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

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Montana Bureau of Mines and Geology

Cover photo: Hell Creek and Fort Union Formations, Makoshika State Park near Glendive, Montana. Photo by Elizabeth Meredith, MBMG.

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TABLE OF CONTENTS

FIGURES

PLATES

PURPOSE

Subsurface geologic maps, generated from a high-quality set of formation tops, are critical for identifying targets for petroleum exploration, CO_2 sequestration, wastewater disposal, geothermal exploration, groundwater aquifers, lithium, and non-hydrocarbon gases. They are also important for understanding the depositional and tectonic histories of Montana and the North American continent through time.

While subsurface formation tops are available from the Montana Board of Oil and Gas (MBOG) and other data vendors, they are predominately derived from well completion reports and are inconsistently picked and use inconsistent nomenclature. The user must spend considerable time and effort editing these data before conducting detailed analyses.

The Montana Bureau of Mines and Geology (MBMG) is systematically building a subsurface formation top database from well log data on a 1:250,000-scale quadrangle-by-quadrangle basis. Using these tops, selected structure and isochore maps were generated to demonstrate that our database provides a consistent set of formation top picks that allows users to more quickly advance to the interpretation phase of subsurface geological projects.

INTRODUCTION

The Glendive 1° x 2° (1:250,000) quadrangle is situated on the western margin of the Williston Basin, a large intracratonic basin located in western North Dakota and extending into portions of Montana, South Dakota, Saskatchewan, and Manitoba (fig. 1).

The Tertiary Fort Union Formation (Fm) crops out over most of the Glendive quadrangle except in the southern and northwestern portions, where Late Cretaceous rocks are exposed along two prominent structural trends (fig. 2; Vuke and others, 2007). The Cedar Creek anticline occurs in the southern portion of the quadrangle and the southwest–northeast-trending Brockton–Froid Fault Zone is located in the northwestern part of the quadrangle.

Subsurface geologic units found within the Glendive quadrangle range from Precambrian to Tertiary in age and consist primarily of cyclic marine sediments 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). Along the southwestern flank of the basin, recurrent movement of faults associated with the Cedar Creek anticline continued until the middle Tertiary (Clement, 1986).

More than 50 oil fields have been discovered within the Glendive quadrangle (MBOG, 2023). The major oil-producing zones range in age from Ordovician to Mississippian. Other than the unconventional oil production from the Devonian Bakken Fm at Elm Coulee and Elm Coulee Northeast fields, the primary targets for conventional oil accumulations are the Ordovician Red River Fm, Devonian Nisku and Winnipegosis Fms, and the Mississippian Madison Group.

The Elm Coulee field is the largest oil field within the quadrangle. It has a cumulative production of about 218 million barrels of oil from the Bakken–Three Forks interval, with more than 1,200 wells producing as of November 2025 (MBOG, 2025). Commercial natural gas production from shallow Late Cretaceous reservoirs has not been established within the Glendive quadrangle.

