target for all the wells analyzed in this study and Nesheim and Starns (2024).

Formation Target	10th Percentile	50th Percentile	90th Percentile
Middle Bakken	296,525	480,857	770,938
Upper Three Forks	279,364	470,303	755,192
Middle Three Forks	274,111	430,262	682,608

While the lower number of horizontals in the middle Three Forks relative to the Middle Bakken and upper Three Forks may suggest that the middle Three Forks has less potential, this study demonstrates that in northeastern McKenzie County, the middle Three Forks Formation is and should be an attractive development target for full scale development utilizing infill drilling. The results presented here indicate that the middle Three Forks has the potential to host 600+ drilling locations and an estimated ultimate recovery of up to four hundred million of barrels of oil or more in northeastern McKenzie County.

DISCUSSION

Variability of middle Three Forks well performance seems to be a function of at least four factors:1) reservoir quality, 2) oil charge, 3) proximity to major structures, and 4) well spacing. Additionally, hydraulic fracture stimulation completion parameters undoubtedly play a role, and some of these parameters were not analyzed here.

Heterogeneity within the middle Three Forks is likely a key driver to reservoir productivity, and as the cross-sections in figure 11 illustrate, these changes in facies and associated reservoir quality are difficult to discern from log responses alone. Gamma ray, resistivity, and porosity logs are good leading indicators for oil charge and reservoir quality, but complex variations in sedimentology are present below log resolution. Conglomeratic deposits with low gamma ray / low clay content tend to have higher oil saturations where charged. The variability in performance of the middle Three Forks wells may partly result from sedimentological intricacies that vary in both spatial location and stratigraphic position, and are potentially below the resolution of petrophysical log models. The internal complexity of the middle Three Forks on a localized and regional scale is a significant uncertainty in well performance. Gamma ray and resistivity are good remote sensing indicators, but empirically derived data from core may be necessary for confirmation; core description, core analysis data, and XRD are critical components for a complete petrophysical characterization of the middle Three Forks.

There is a positive correlation between increased thickness and maturity of the Lower Bakken and middle Three Forks productivity (Nesheim, 2019a). However, in the northeast, a discrepancy exists between the Lower Bakken thickness and middle Three Forks productivity. This suggests that declining reservoir quality in the middle Three Forks or reduced thermal maturity of the Lower Bakken is the primary limiting factor in this region, as middle Three Forks thickness remains relatively consistent. While Lower Bakken thickness clearly influences oil charge in the Middle Three Forks, northeastern areas (i.e., Northeast Elm Tree and Southwest Sanish) likely experience decreased oil production due to lower maturity of the Lower Bakken or degraded reservoir quality in the middle Three Forks (Nesheim, 2019a). To the southeast of the study areas, an expected decrease in oil charge is attributed to immaturity or reduced thickness of the Lower Bakken (Nesheim, 2019a). The thickness of the Pronghorn Member may also have an impact on the performance of the middle Three Forks in the Southwest Sanish area (Appendix I (d)). A potential sweet spot opportunity in the region for the middle Three Forks is the area north and west of the Twin Valley study area (Nesheim and Starns, 2024), where at least one township has seen no middle Three Forks development (T153 N, R96W).

There is a strong spatial correlation between middle Three Forks wells' early performance and proximity to major structures, particularly the Antelope anticline (fig. 15). As these features exhibit relief on the Bakken and Three Forks Formations, there has clearly been structural modification post-deposition. Associated with this deformation is an inferred increase in natural fractures which are assumed to augment downward oil charge from the Bakken Formation source rocks, and increase the porosity and permeability of the reservoirs in the petroleum system. Future efforts to develop the middle Three Forks could find the natural assistance afforded by these structures to be a helpful advantage in gaining momentum for development campaigns.

Tight well spacing (generally less than 500′ in map view), was commonly observed to be detrimental to the performance of a DSU. A comparison of total wells per DSU within study areas highlights these examples, as noted in previous figures. In contrast, even well spacing with wells distributed between all three reservoirs oftentimes has the best performance (e.g., Northeast Elm Tree DSU#40 & 41; Southwest Elm Tree #42; Southwest Sanish #20 & 19; Camel Butte #6 & 11; Croff / Grail #28 & 23). In future middle Three Forks infill efforts, attaining even well spacing with lateral placement should be considered. Infilling directly below existing wells was consistently seen to be a detractor to performance. The extrapolation of this observation to other nascent unconventional developments is that simultaneous co-development of all oil charged reservoirs could be an effective method to maximize recovery, as long as fracture stimulation design and rock properties do not cause negative interference.

