STRATIGRAPHIC FRAMEWORK OF THE WOLF POINT 1° X 2° QUADRANGLE, MONTANA: FORMATION TOPS DATABASE AND SELECTED STRUCTURE AND ISOCHORE MAPS

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Cover photo: Pumpjack producing oil from the East Poplar Unit #12 well, located in Roosevelt County. Photo by Clay Schwartz, MBMG.

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ERRATUM

The contact between the Charles Fm and the Kibbey Fm was incorrectly illustrated as an unconformity in figure 3 on page 9, figure 9 on page 12, figures 10 and 11 on page 13, plate 12 on page 27, and plate 13 on page 28. Reexamination of the literature indicates this contact is most likely a conformable contact in the Williston Basin (e.g. see page 13 of Sando, W.J., 1995, Geologic history of salt beds and related strata in the upper part of the Madison Group (Mississippian), Williston Basin, Montana and North Dakota: U.S. Geological Survey Bulletin 2112, 51 p.

PURPOSE

Subsurface geologic maps, generated from a high-quality set of formation tops, are critical for identifying targets for petroleum exploration, CO_2 sequestration, waste water disposal, geothermal exploration, and groundwater aquifers. They are also important for understanding the depositional and tectonic histories of geologic provinces.

For wells drilled in Montana, subsurface formation tops are publicly available from the Montana Board of Oil and Gas (MBOG). They are also available for purchase from several private data vendors. These formation tops are primarily those reported to the MBOG by well operators; they are generally unverified, incomplete, and use inconsistent nomenclature. Although they represent a starting point for subsurface geologic studies, users must spend considerable time and effort interpreting these data before conducting detailed analyses.

The Montana Bureau of Mines and Geology (MBMG) is systematically interpreting subsurface formation tops from well log data on a 1:250,000-scale quadrangle-by-quadrangle basis. From these, we present selected structure and isochore maps. Our database provides a more consistent and complete set of formation top picks, allowing the MBMG and other geoscientists to more quickly advance to the interpretation phase of subsurface geological projects.

INTRODUCTION

The Wolf Point 1° x 2° (1:250,000) quadrangle in northeastern Montana is situated on the western margin of the Williston Basin, a large intracratonic basin centered in western North Dakota and extending into portions of Montana, South Dakota, Saskatchewan, and Manitoba (fig. 1; all figures at end of report).

The surface geology of the Wolf Point quadrangle consists almost entirely of the Tertiary Fort Union Formation (Fm) except at Poplar Dome and to the west, where Late Cretaceous rocks are exposed (fig. 2). Two prominent tectonic features occur in the quadrangle. The dominant feature, Poplar Dome, is a small basement-cored uplift (Shurr and Monson, 1995) in the south-central portion of the quadrangle. The SW–NE-trending Brockton–Froid fault zone in the southeastern quarter of the quadrangle is a major fault zone that also appears to be related to basement structure and regional wrench-fault tectonism (Thomas, 1974; Brown and Brown, 1987). It transects the southeastern edge of Poplar Dome.

Geologic units in the subsurface range in age from Precambrian to Tertiary and consist primarily of cyclic shallow marine sediments (carbonates, sandstones, shales) deposited during Paleozoic and Mesozoic time. Basin subsidence originated during the Middle Ordovician (Heck and others, 2006), with episodic subsidence continuing until late Permian or Early Triassic time (Carlson and Anderson, 1965).

Approximately 150 oil fields have been discovered entirely or partially within the Wolf Point quadrangle (MBOG, 2023). The major oil-producing zones are highlighted on the stratigraphic column in figure 3. Unconventional oil production from the Bakken Fm occurs at Elm Coulee and Elm Coulee Northeast fields. The most prolific conventional oil-producing zones in the study area are the Madison Group (primarily Charles Fm), Red River Fm, Nisku Fm, and Winnipegosis Fm.

DATA AND METHODS

Approximately 3,000 petroleum exploration wells have been drilled within the Wolf Point quadrangle. Well header and location data were acquired from the MBOG. Raster images of geophysical logs and mudlogs were obtained from MJ Systems of Calgary, Alberta. Northwest Geological Society logs were acquired from the Montana Geological Society (https://mtgeo.org/resources/nwgs-projects/). Formation tops reported by well operators are available from the MBOG. All data were loaded into S&P Global's PETRA software for interpretation.

The formation names used in this study are based on names recognized in the USGS National Geologic Map Database (https://ngmdb.usgs.gov/Geolex/), names most commonly cited in the literature, and names (both formal and informal) most commonly applied by well operators and reported to the oil and gas commissions of Montana and North Dakota. The reader is encouraged to compare the names used in our database (fig. 3) with published stratigraphic columns for the Williston Basin of Montana and North Dakota (Balster, 1980; Donovan, 1988; Sandberg, 1962; Murphy and others, 2009). Most of our stratigraphic picks are actual formation tops, but we also include the tops of some stratigraphic groups, formation members, and a few intraformational marker beds. For simplicity, we use the terms *formation tops, formation picks,* or *stratigraphic picks* in this report as general terms that include all of these picks.

Stratigraphic picks were made by correlating geophysical log signatures on a well-by-well basis; all are lithostratigraphic correlations, although some of these picks are also major unconformities (sequence boundaries). Where possible, lithology descriptions from various types of sample logs as well as those from geological reports found in MBOG files were used to correlate lithologic units to geophysical log signatures (MBOG, 2023). For deviated/horizontal wells, formation tops were picked using available true vertical depth (TVD) logs. No picks were made for deviated wells where TVD logs were unavailable.

Structure and isochore maps were created for select formations and intervals using our stratigraphic picks. Structural elevation and formation thickness data were gridded using PETRA's "Least Squares Method" interpolation algorithm with a square grid spacing that varied from map to map depending on data distribution. Hand-drawn contours based on our interpretations were used to guide the gridding process.

Type logs that document our stratigraphic picks are provided in figures 4 through 15. Explanations and a few additional comments are included below for clarification of nomenclature, explanation of stratigraphic picks on logs, and/or observations about formation thickness and extent.

Cretaceous

Five stratigraphic horizons were picked within the Cretaceous section (fig. 4). They can be correlated across the entire Wolf Point quadrangle, and are generally consistent with the interpretation of other authors for this area (e.g., Rice, 1976; Condon, 2000; Gunderson and Furer, 2019). Nomenclature for the interval between the top of the Fall River Fm and the top of the Mowry Fm varies, and is discussed by Condon (2000).

Jurassic

Five tops of Jurassic age were selected as part of this database (fig. 5) and follow Nordquist (1955), Zieglar (1956), and Carlson (1993). Jurassic strata are primarily composed of thick marine limestones and shales that unconformably overlie Triassic strata.

- We picked the informal "Piper limestone" [Firemoon Member (Mbr) of the Piper Fm] rather than the top of the Piper Fm because it is easily identified and serves as an excellent stratigraphic marker bed. We note that many operators erroneously report the depth/elevation of the "Piper limestone" as the top of the Piper Fm.
- The Jurassic section thins to the southwest across the project area, to where the Nesson Fm completely pinches out due to onlap. The Dunham Mbr of the Nesson Fm (informal "Dunham salt") is only observed in the southeastern portion of the Wolf Point quadrangle. It can be very discontinuous due to post-depositional dissolution (LeFever and LeFever, 2005; Stolldorf, 2021).

Permian–Triassic

The seven Triassic and Permian stratigraphic names used here follow those used by the North Dakota Geological Survey for the Williston Basin (fig. 6). According to Murphy and others (2009), the Permian–Triassic boundary occurs at the top of the Pine Mbr (or "Pine salt") of the Spearfish Fm (see also https://www.dmr.nd.gov/dmr/ndgs/spearfish).

The top of the Spearfish Fm (base of Jurassic section) is an unconformity. The entire Spearfish Fm gradually thins southwestward. In places, such as within portions of T. 31 N., R. 46–47 E. and T. 27 N., R. 49 E., the Spearfish Fm thins to a zero edge over what may have been paleotopographic highs.

- A marker bed within the Spearfish Fm, designated "SPRF_MKR_1," was picked to facilitate correlation within the Spearfish Fm.
- The Permian Pine Mbr (informal "Pine salt") of the Spearfish Fm only occurs in the southeastern portion of the Wolf Point quadrangle. As with the Jurassic-age Dunham salt, the Pine salt can be very discontinuous (Stolldorf, 2022). Log correlations show that more than 50 ft of salt can disappear over distances of less than 0.5 mile.
- The Permian unconformity is picked at the base of the Pine salt (Zieglar, 1956; Carlson, 1993). The unconformity truncates Permian–Pennsylvanian strata (Belfield Mbr, Minnekah-

ta Fm, Opeche Fm, and Minnelusa Group) in the southeast portion of the quadrangle (fig. 7), and truncates older, Mississippian Big Snowy Group strata to the west and northwest.

Pennsylvanian

Two stratigraphic picks from the Pennsylvanian section are stored in the database (fig. 8). They are the top of the Minnelusa Group and the top of the Tyler Fm. Our use of the name Minnelusa Group follows that of Murphy and others (2009).

The Tyler Fm top is placed at the base of the lowermost thick limestone within the Minnelusa Group carbonates. It is a difficult pick because Tyler strata record multiple episodes of erosion and deposition of valley-fill sediments (Bottjer, 2017; Bottjer and others, 2020). Further, since the Tyler Fm can also include some limestone beds, it is possible that the top of the Tyler Fm could be stratigraphically higher than our pick.

Mississippian

Stratigraphic picks of Mississippian age in this database belong to the Big Snowy and Madison Groups. The Big Snowy Group comprises, in descending order, the Heath, Otter, and Kibbey Formations (fig. 9). We also include the informal "Kibbey limestone" because it is a distinctive stratigraphic marker and useful stratigraphic datum. The top and base of the Big Snowy Group are unconformities.

Because the top of the Heath Fm is an unconformity, it can be difficult to pick. Heath Fm strata contain several marker beds that exhibit high gamma ray and resistivity, designated Heath_Mkr_1, Heath_Mkr_2, and Heath_Mkr_3 in ascending order. These markers are comparable to those described by Bottjer and others (2020), and can be correlated for tens of miles across the southern portion of the Wolf Point quadrangle. The top of the Heath is picked at the uppermost point where internal correlations are no longer possible. When some or all of the Heath markers are absent, it is very likely that they were eroded and replaced by younger sediments of the Tyler Fm (fig. 10).

Stratigraphic picks within the Madison Group are the top of the Charles Fm, Charles C, Charles C salt (where present), Mission Canyon Fm, and the Lodgepole Fm (fig. 11). The Charles C (also known as Ratcliffe) pick follows that of Longman and Schmidtman (1985).

Devonian

Our Devonian picks, shown in figures 12 and 13, can be traced across the entire Wolf Point quadrangle.

- The Bakken Fm straddles the Devonian–Mississippian boundary (LeFever and Nordeng, 2011; LeFever and others, 2013; Sonnenberg, 2017). It is subdivided into lower, middle, and upper lithologic units (fig. 12). The upper and lower shales of the Bakken Fm have a distinctively high GR response. The entire Bakken interval thins to the southwest due to onlap.
- Thick beds of salt in the Prairie Fm (or "Prairie evaporite") are only observed in the north-central, northeastern, and southeastern portions of the quadrangle. Dissolution of Prairie Fm salt has caused local thickness and structural variations of the overlying strata.

Precambrian–Cambrian–Ordovician–Silurian

The Interlake Fm is the sole Silurian top stored in the database (fig. 14). Seven stratigraphic picks from Precambrian through Ordovician age were stored in the database (fig. 15). Our terminology follows that of Murphy and others (2009).

- The Red River Fm top becomes increasingly difficult to correlate in the western portion of the quadrangle as the overlying distinctive shale disappears. Immediately below the Red River Fm top, there are two persistent anhydrites, designated Red River B and Red River C (fig. 15).
- The top of the Cambrian–Ordovician Deadwood Fm typically exhibits higher resistivity than the overlying Winnipeg Fm strata. Our top of Deadwood pick is, in part, based on correlation with Deadwood picks in North Dakota wells that were obtained from the North Dakota Industrial Commission.
- Eleven wells penetrated Precambrian rocks. The top of Precambrian can be a difficult pick; sample descriptions do not always appear to match log responses. The Precambrian top picks in this database are from Gunderson (2024).

RESULTS

The primary product from this study is a high-quality database of formation top depths for more than 2,400 petroleum exploration wells located in the Wolf Point quadrangle. These data are contained in the Wolf_Point_tops_v1.xlsx file and subject to change. The number of formation tops picked per well varies based on well depth and the availability of geophysical logs; as many as 50 formation picks were made for the deepest wells.

Our formation tops data can be used to generate a variety of geologic structure and isochore maps that improve our understanding of subsurface geology and facilitate resource exploration and management. As examples, we used our stratigraphic picks to create structure maps for five horizons (plates 1–5). In addition, five isochore maps were generated for specific intervals that have implications for petroleum exploration and/or depositional and tectonic history (plates 6–10).

Several regional unconformities are present in the stratigraphic record. They indicate periods of erosion that have significantly impacted formation distribution and thickness, particularly from Mississippian to Early Jurassic time (refer to figs. 7, 10). For example, a subcrop map beneath the Permian unconformity shows successive truncation of Permian, Pennsylvanian, and Mississippian strata in a northwesterly direction (plate 11). The two regional cross-section lines depicted on plate 11 illustrate some of the lateral changes in stratigraphy in response to these unconformities (plates 12, 13).

Grid files for the maps illustrated in plates 1–10 are provided in a single zipped file (DP7_Wolf_Point_grid_files.zip). It contains the individual Excel data files for structure and isochore grids (Wolf_Point_*{fm_name}*_struct.csv and Wolf_Point _*{fm_name}*_iso.csv). Structure grids are in XYZ format, where X is longitude, Y is latitude, and Z is elevation of the top of the formation or zone in feet. Isochore grids are in XYZ format, where X is longitude, Y is latitude, and Z is thickness in feet. The latitudes and longitudes are based on NAD83 datum. All grid files are provided within a single zipped file (DP7_Wolf_Point_grid_files.zip).

It is beyond the scope of this project to generate structure and isochore maps for all formations and intervals. Rather, it is our intent and hope that other geoscientists will utilize the formation tops data we provide to generate additional subsurface maps and geologic interpretations.