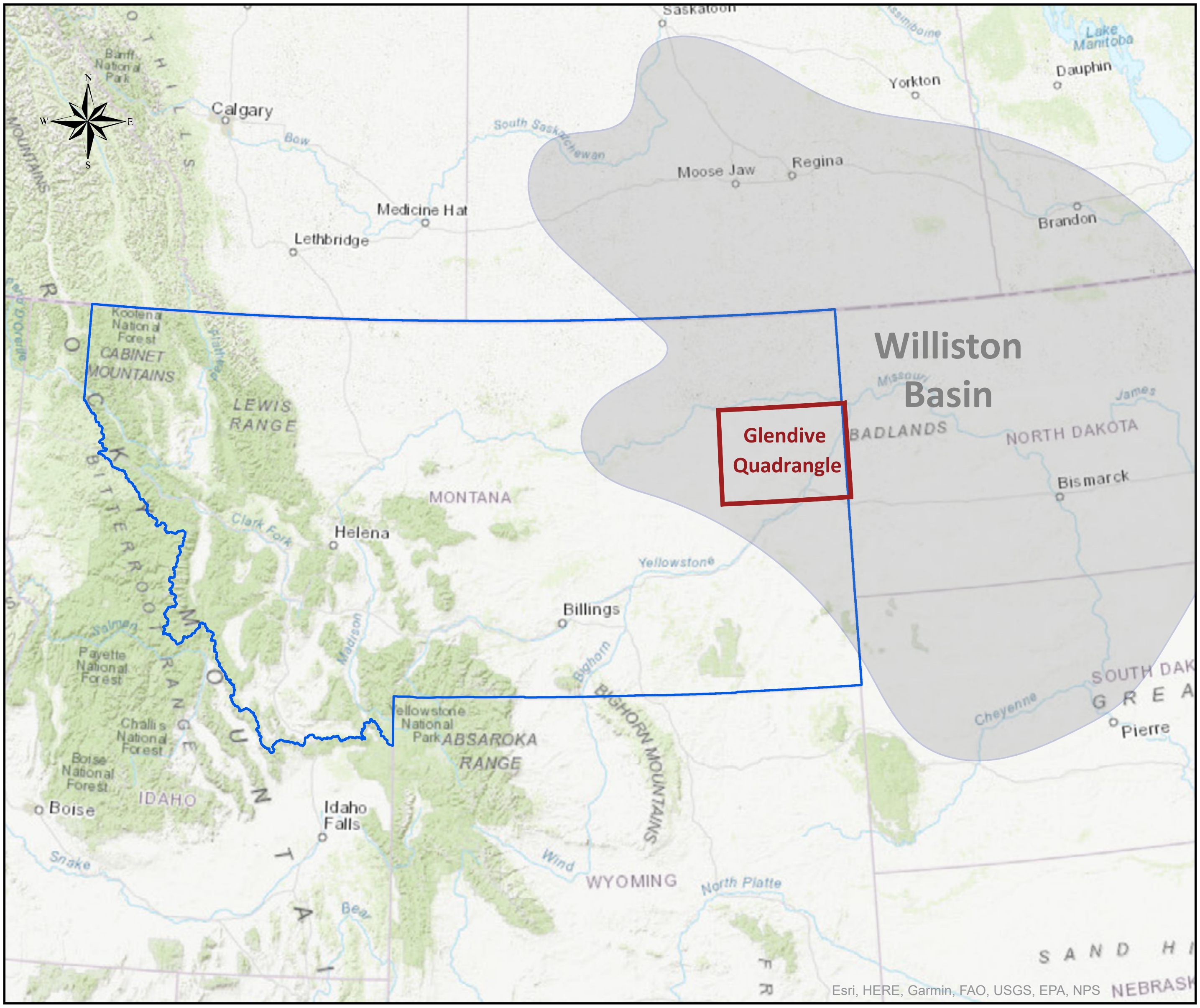

Figure 1. Index map showing the location of the Glendive 1° x 2° quadrangle.