The analysis of completion data (fig. 14, Appendix II) did not reveal any definitive correlation between selected fracture stimulation parameters and EUR. However, there are variables not included in this analysis which are likely significant and could yield insightful results. Some examples for consideration include the composition of the fluid utilized, the type of proppant, number of perforations per stage, perforation and stage spacing, completion style (e.g., sliding sleeve vs. plug-and-perf), wellbore tortuosity, wellbore pressure variation, and reservoir pressure. Many other variables are likely impactful in this complex environment. Completion engineering experts would likely consider all of the above factors, among others, in a more robust analysis.

Two examples of optimization efforts completed on mid-life wells were observed in this study that illustrate opportunities for increased oil recovery. First, in DSU #16 of the Southwest Sanish study area (T152N, R93W, Sec. 4&5), a change in the artificial lift method from gas lift to rod pump is expected to significantly increase EUR (fig. 20). Second, in DSU #22 of the Croff/Grail Study area (T150N, R95W, Sec 30&35), a dedicated recompletion campaign that removed sliding sleeves and converted to plug-and-perf with repeat fracture stimulations was highly successful in three wells. While not specifically germane to the topic of this study, these observations have implications for aging acreage and highlight some of the many opportunities for continued development of the Bakken-Three Forks petroleum system.

Ten lower Three Forks wells were identified and analyzed within the five study areas. EUR for five of these wells was low compared to other formations in the petroleum system (fig. 28, Appendix II). Two lower Three Forks well in the Northeast Elm Tree study area (NDIC #25688 and NDIC #28061) have EURs higher than 500,000 BO. Additionally, the Mangum 5493 44-7 T3 well (NDIC #25688; fig. 11a), shows elevated oil saturations in the lower Three Forks and some prospective reservoir in core. The lower Three Forks appears to have some localized potential. However, overall observations of the lower Three Forks potential are less encouraging, both from the oil saturations in the reservoir and in the reservoir quality, and it is unlikely that the lower Three Forks is a consistently viable target over a large area.

Forty-three middle Three Forks wells have been drilled in a concentrated area in northwestern Dunn County in T148N, R96W, T147N, R96W and T146N, R96W. Some of these wells were associated with the EERC Project Hawkinson and exhibit strong early production performance and low-end water cuts. This area was not selected to be part of this study because of previous detailed work on the area. Further details can be found in EERC reports. One-hundred and thirty middle Three Forks wells have been drilled in the broader region of the Bakken-Three Forks petroleum system that are not within the prospective area outlined in Figure 27 and are not related to Project Hawkinson development. One hundred and eighteen of those wells have more than one year of production history and are of limited promise. The average water cut of these 118 wells is 0.65 and the average 36-month initial production is ~150,000 BO. The greatest potential for expansion of the potential development area is west of the Croff/Grail study area and west and southwest of the Camel Butte study area in T151N, R97W, T150N, R97W, and T149N, R97W, where some of the recently drilled middle Three Forks wells show promising early results.

CONCLUSION

This study, in concert with Nesheim and Starns (2024), illustrates the tremendous potential of the middle Three Forks in northeastern McKenzie County, North Dakota, and illustrates an initial, large, contiguous area for infill development. Some key points for consideration for middle Three Forks development campaigns include:

- Approximately 600 more middle Three Forks development wells could be drilled in northeastern McKenzie County, with a 50th percentile outlook of 258 million barrels of undeveloped recoverable oil.
- Middle Three Forks horizontal well production results are variable, and a significant range of outcomes should be considered in forecasting methodologies; reservoir quality is an important uncertainty and core and petrophysical analysis, in addition to offset production analysis, are important components.
- Infill drilling runs the risk of impacting existing production, but those are not always negative impacts; placing infill wells directly below existing wells was observed to negatively impact existing production. Even well spacing, both horizontally and vertically, minimizes disruptions and optimizes production.
- Production optimization efforts (i.e., restimulation and artificial lift redesign) were observed to have had a strongly positive impact on EUR for all reservoirs. It is likely that great potential remains to enhance recovery through engineering optimization efforts.
- Development of middle Three Forks with dedicated horizontal wells is effectively adding resource in certain places, both on and off major structures. Northeastern McKenzie County is highly prospective for future development. The Antelope anticline is a prime target for continued development, and the areas adjacent to study areas detailed here and in Nesheim and Starns (2024) are excellent locations to begin an assessment.

The production analysis presented in this report, and Nesheim and Starns (2024) presents a case for continued infill development of the middle Three Forks as a significant resource target. Recent infill drilling has demonstrated early success (e.g., DSU #28, fig. 26), the region of oil-charged middle Three Forks is generally well defined, and 300+ examples of middle Three Forks horizontal well implementation and performance exist for the definition of type curves and drilling feasibility. As the Bakken – Three Forks petroleum system sees steady development in the decades to come, the middle Three Forks (2nd bench) reservoir is a prime candidate for continued infill drilling to provide resource for the State of North Dakota and all stakeholders.