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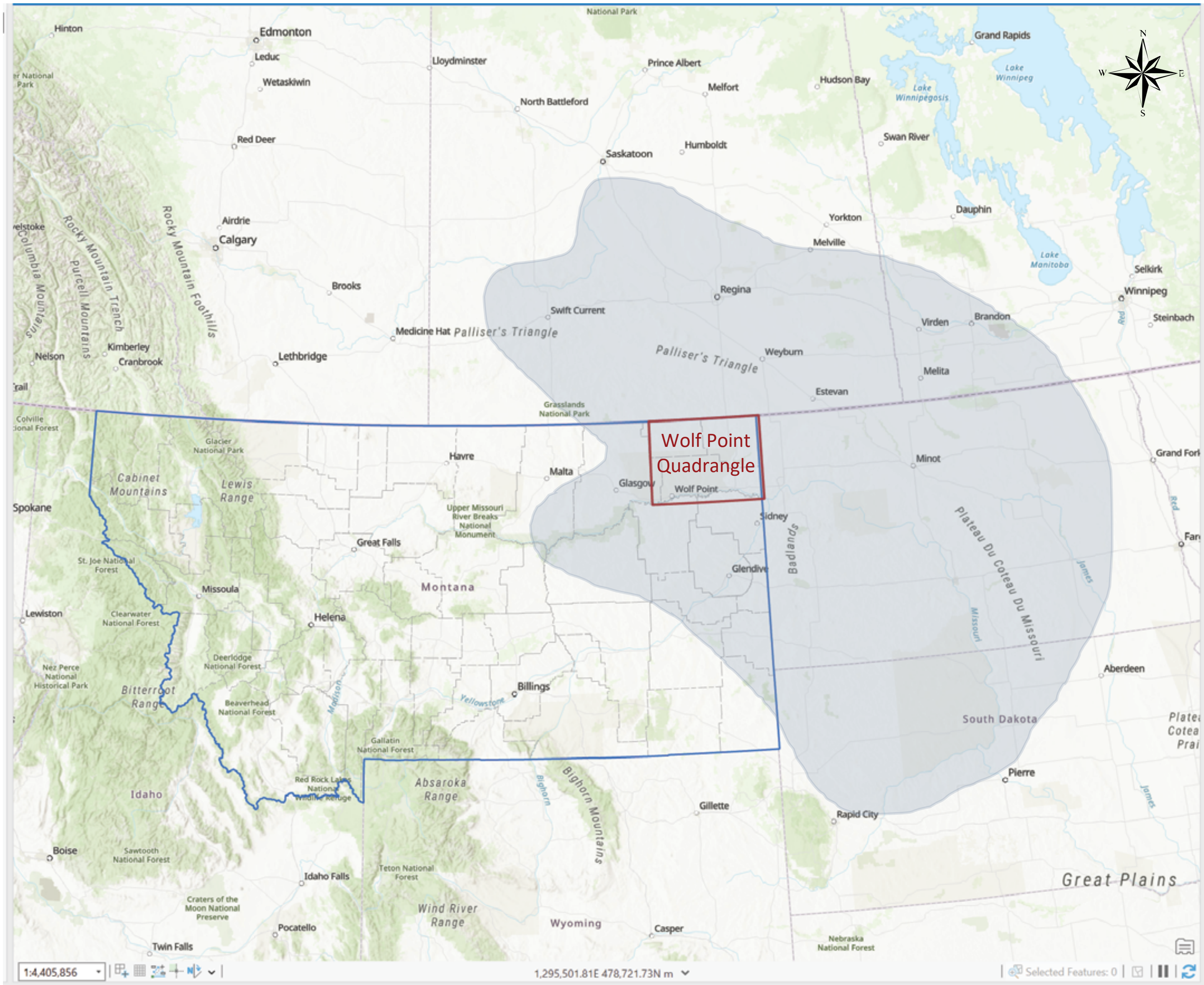

Figure 1. Index map showing the location of the Wolf Point 1° x 2° quadrangle. The gray shaded area is the approximate extent of the Williston Basin.

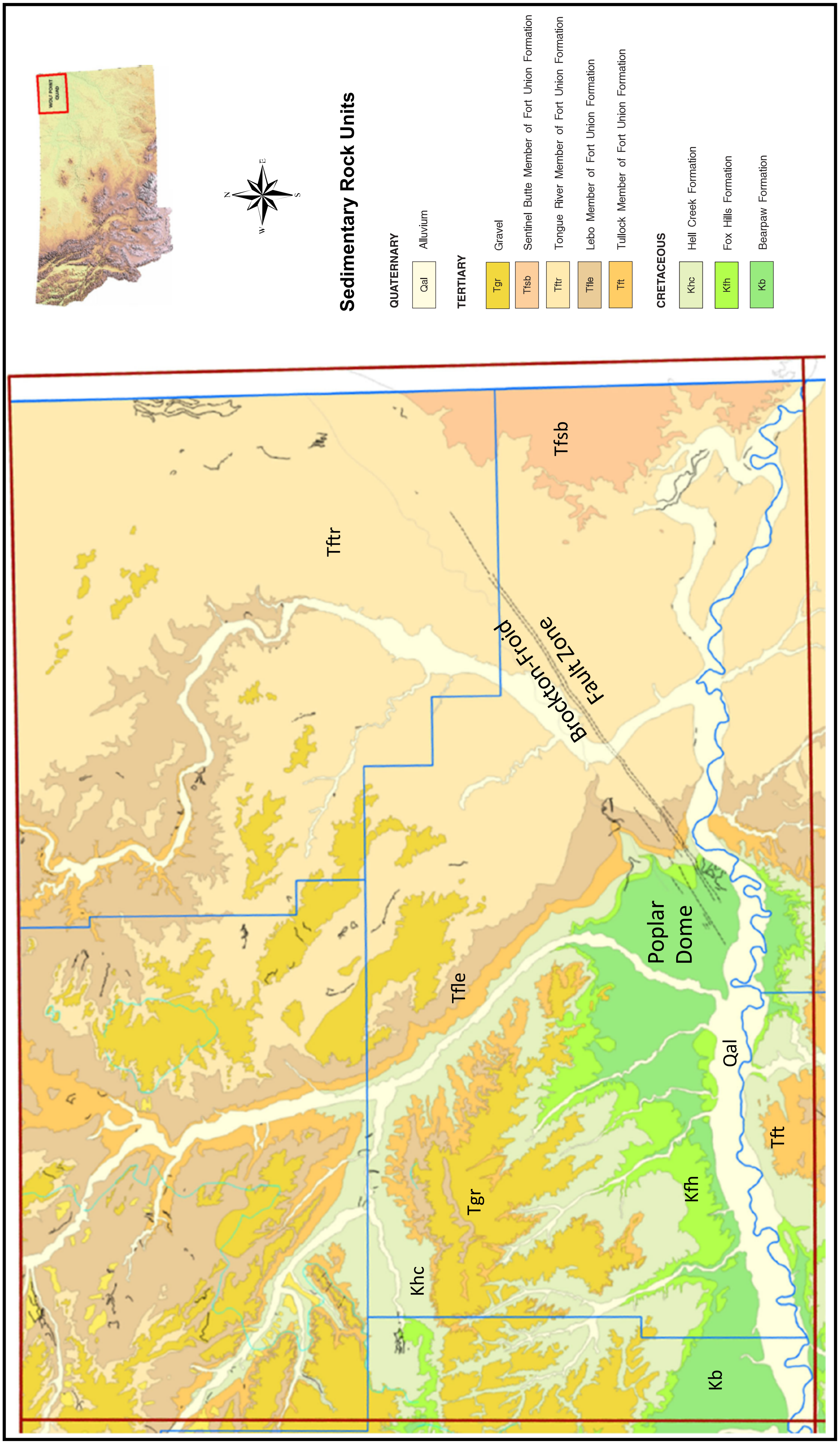

Figure 2. Surface geology of the Wolf Point 1° x 2° quadrangle (modified from Vuke and others, 2007).

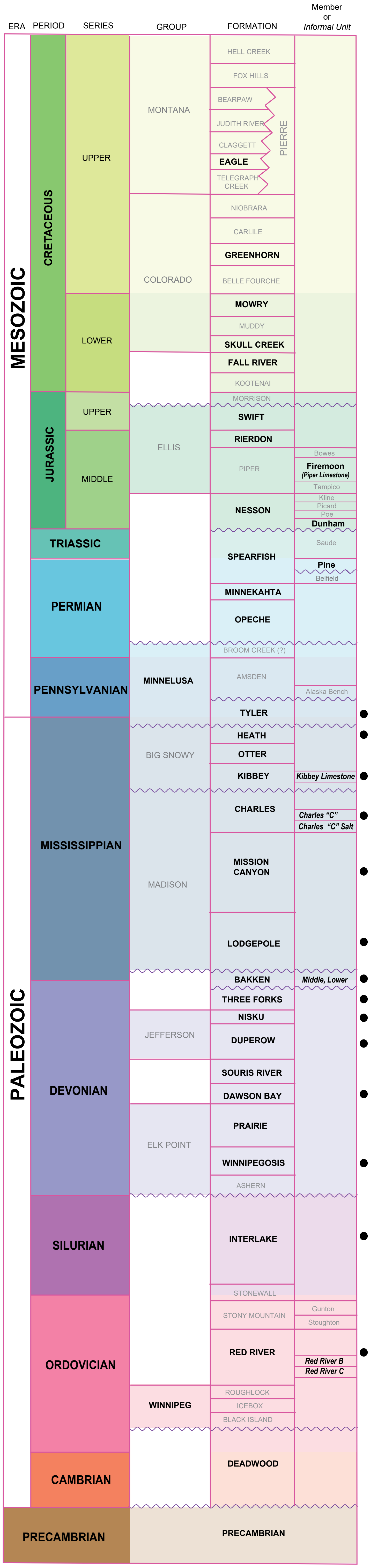

Figure 3. Stratigraphic column for the Wolf Point quadrangle (modified from Murphy and others, 2009). Stratigraphic tops stored in the database are highlighted in bold; they include formal groups (Minnelusa, Winnipeg), formations, and formation members. They also include several informal lithologic subunits. Black dots indicate major oil-producing zones within the Wolf Point quadrangle.

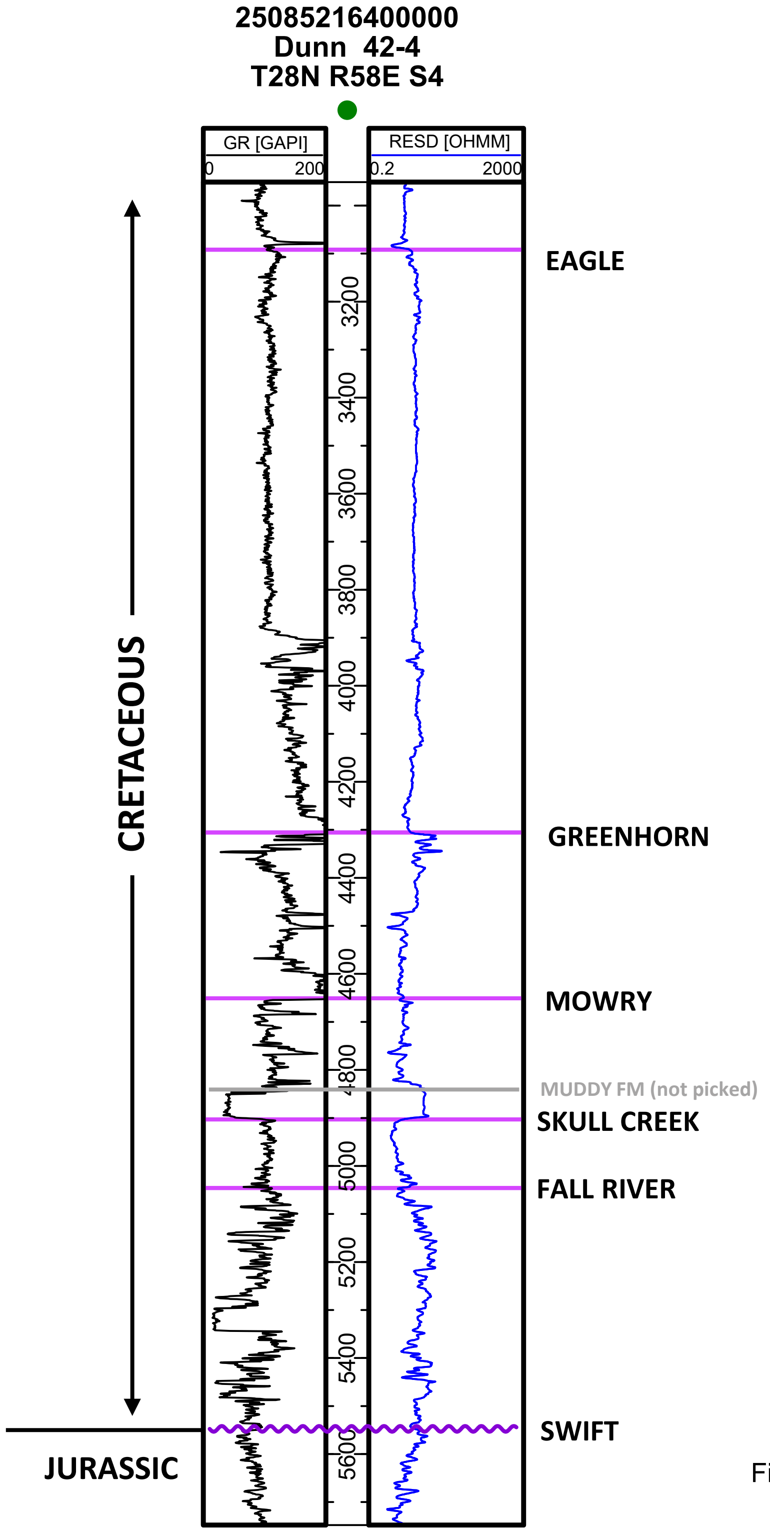

Figure 4. Type log showing the Cretaceous formation tops correlated in this study.

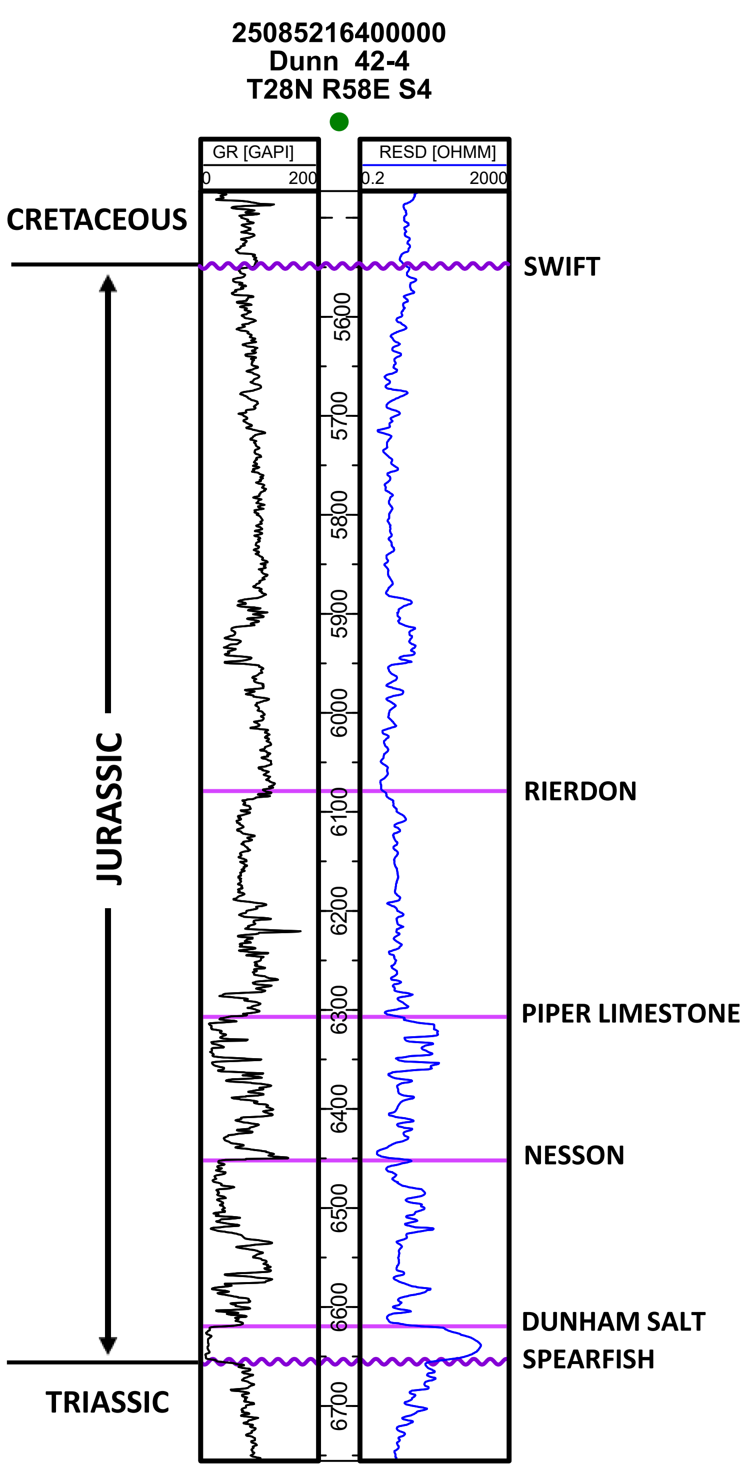

Figure 5. Type log showing Jurassic formation tops correlated in this study.

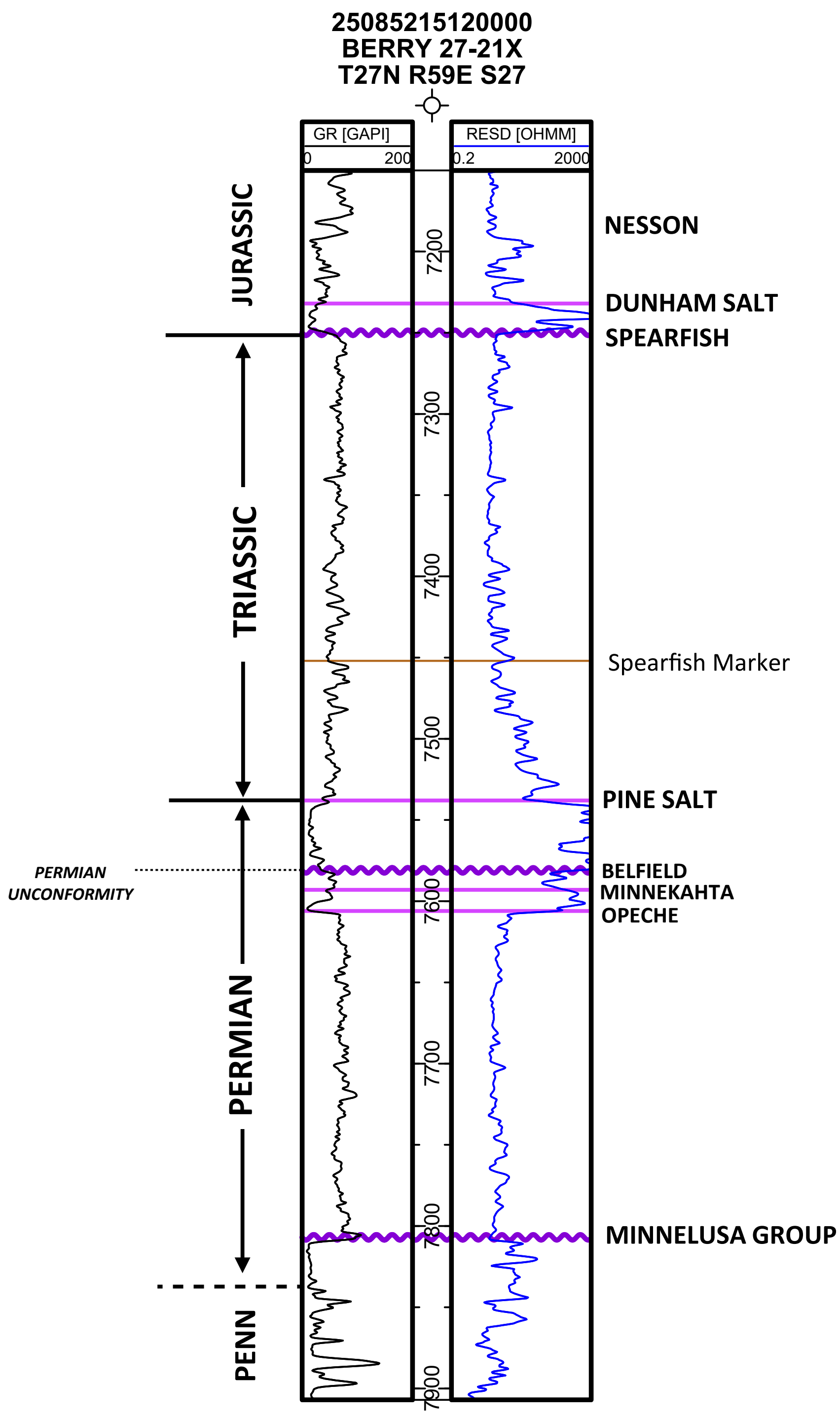

Figure 6. Type log showing Triassic and Permian formation tops correlated in this study.

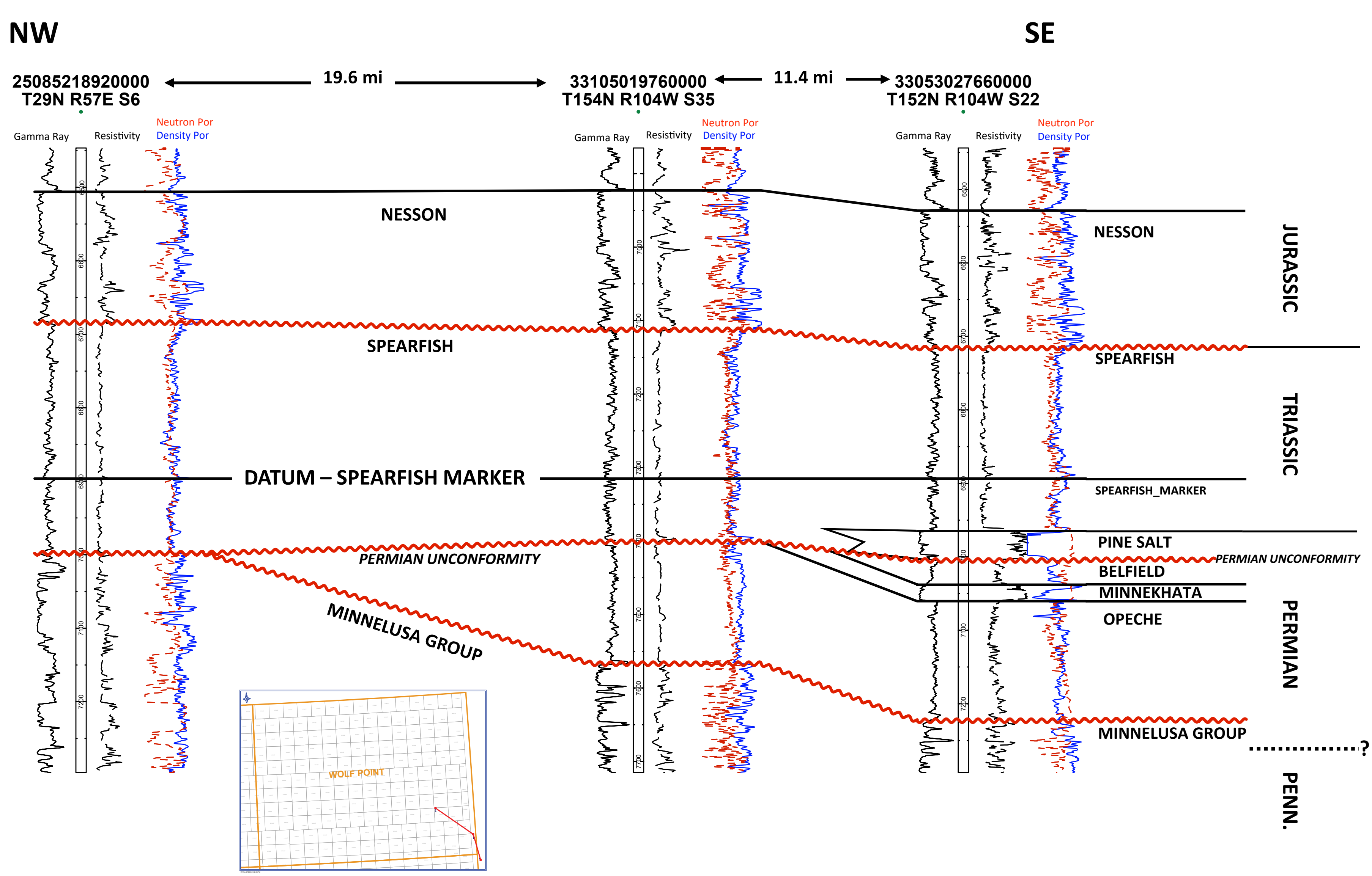

Figure 7. Cross-section showing Pennsylvanian to Jurassic strata. The Pine Salt and Belfield members of the Spearfish Formation are only present in the south-easternmost corner of the quadrangle. The Permian Unconformity truncates progressively older formations to the northwest.

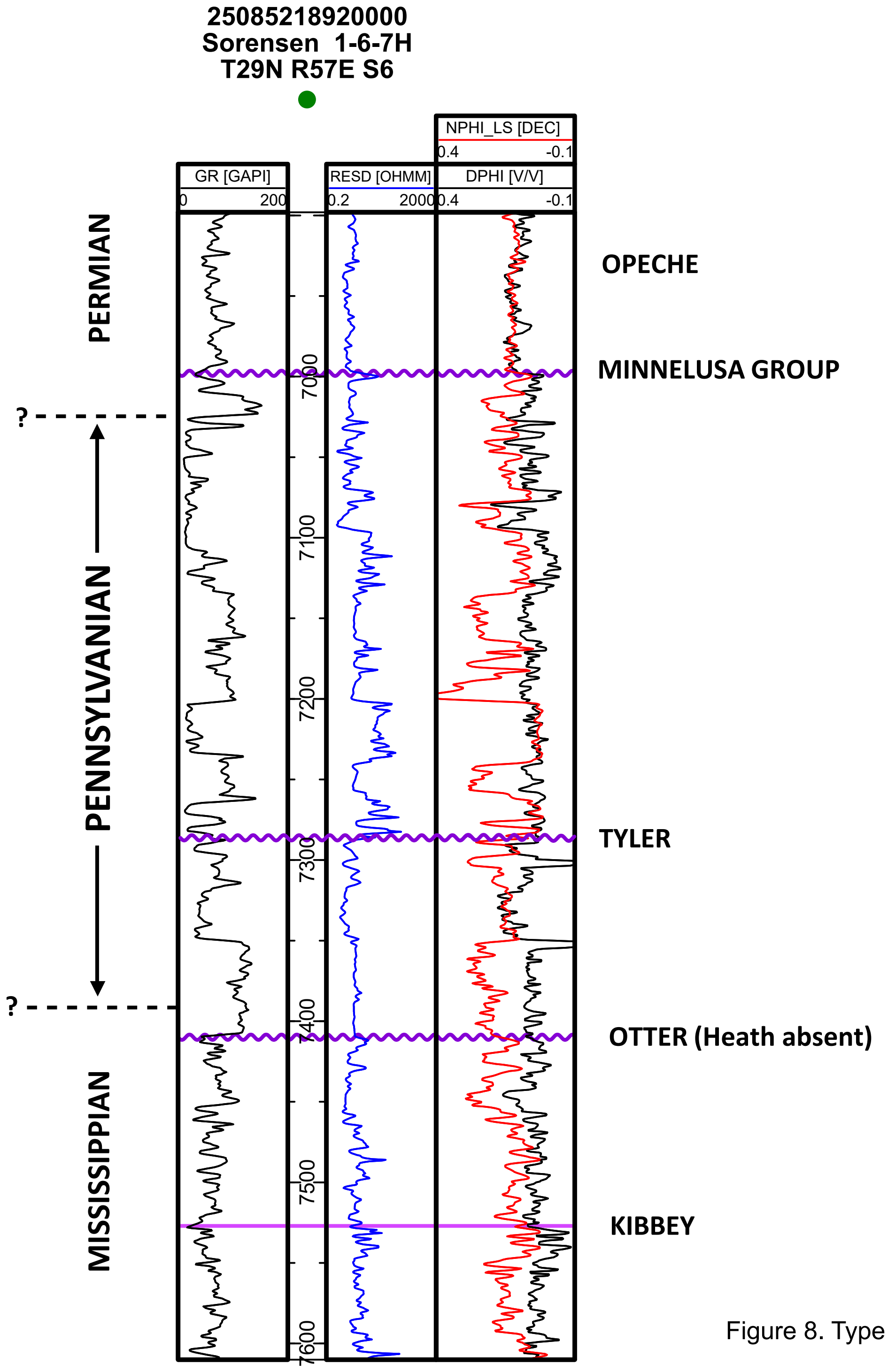

Figure 8. Type log showing Pennsylvanian formation tops correlated in this study.

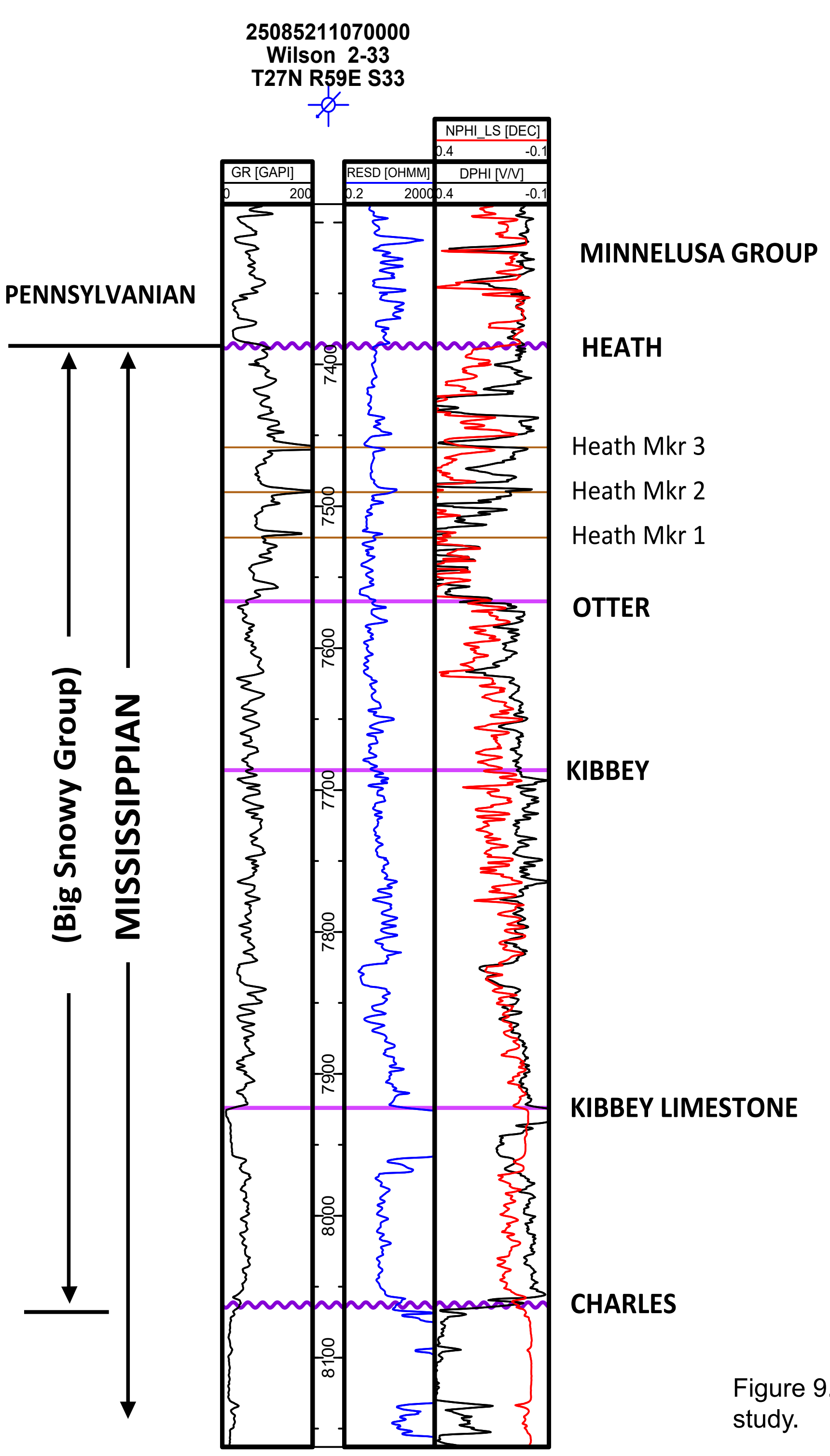

Figure 9. Type log showing Mississippian Big Snowy Group formation tops correlated in this study.