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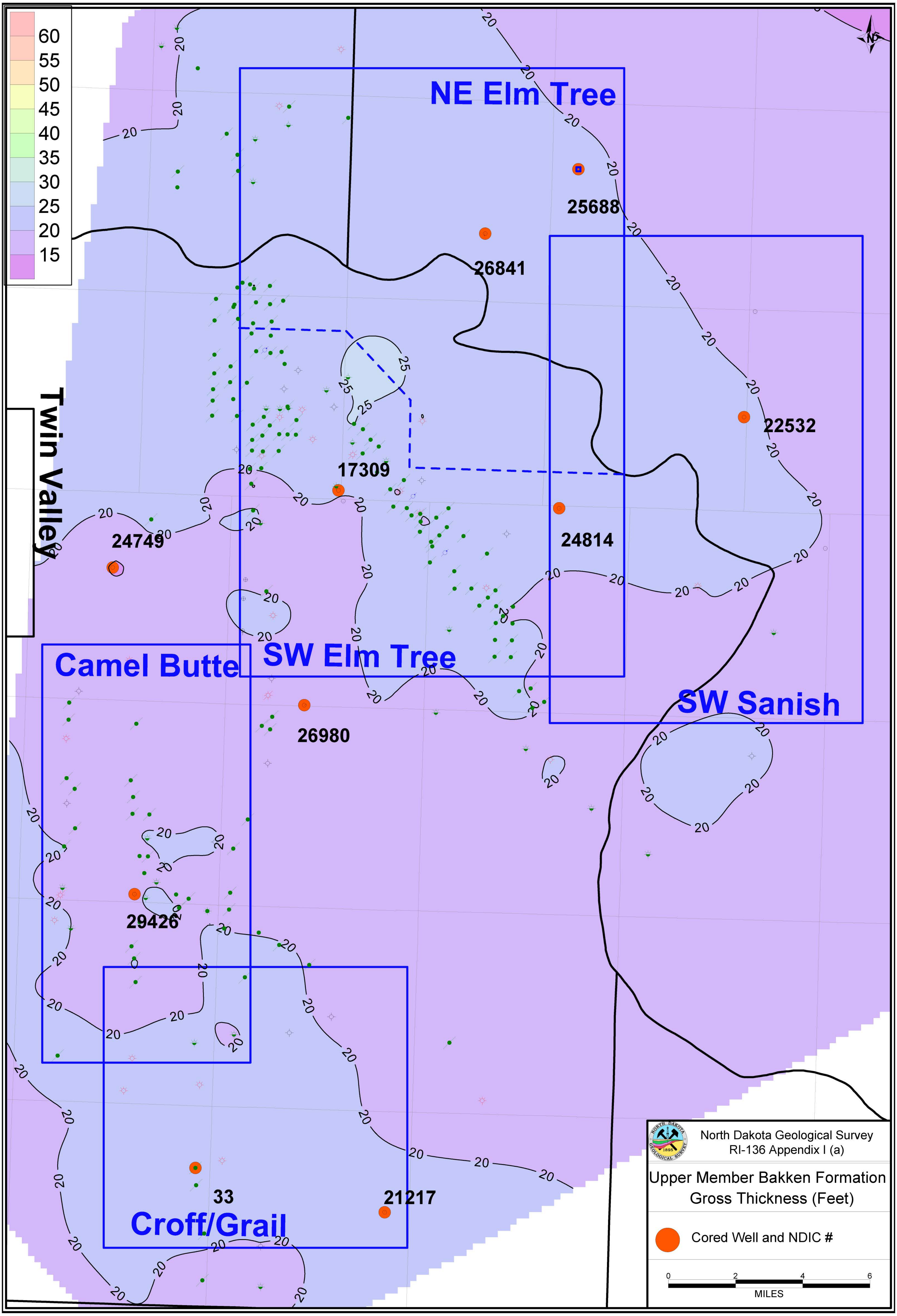
APPENDIX I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North Dakota Geological Survey
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Upper Member Bakken Formation
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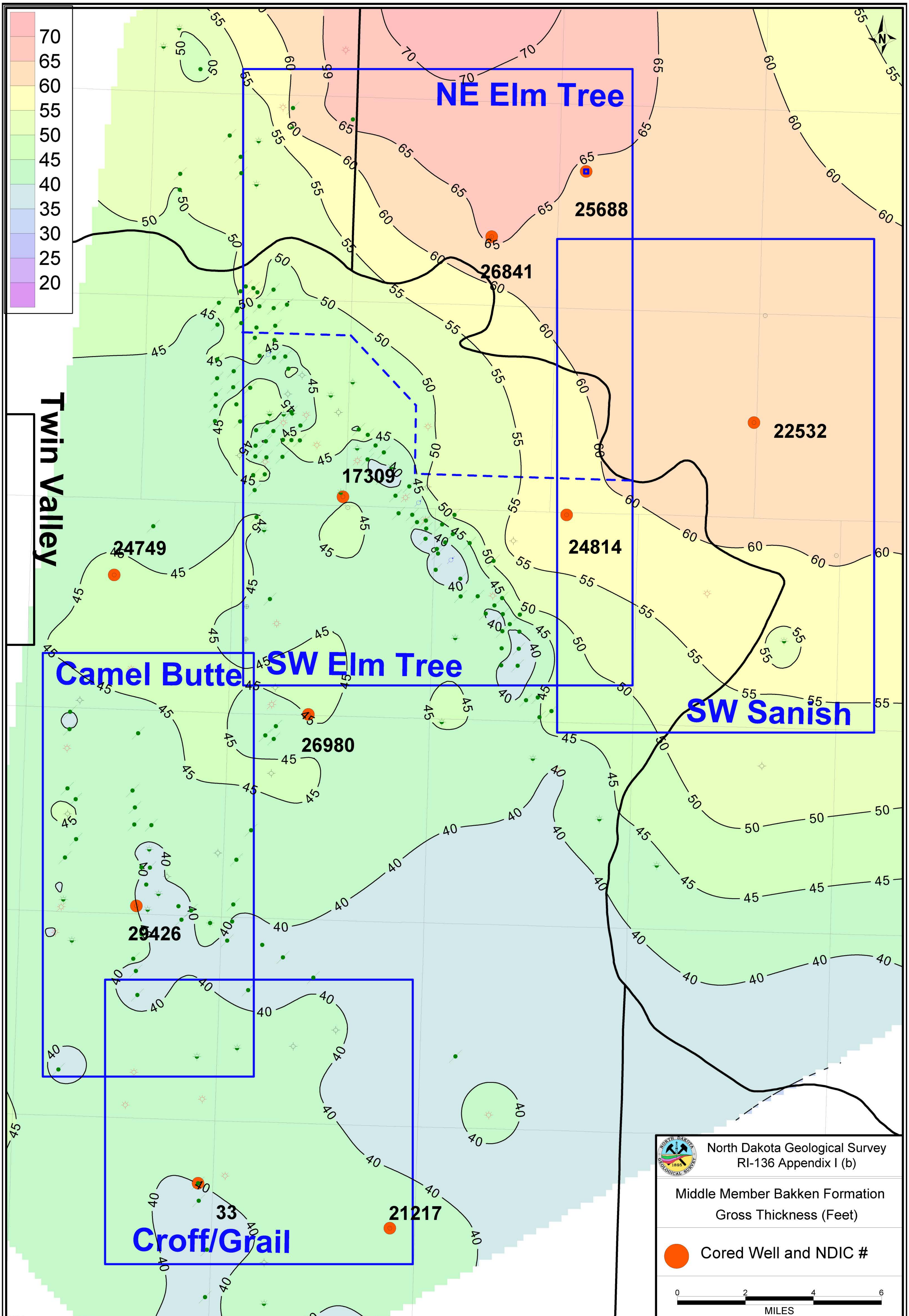
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