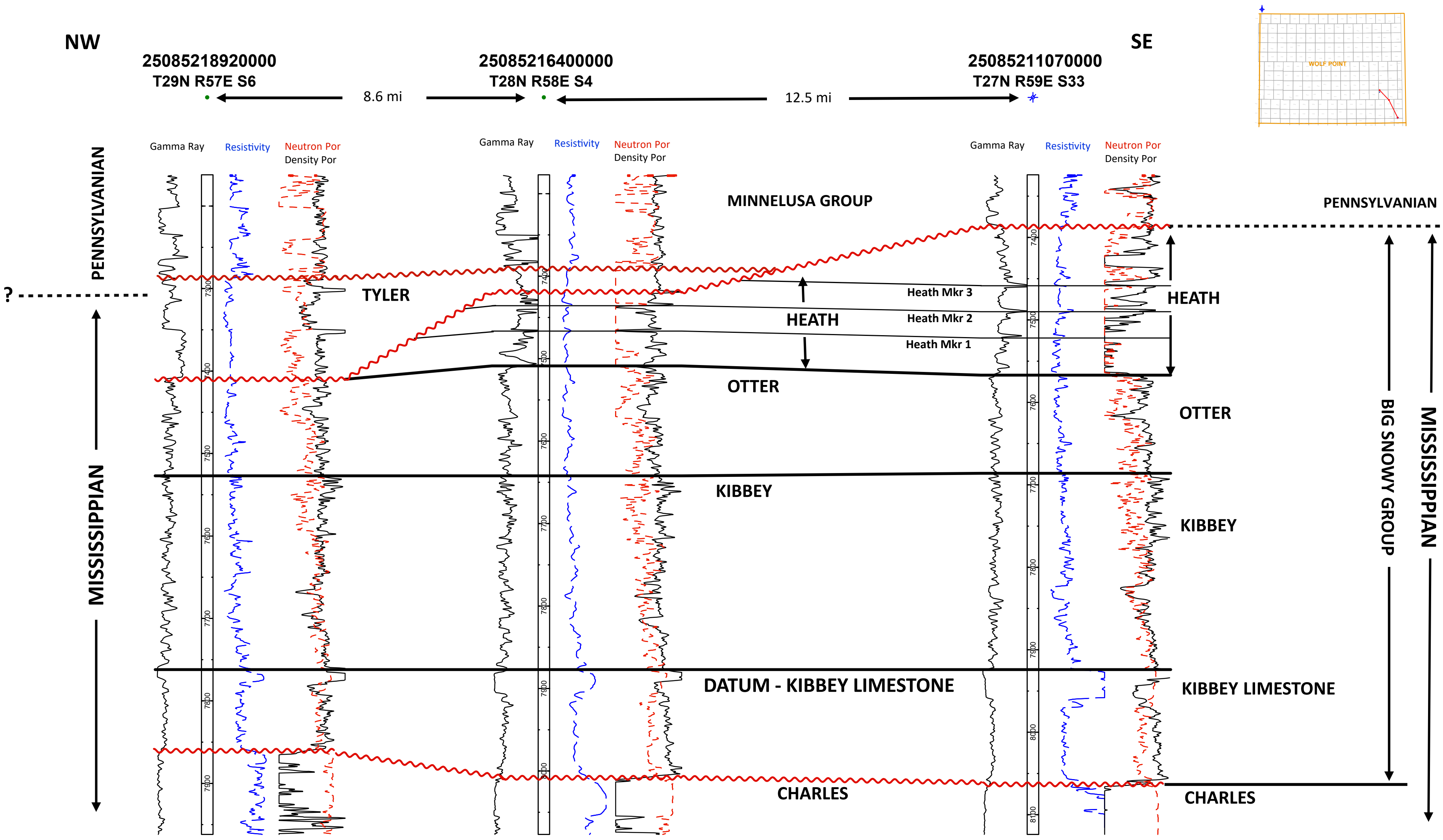

Figure 10. A Late Mississippian regional unconformity truncates progressively older units of the Big Snowy Group to the northwest. Locally, the Heath and Otter Formations are eroded and replaced by valley-fill sediments of the Tyler Formation.

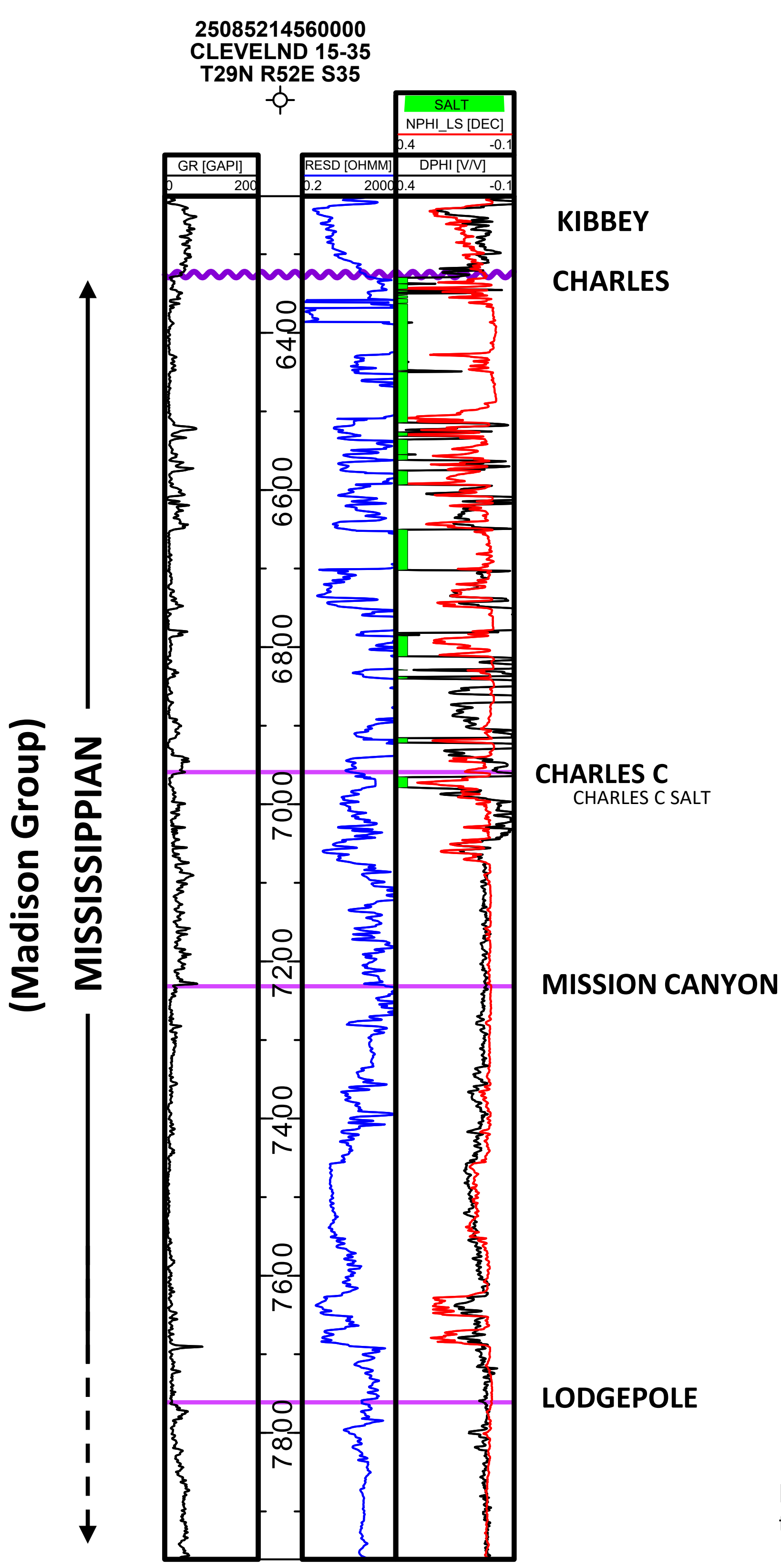

Figure 11. Type log showing Mississippian Madison Group formation tops correlated in this study.

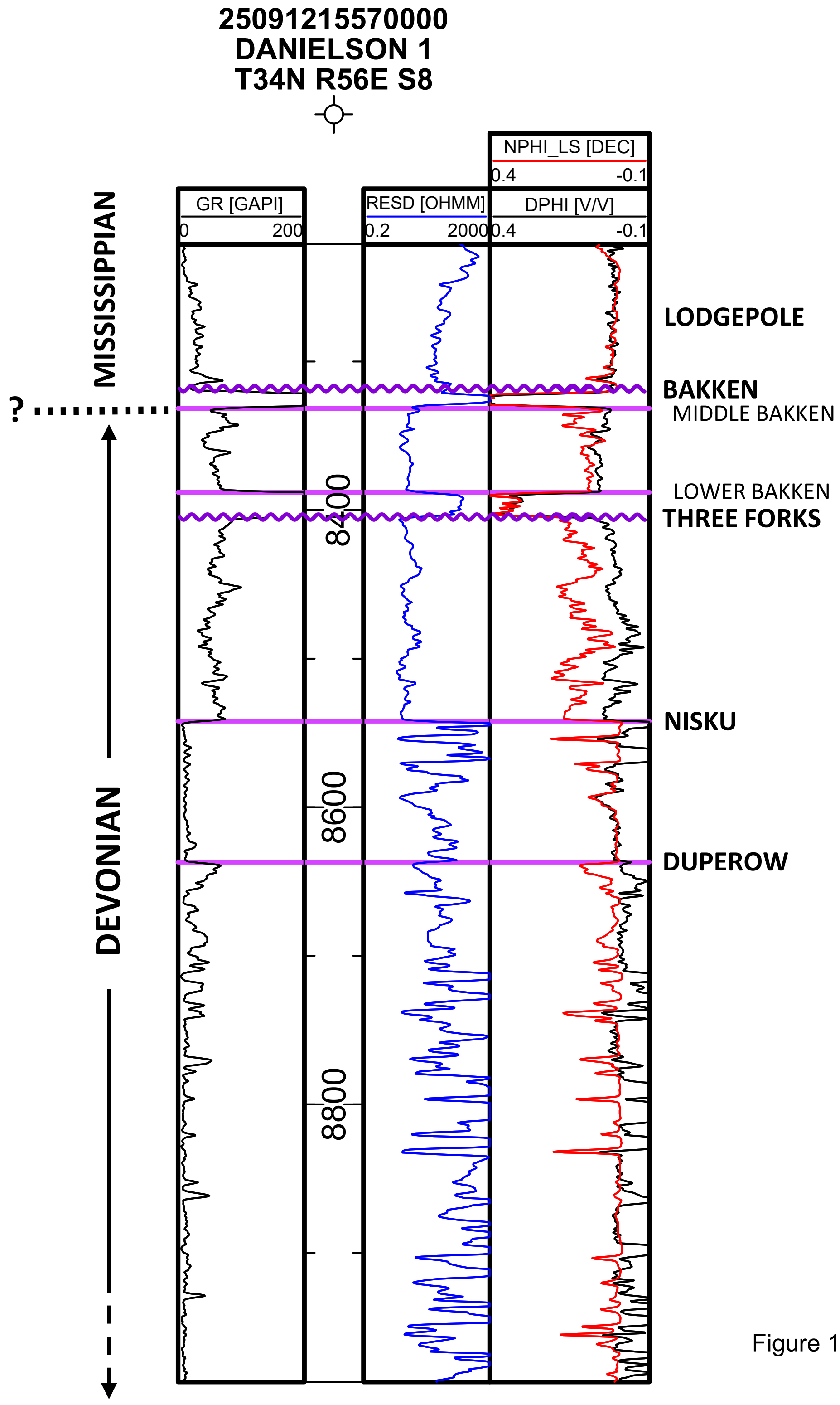

Figure 12. Type log showing Upper Devonian formation tops correlated in this study.

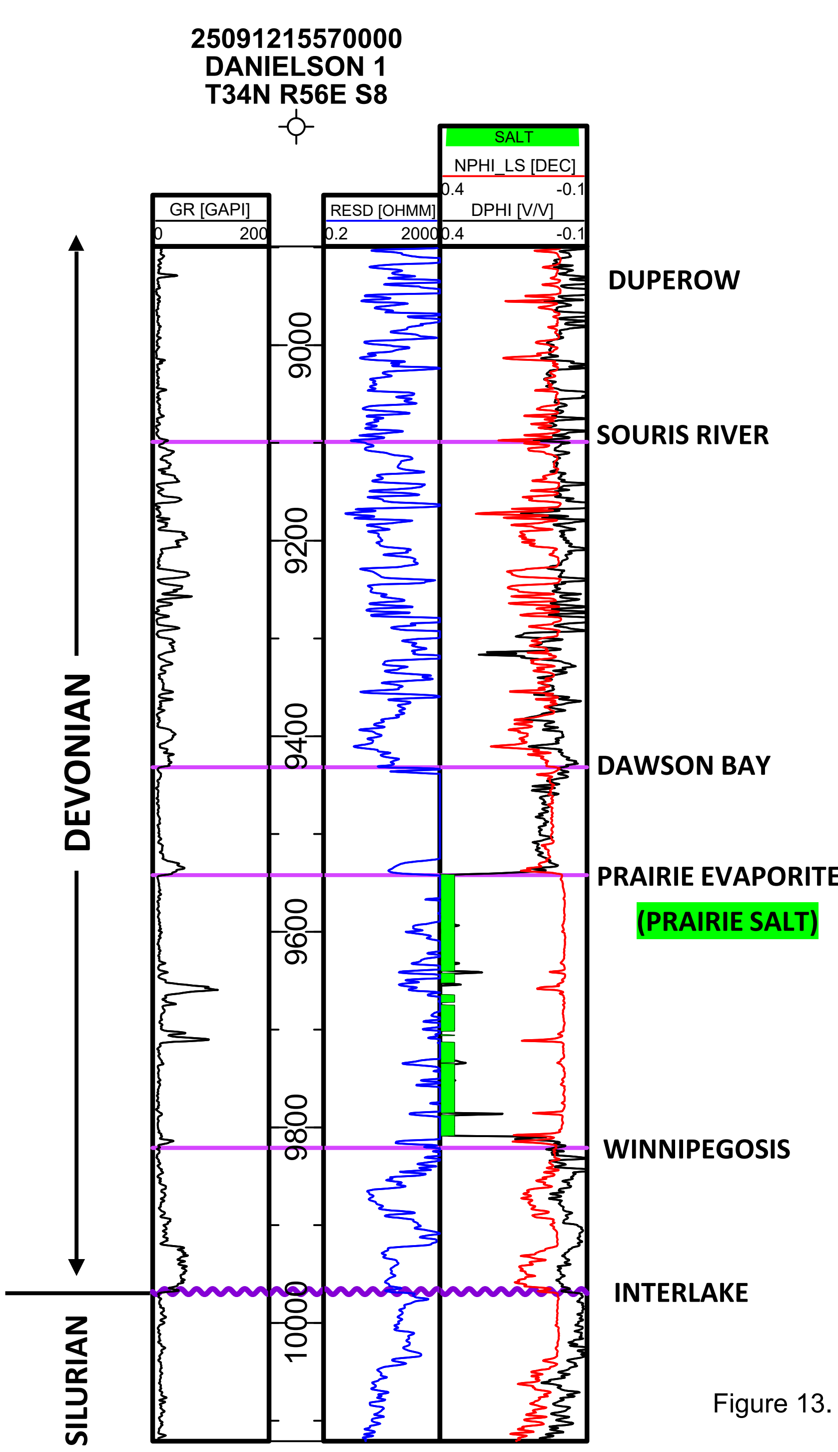

Figure 13. Type log showing Middle Devonian formation tops correlated in this study.