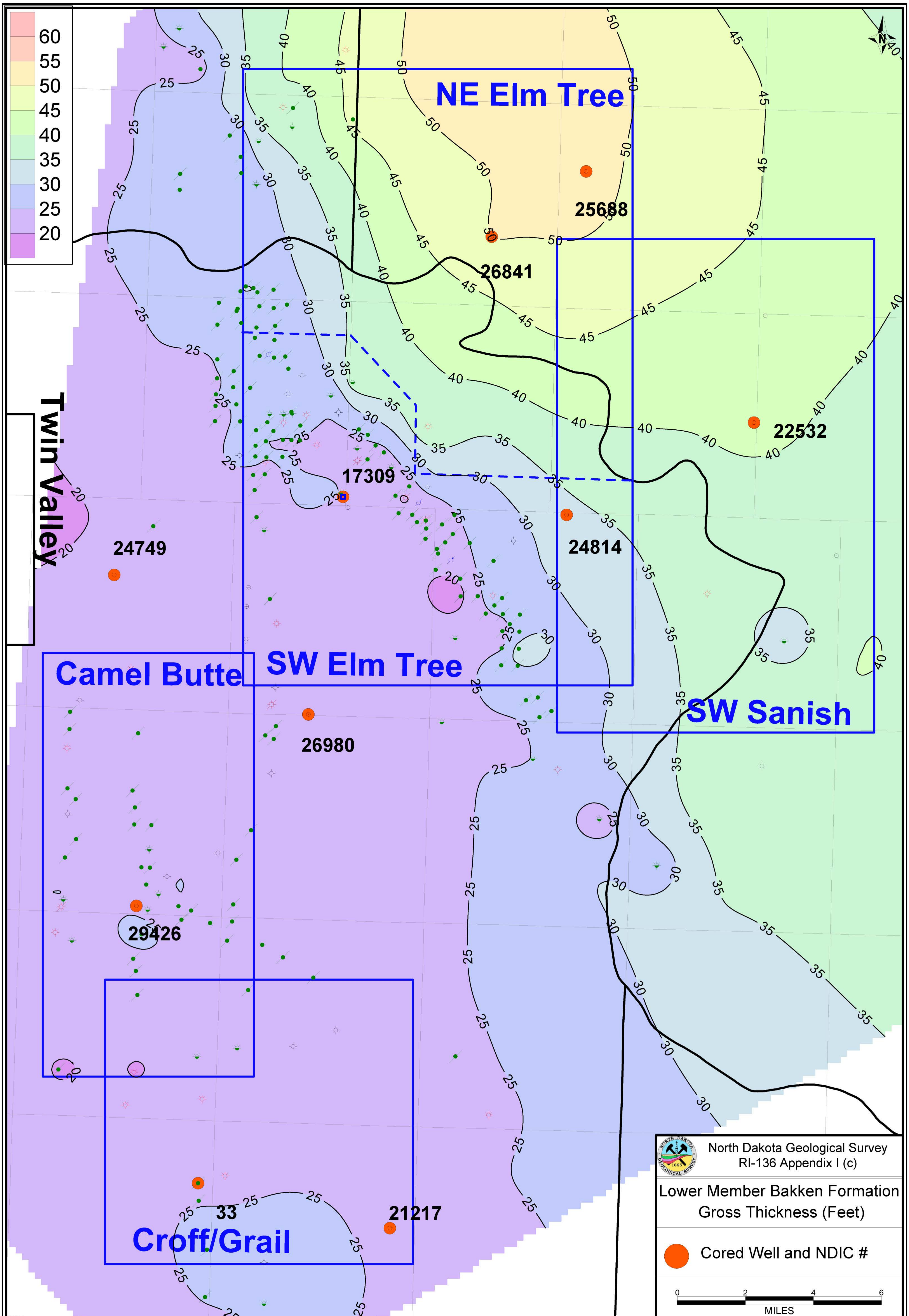
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North Dakota Geological Survey
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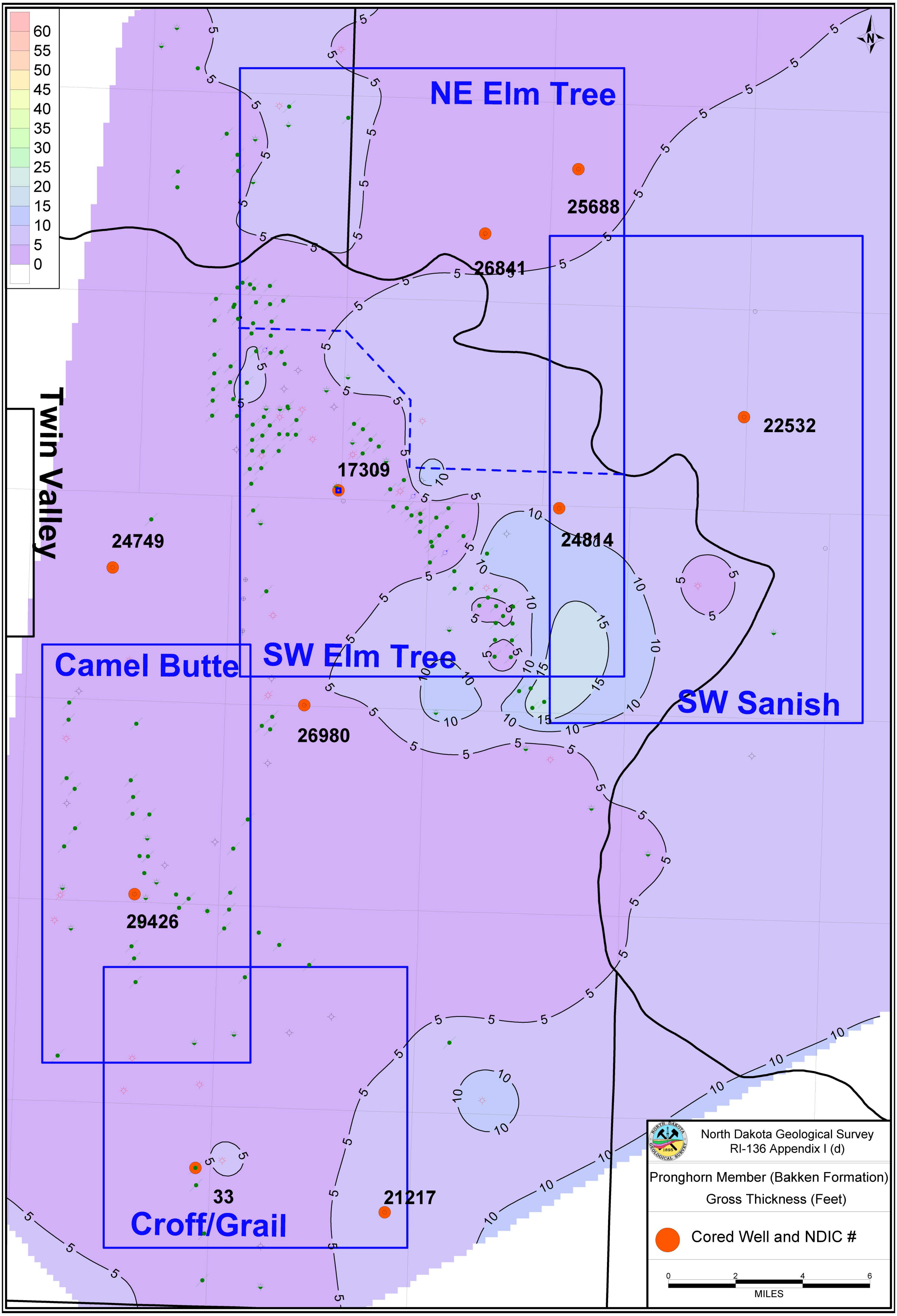