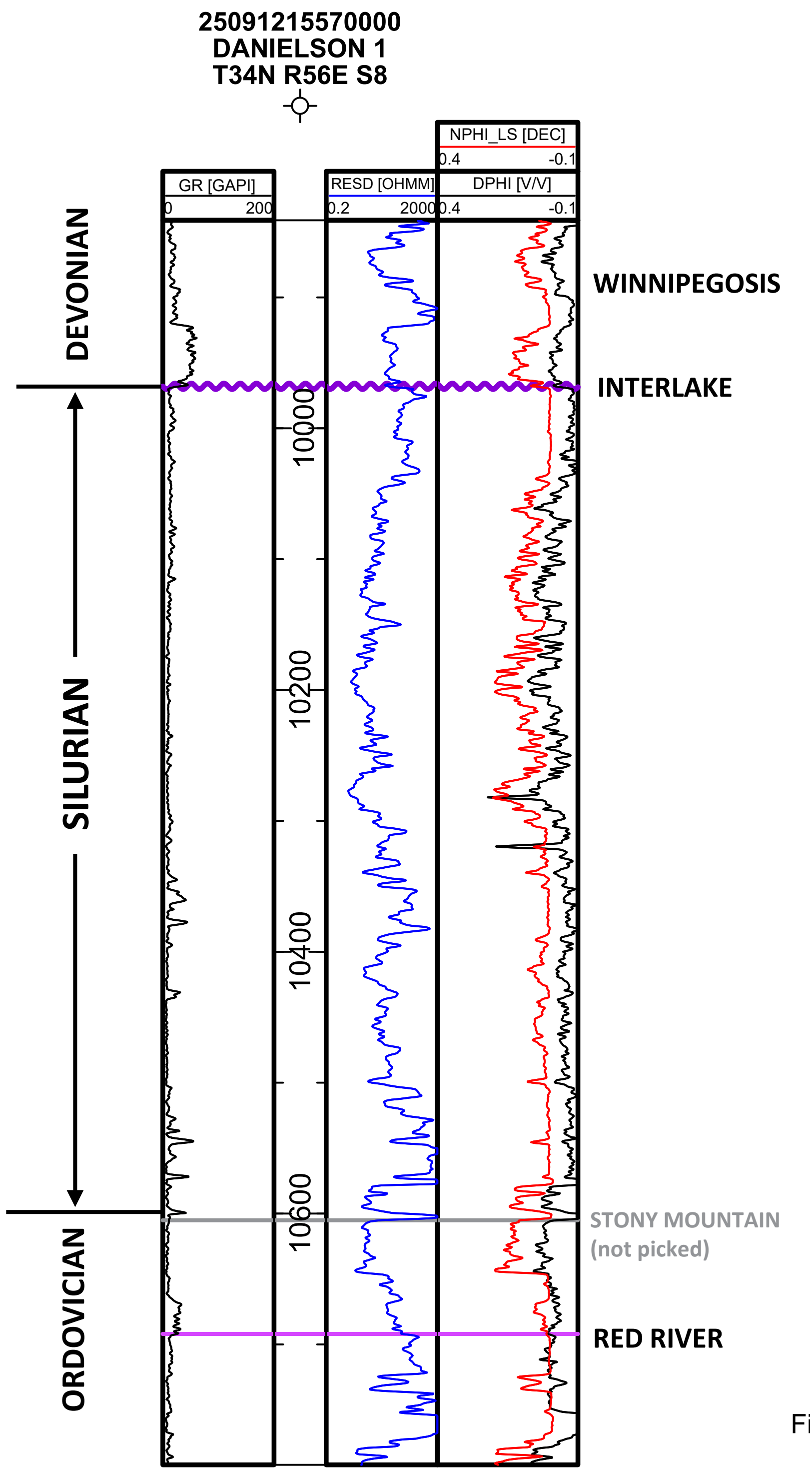

Figure 14. Type log showing Silurian formation tops correlated in this study.

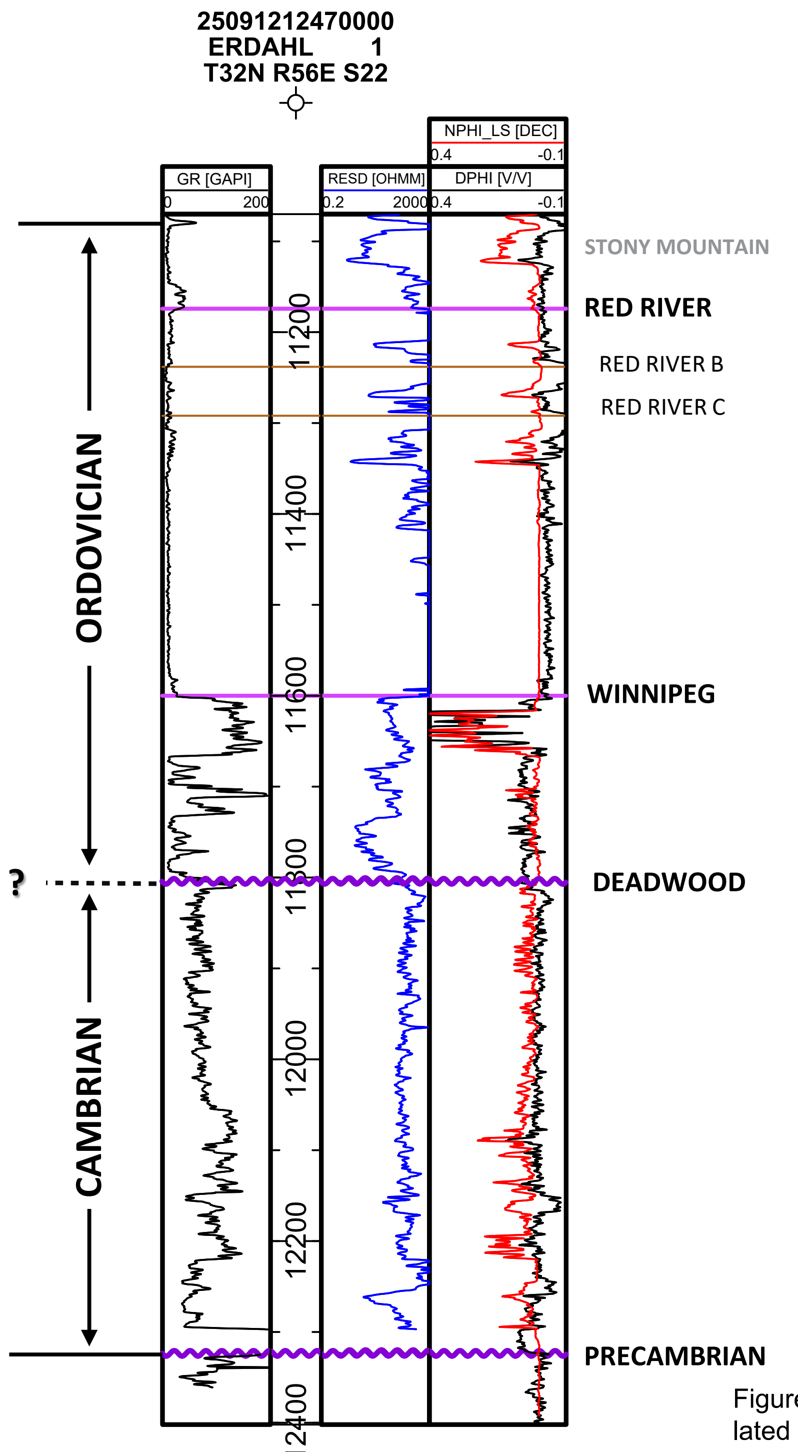

Figure 15. Type log showing Ordovician, Cambrian, and Precambrian formation tops correlated in this study.

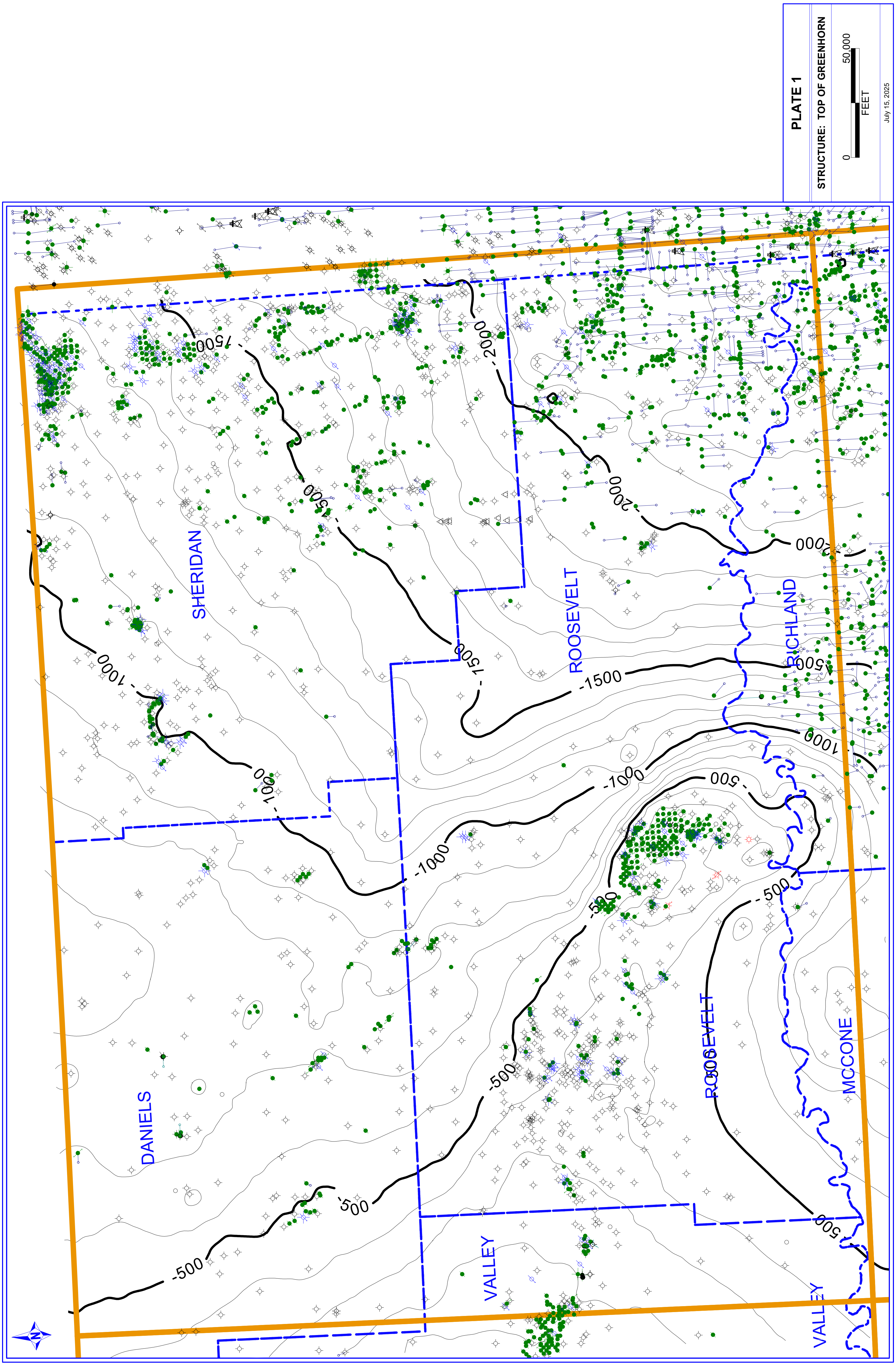

PLATE 1
STRUCTURE: TOP OF GREENHORN
0
50,000
FEET
July 15, 2025
SHERIDAN
ROOSEVELT
RICHLAND
DANIELS
VALLEY
MCCONE
-500
-1000
-1500
-2000

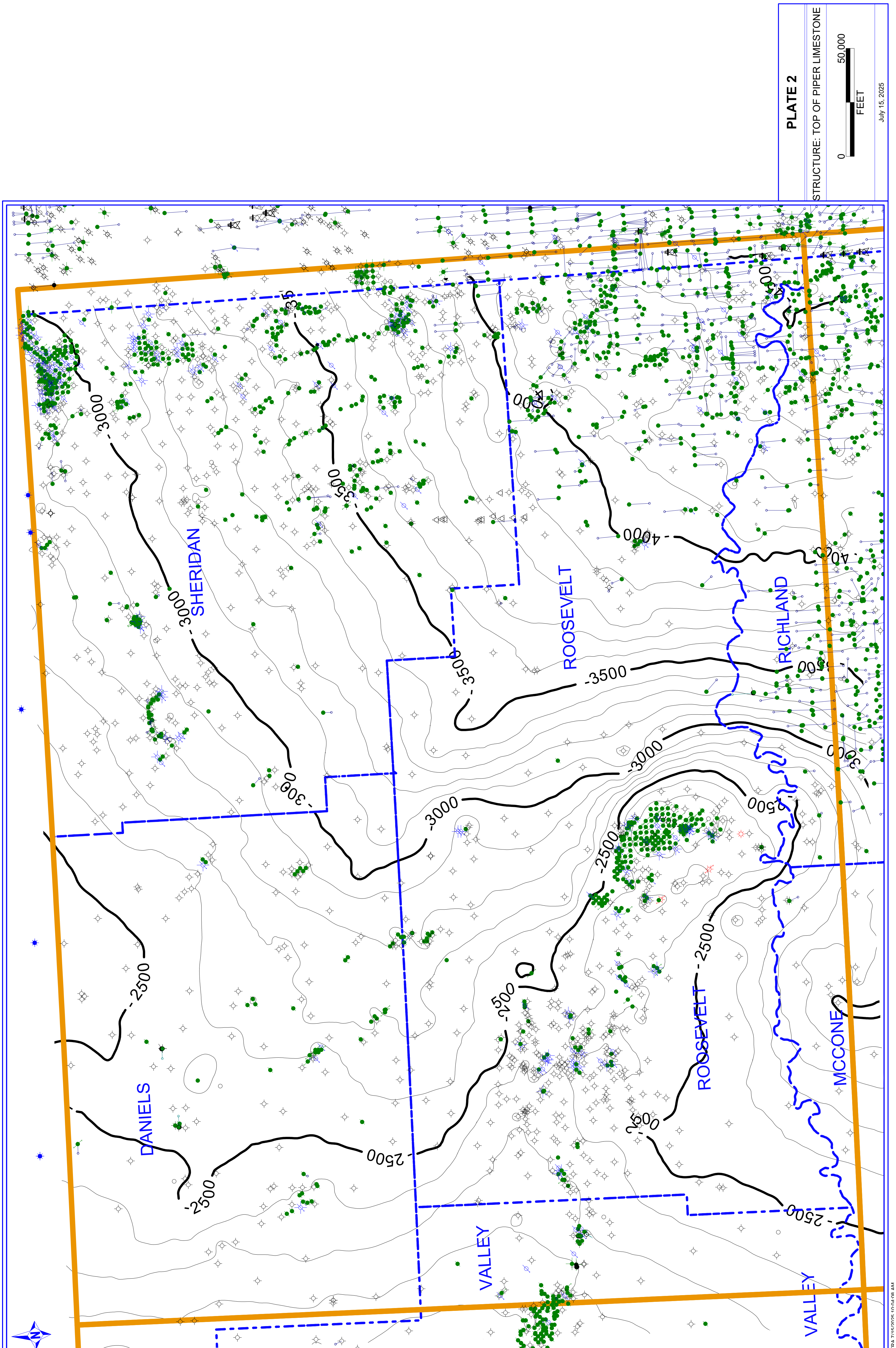
PLATE 2
STRUCTURE: TOP OF PIPER LIMESTONE
0
50,000
FEET
July 15, 2025
SHERIDAN
ROOSEVELT
RICHLAND
DANIELS
VALLEY
MCCONE
-3000
-3500
-4000
-2500

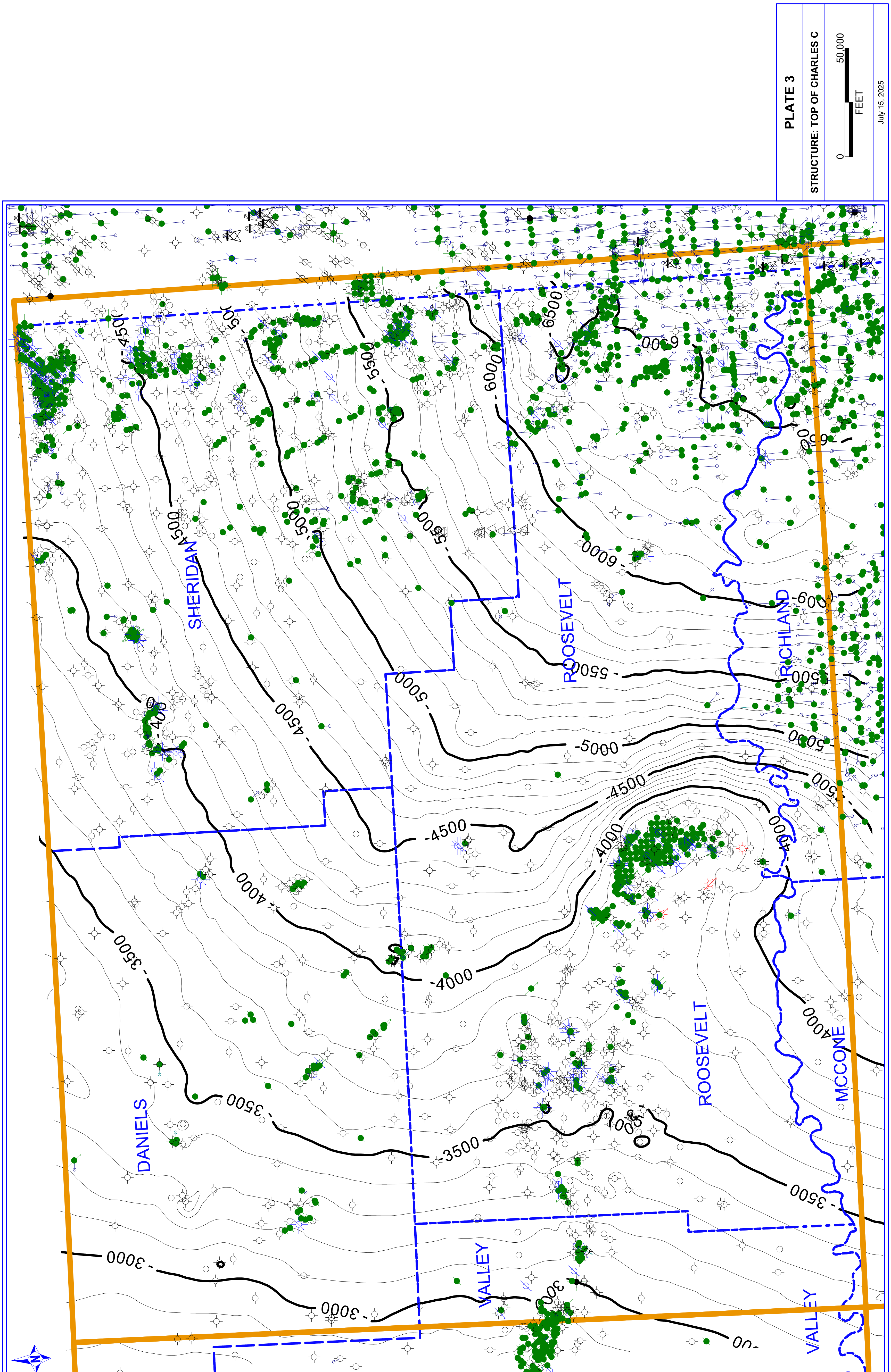
PLATE 3
STRUCTURE: TOP OF CHARLES C
0
50,000
FEET
July 15, 2025
SHERIDAN
ROOSEVELT
RICHLAND
DANIELS
VALLEY
MCCONE
-3000
-3500
-4000
-4500
-5000
-5500
-6000
-6500

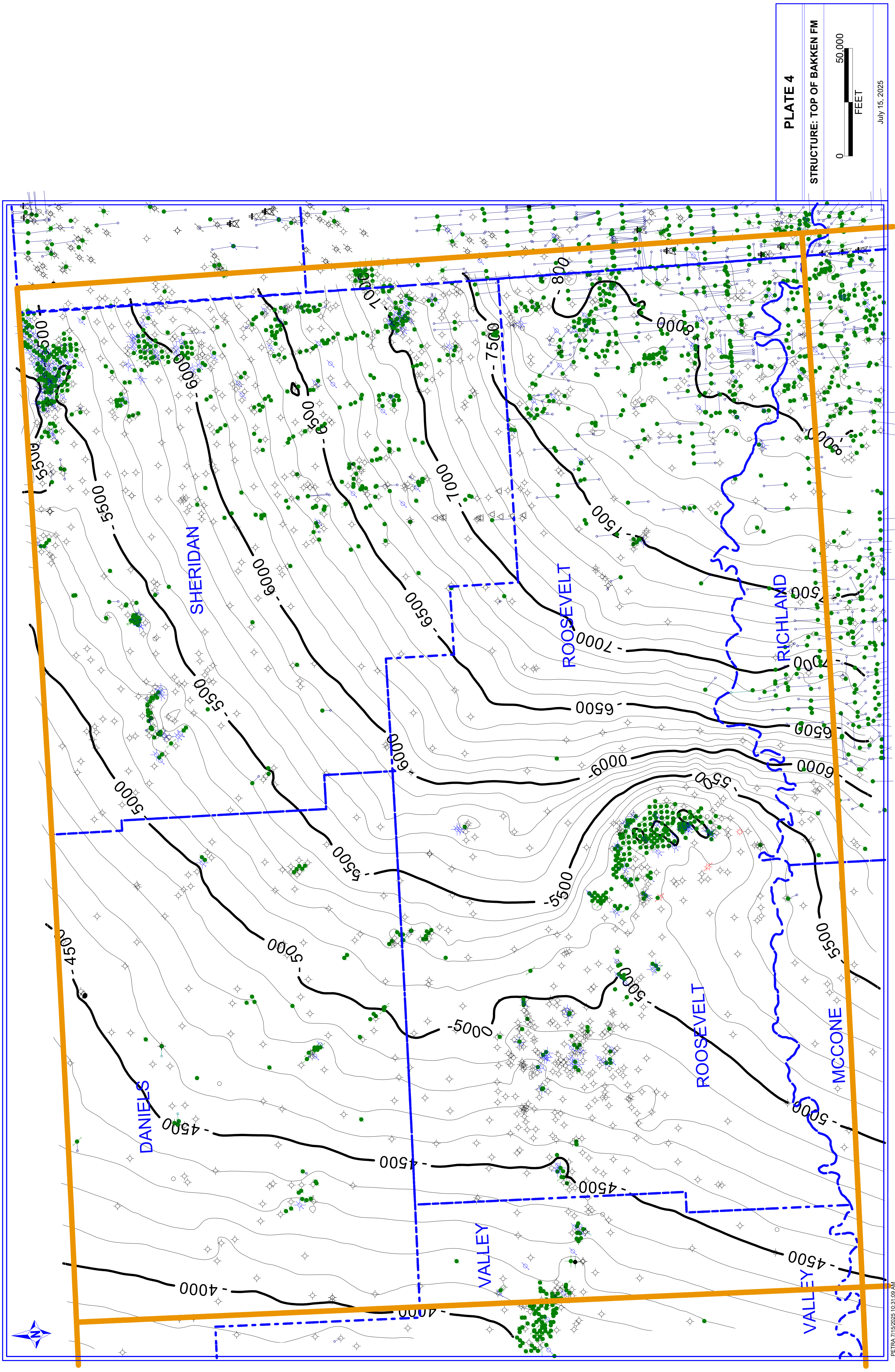
PLATE 4
STRUCTURE: TOP OF BAKKEN FM
0
50,000
FEET
July 15, 2025
SHERIDAN
ROOSEVELT
RICHLAND
DANIELS
VALLEY
ROOSEVELT
MCCONE
VALLEY
4000
4500
5000
5500
6000
6500
7000
7500
8000

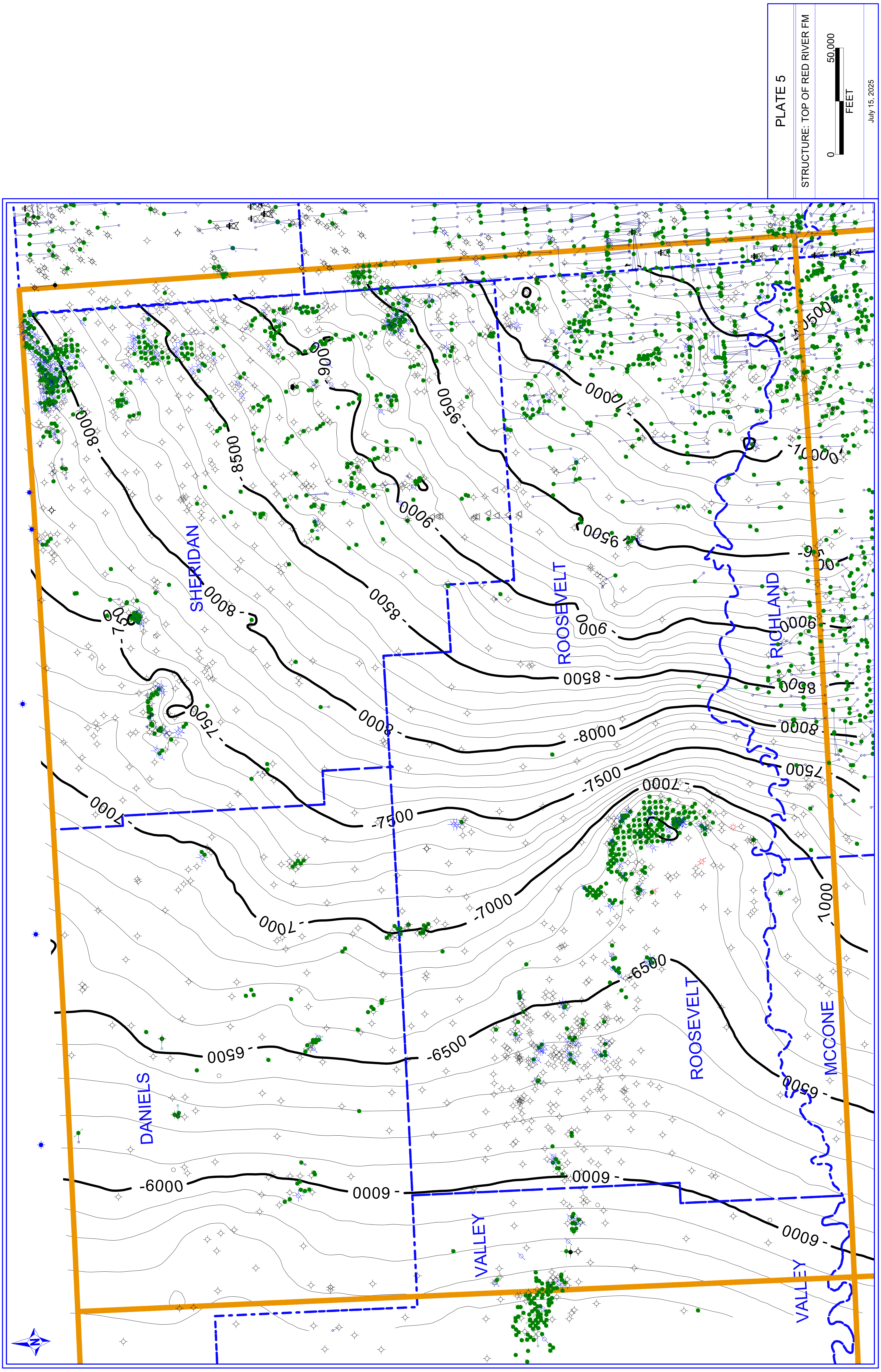
PLATE 5
STRUCTURE: TOP OF RED RIVER FM
0
50,000
FEET
July 15, 2025
SHERIDAN
ROOSEVELT
RICHLAND
DANIELS
VALLEY
MCCONE
-6000
-6500
-7000
-7500
-8000
-8500
-9000
-9500
-10000