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North Dakota Geological Survey
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Pronghorn Member (Bakken Formation)
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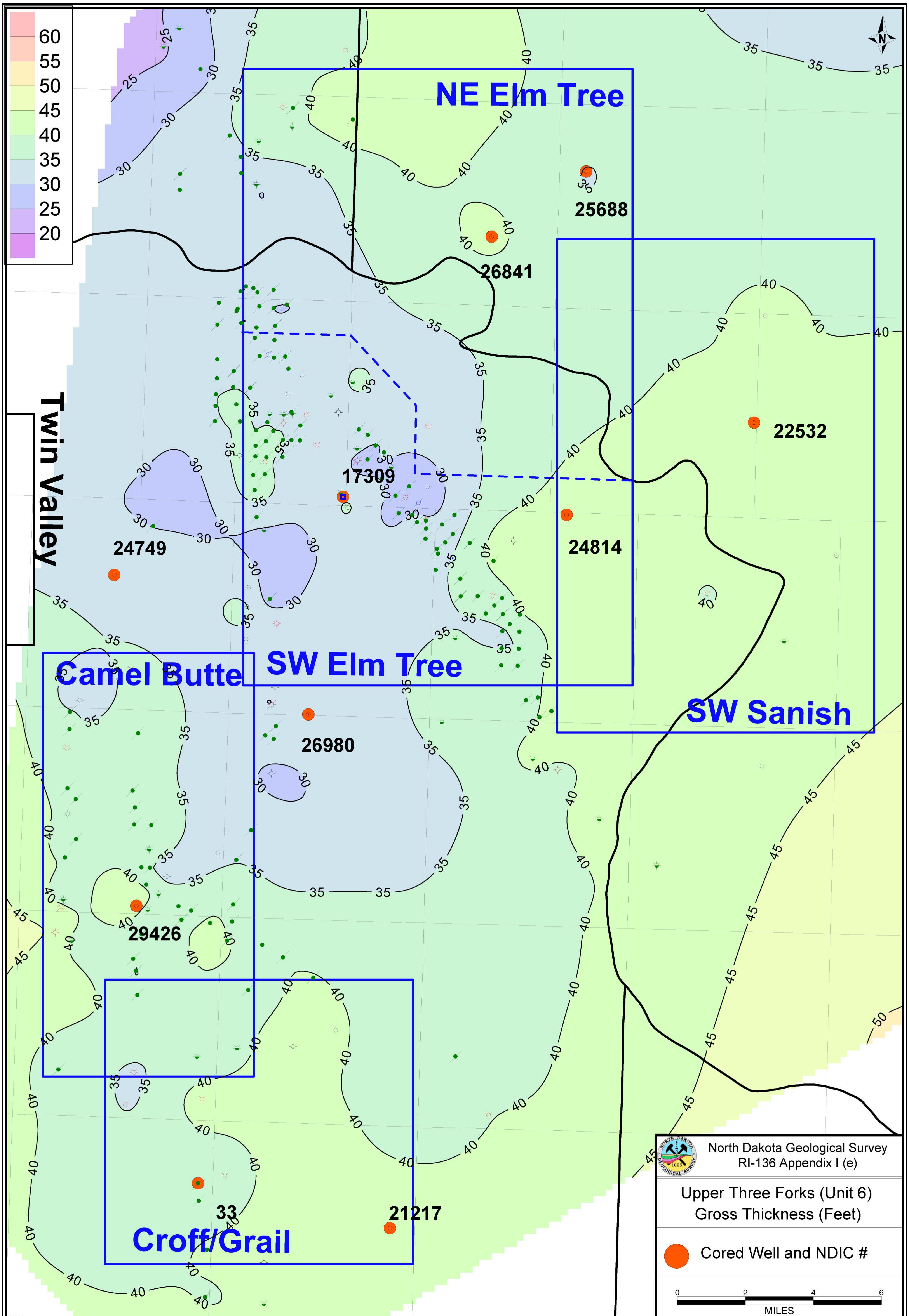
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North Dakota Geological Survey
RI-136 Appendix I (e)