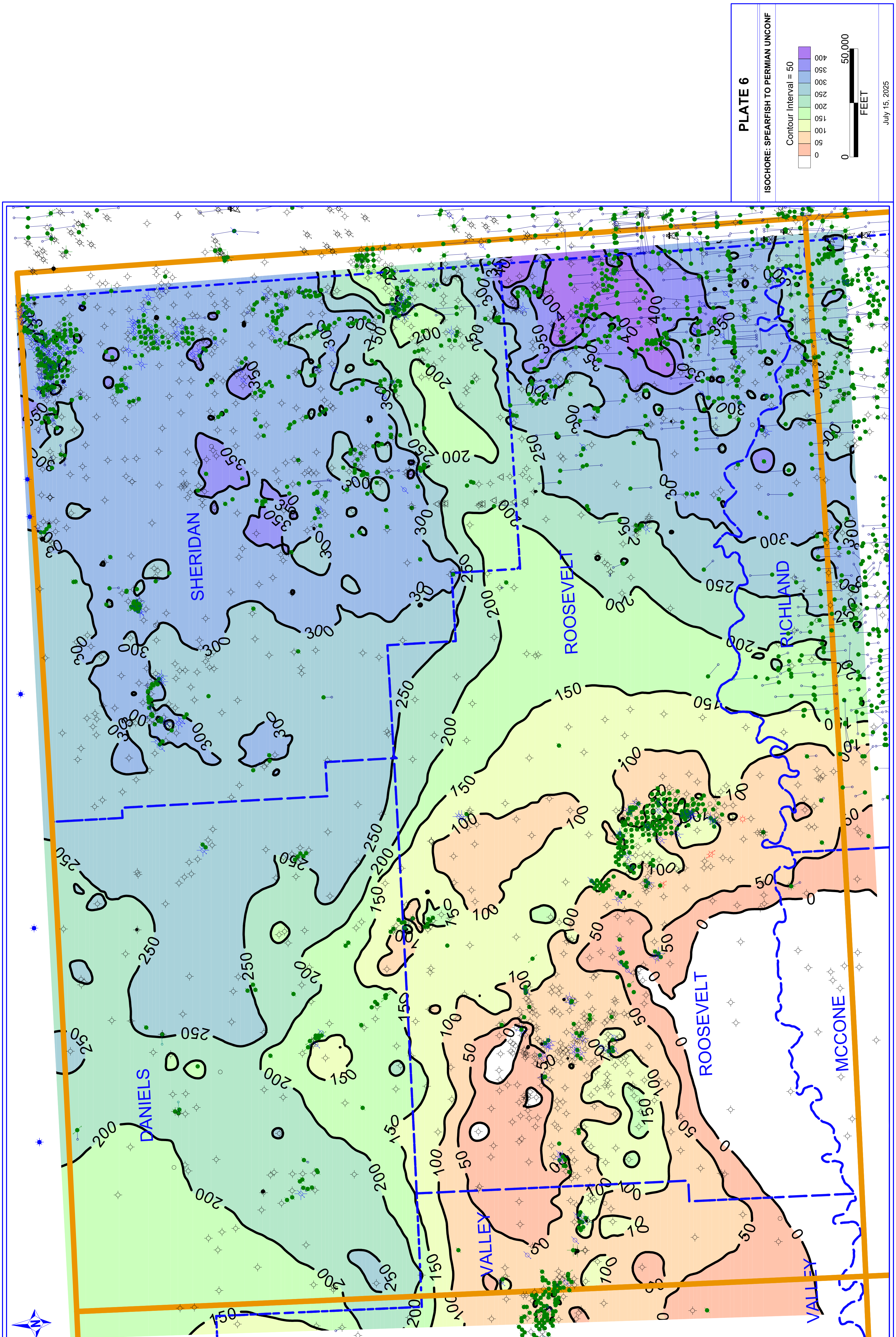
PLATE 6
ISOCHORE: SPEARFISH TO PERMIAN UNCONF
Contour Interval = 50
0
50
100
150
200
250
300
350
400
0
50,000
FEET
July 15, 2025
SHERIDAN
ROOSEVELT
RICHLAND
DANIELS
VALLEY
MCCONE

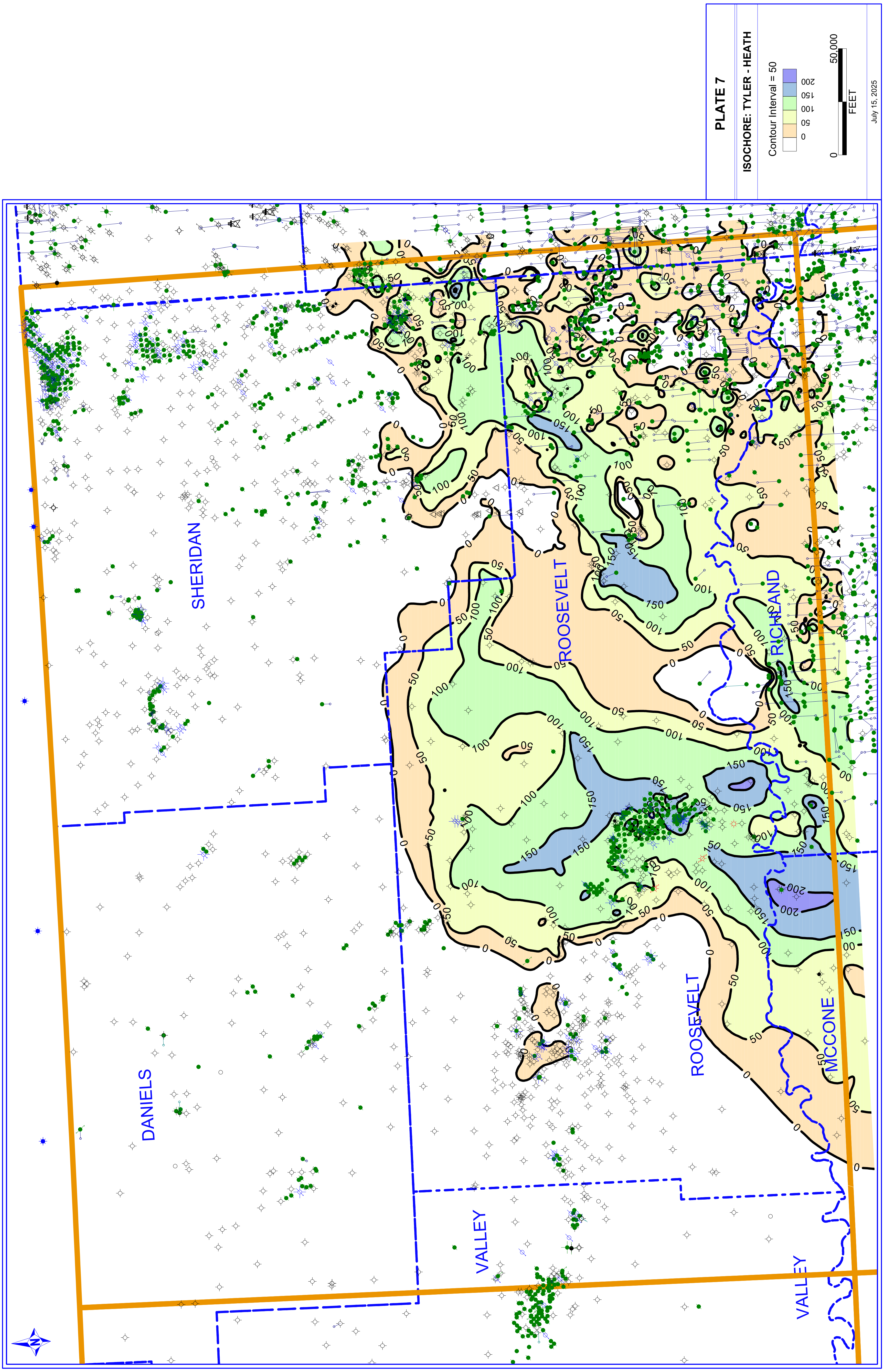
PLATE 7
ISOCHORE: TYLER - HEATH
Contour Interval = 50
0
50
100
150
200
0
50,000
FEET
July 15, 2025
SHERIDAN
DANIELS
ROOSEVELT
RICHLAND
VALLEY
MCCONE
ROOSEVELT
VALLEY

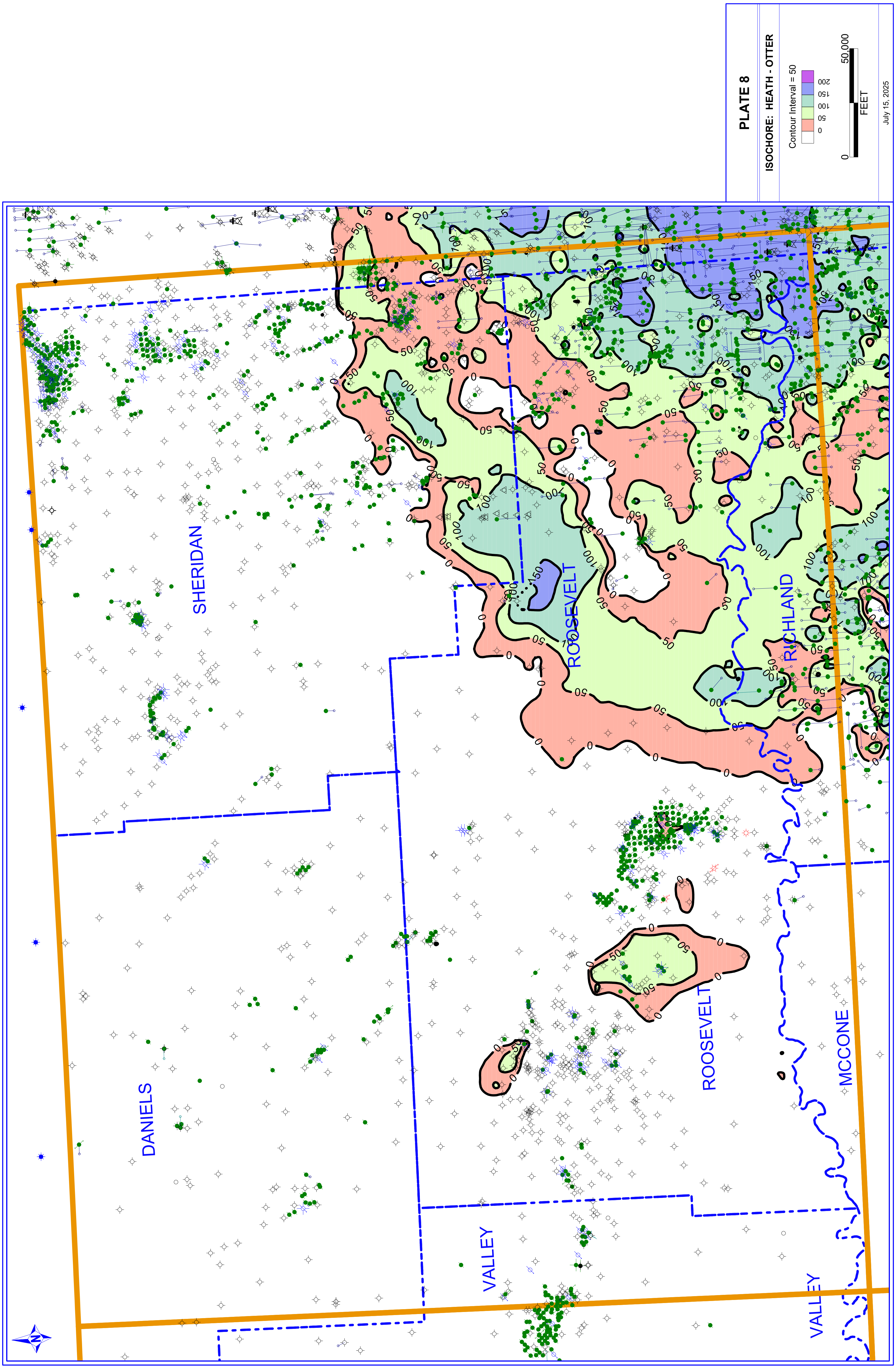
PLATE 8
ISOCHORE: HEATH - OTTER
Contour Interval = 50
0
50
100
150
200
0
50,000
FEET
July 15, 2025
SHERIDAN
DANIELS
ROOSEVELT
ROOSEVELT
RICHLAND
VALLEY
VALLEY
MCCONE

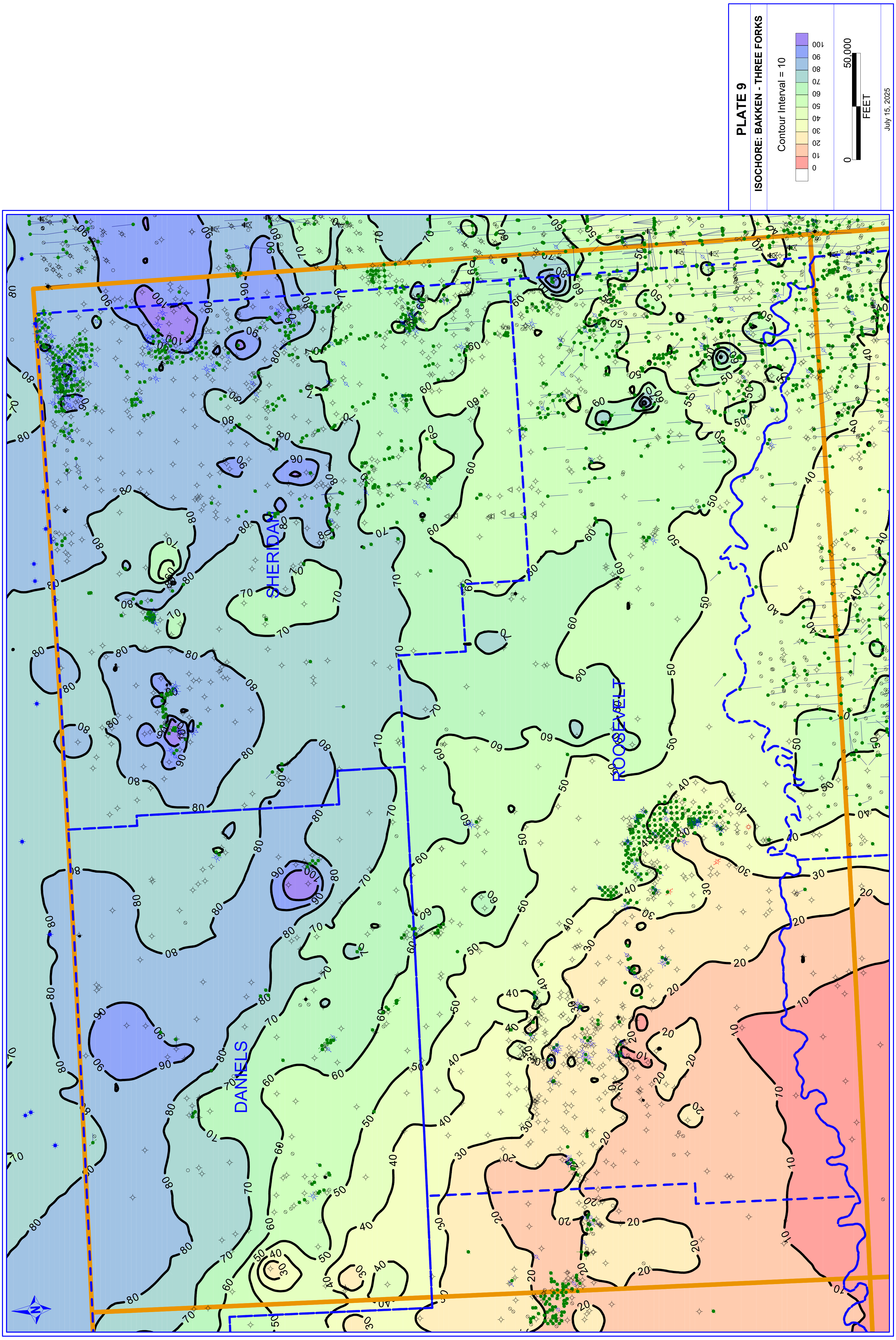
PLATE 9
ISOCHORE: BAKKEN - THREE FORKS
Contour Interval = 10
0
10
20
30
40
50
60
70
80
90
100
0
50,000
FEET
July 15, 2025
SHERIDAN
ROOSEVELT
DANIELS

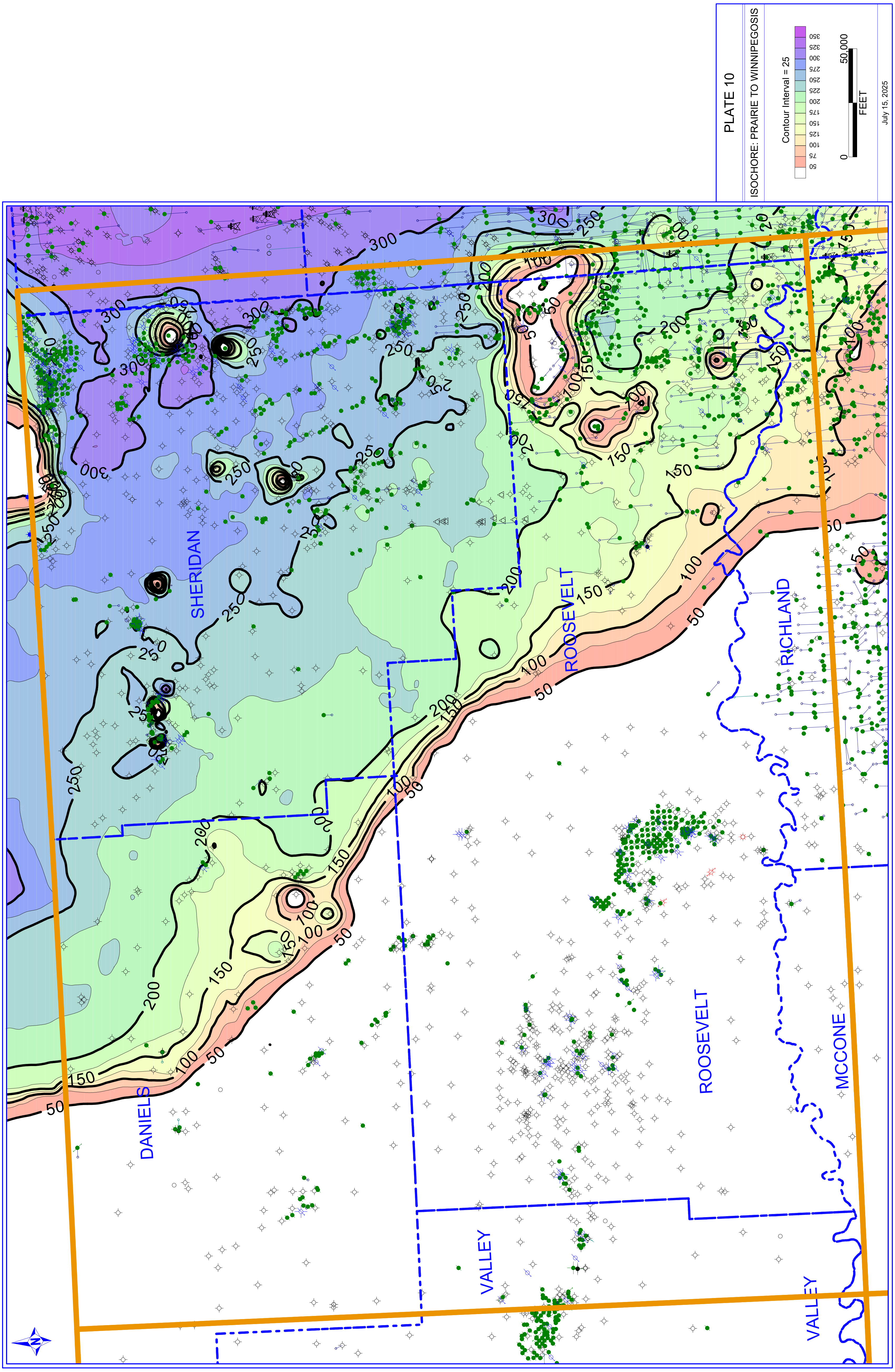
PLATE 10
ISOCHORE: PRAIRIE TO WINNIPEGOSIS
Contour Interval = 25
50
75
100
125
150
175
200
225
250
275
300
325
350
0
50,000
FEET
July 15, 2025
SHERIDAN
ROOSEVELT
RICHLAND
DANIELS
VALLEY
MCCONE

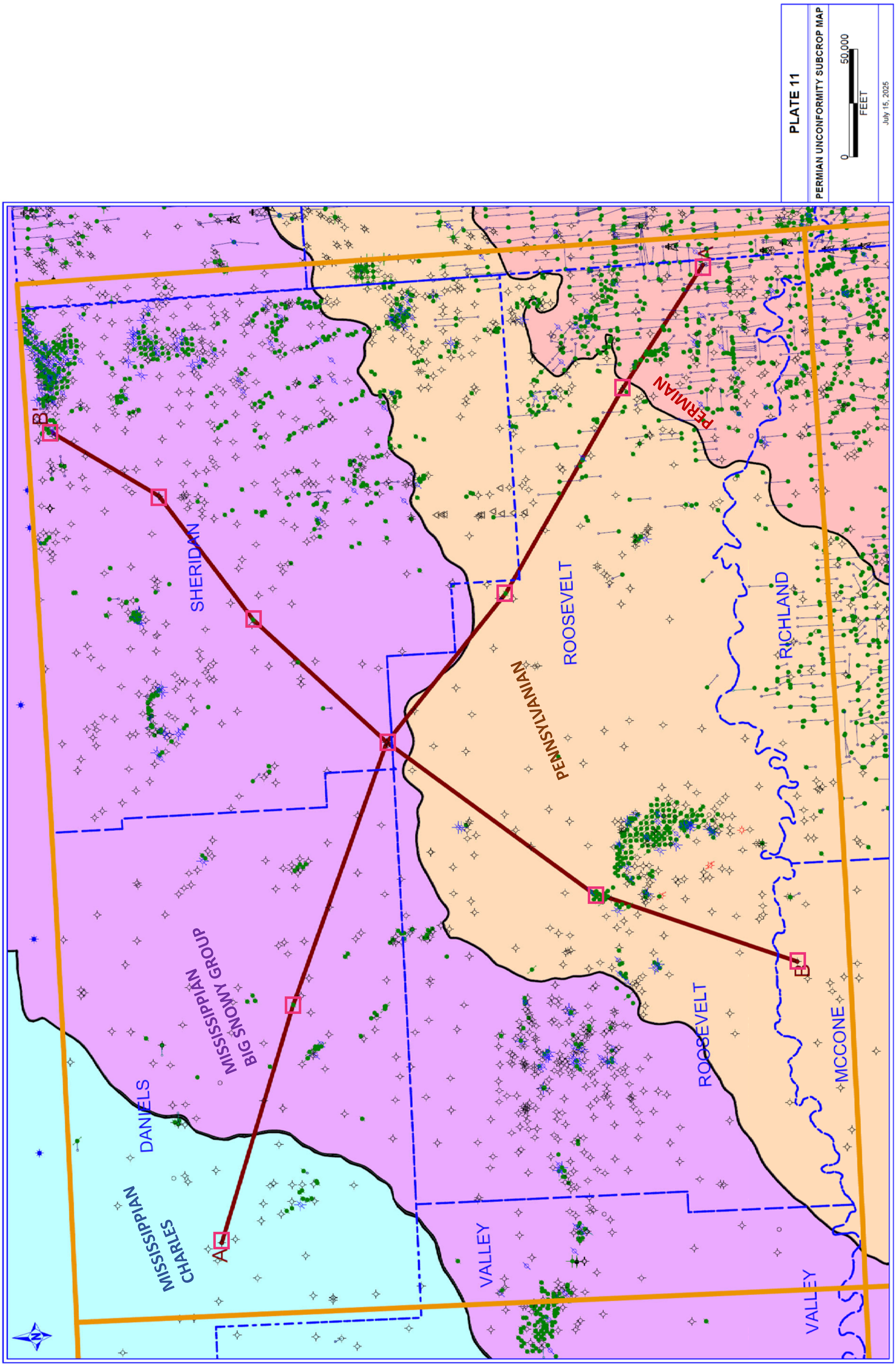
PLATE 11
PERMIAN UNCONFORMITY SUBCROP MAP
0
50,000
FEET
July 15, 2025
PERMIAN
PENNSYLVANIAN
MISSISSIPPIAN
BIG SNOWY GROUP
MISSISSIPPIAN
CHARLES
SHERIDAN
ROOSEVELT
ROOSEVELT
RICHLAND
DANIELS
VALLEY
VALLEY
MCCONE
A
A'
B
B'

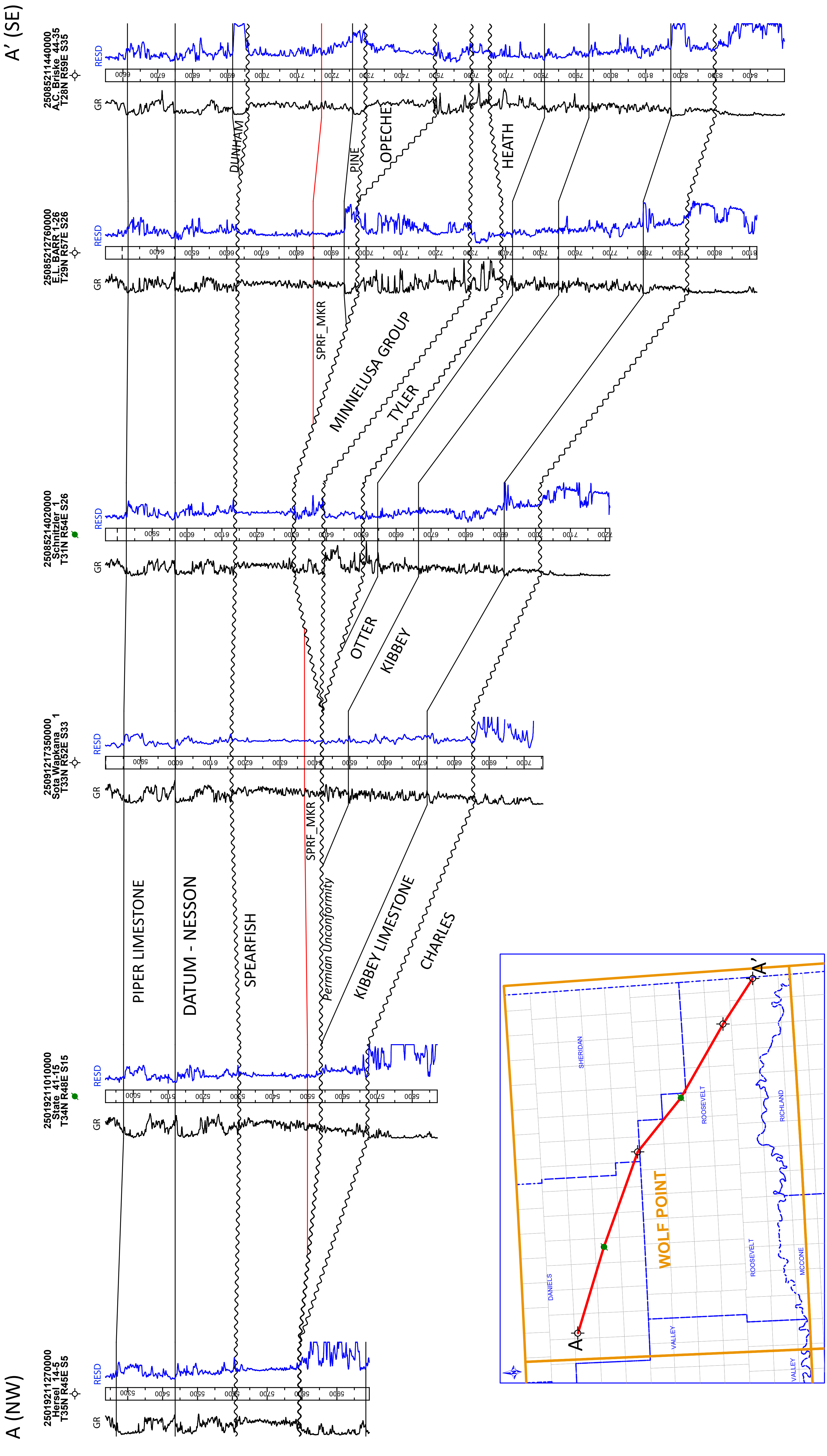

Plate 12. NW–SE cross-section depicting Mississippian to Jurassic stratigraphy and truncation of units beneath the Permian unconformity toward the northwest.

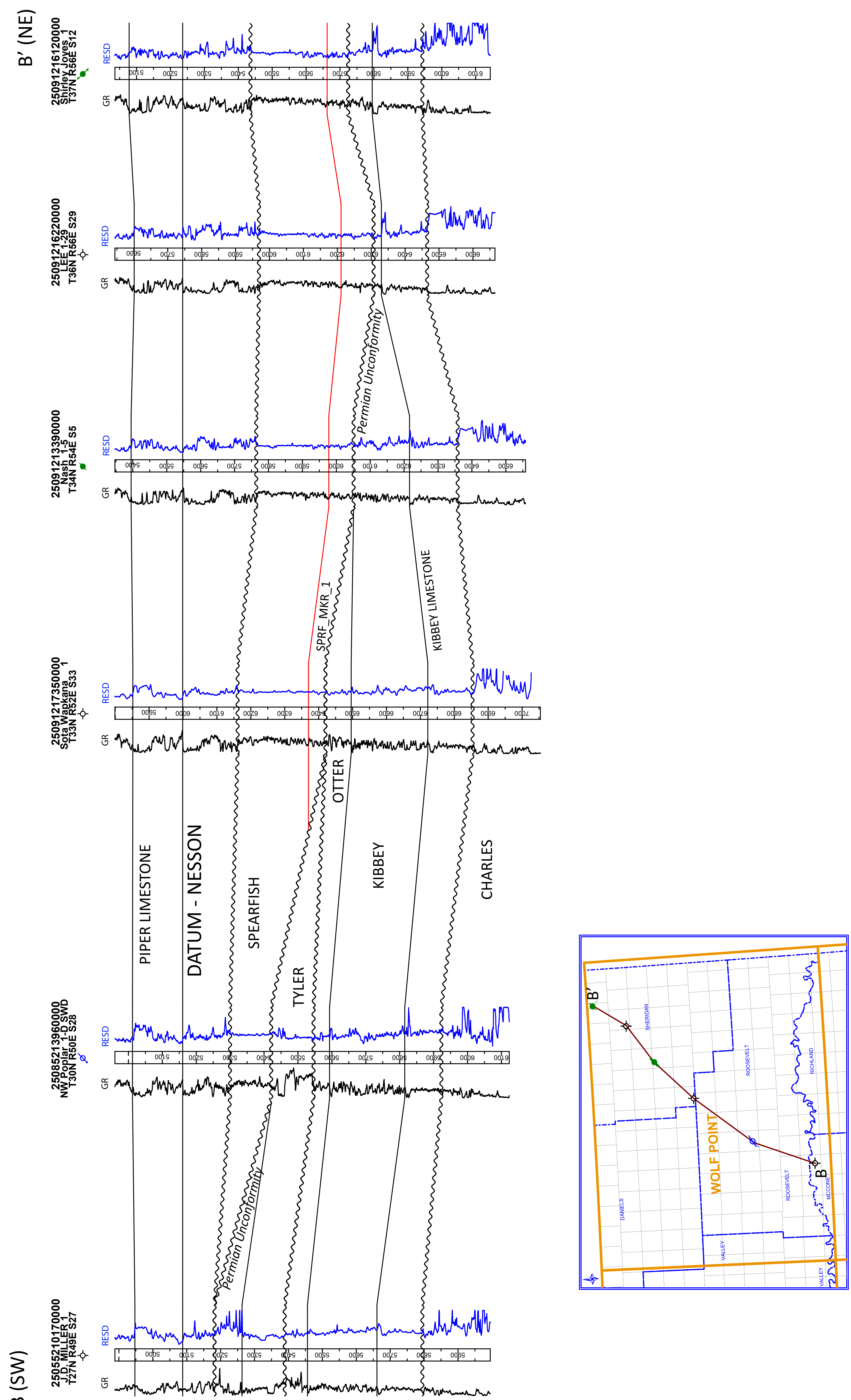

Plate 13. SW–NE cross-section depicting Mississippian to Jurassic stratigraphy and several regional unconformities.