Upper Three Forks (Unit 6)
Gross Thickness (Feet)
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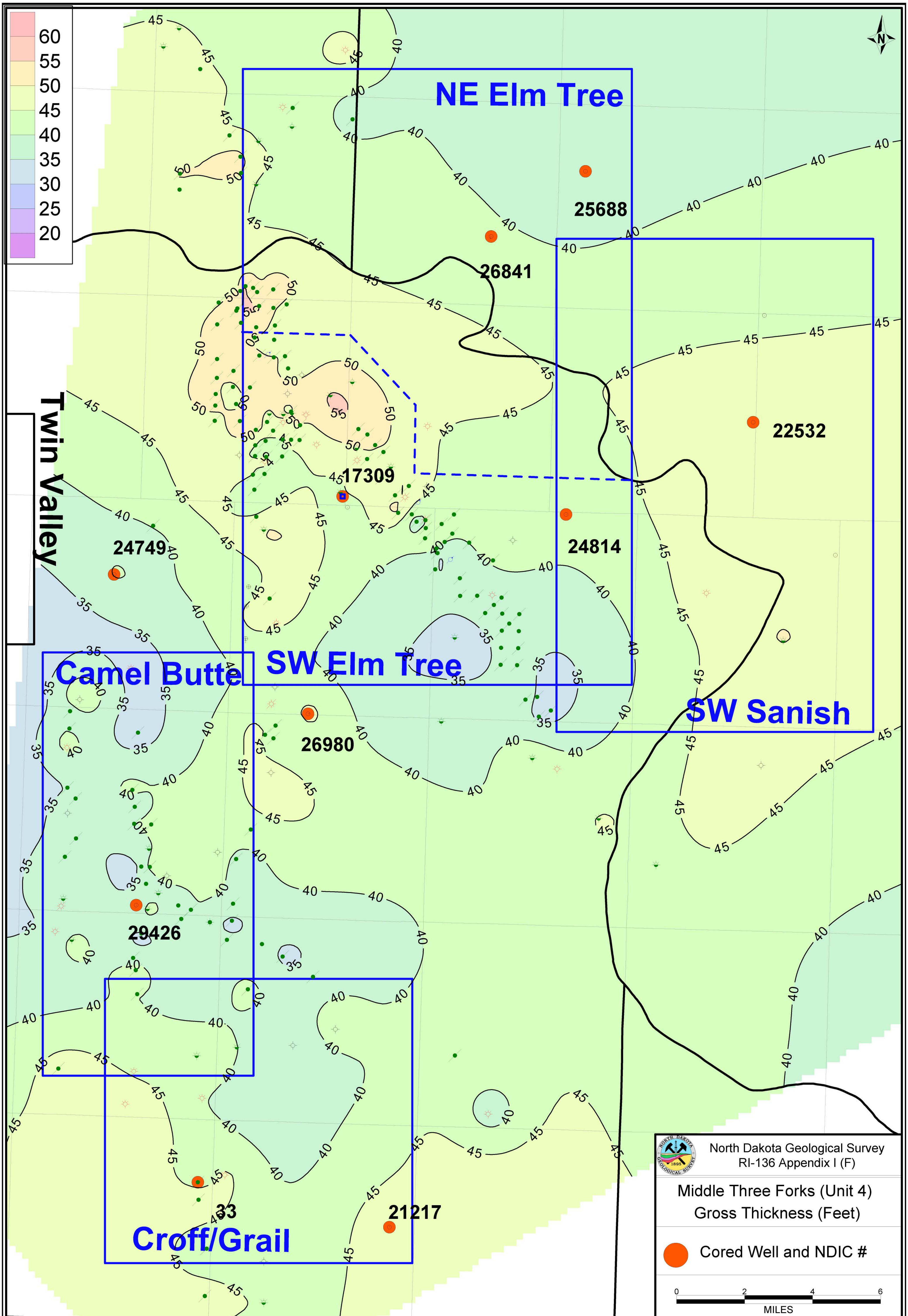
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North Dakota Geological Survey
RI-136 Appendix I (F)
Middle Three Forks (Unit 4)
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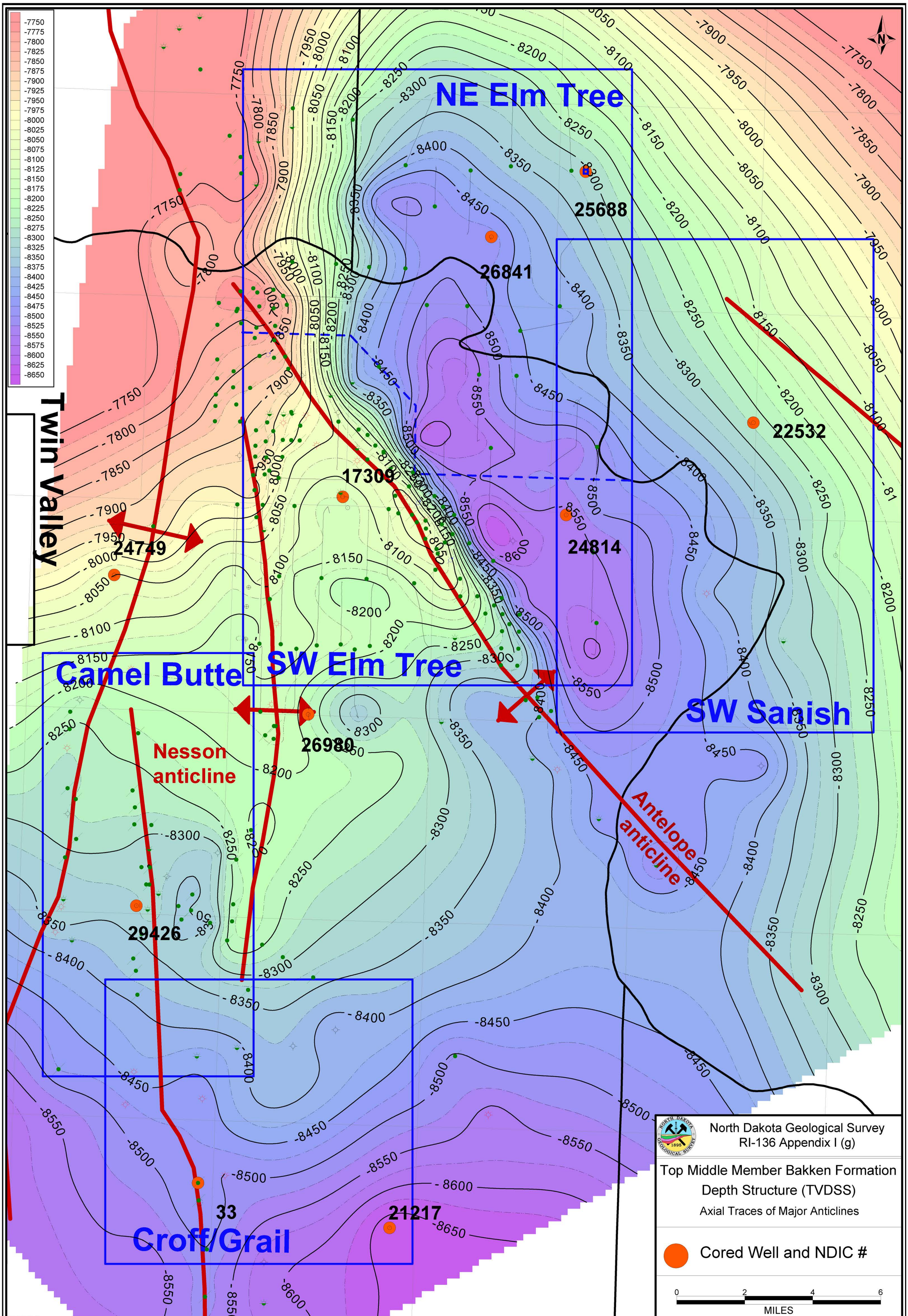

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Antelope anticline
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North Dakota Geological Survey
RI-136 Appendix I (g)
Top Middle Member Bakken Formation
Depth Structure (TVDSS)
Axial Traces of Major Anticlines
Cored Well and NDIC #
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