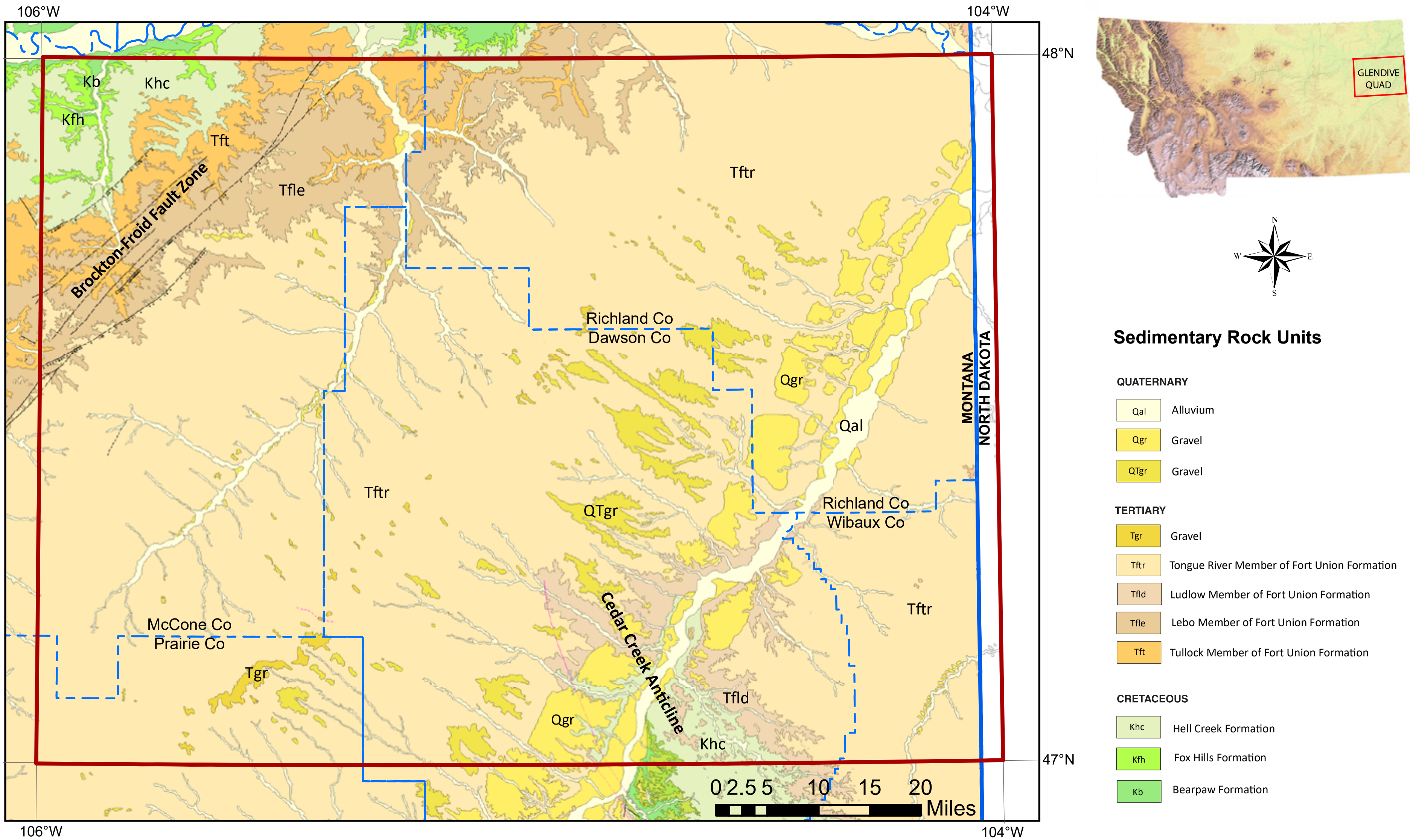

Figure 2. Surface geological map of the Glendive 1° x 2° quadrangle. Tertiary rocks are exposed at the surface, except along the larger drainages and prominent structural trends where underlying Upper Cretaceous strata crop out (modified from Vuke and others, 2007).

DATA AND METHODS

More than 3,000 petroleum exploration wells have been drilled within the Glendive quadrangle since 1900. Well header and location data were acquired from the MBOG. Raster image well logs were obtained from MJ Systems of Calgary, Alberta for 2,414 wells. Sample logs from the Northwest Geological Society (NWGS) were acquired from the Montana Geological Society (https://mtgeo.org/resources/nwgs-projects/). Formation tops reported by well operators were acquired from the MBOG. All data were loaded into S&P Global's PETRA software for interpretation. We have omitted some wells from the database, particularly in areas of high well density.

Stratigraphic picks were made by correlating geophysical log signatures on a well-by-well basis; all are lithostratigraphic correlations. Sample descriptions from the NWGS logs or MBOG well files were used where possible to correlate lithologic units to geophysical log signatures. Because we lack directional surveys in our database, formation tops from deviated and horizontal wells were identified using available true vertical depth (TVD) logs. If TVD logs were not available for the deviated portion of the well bore, formation tops were not picked.

The stratigraphic picks that constitute the database are listed in the stratigraphic column in figure 3. Most of our stratigraphic picks are actual formation tops, but we also include tops of some formation members and a few intraformational marker beds. For simplicity, we use *formation tops, formation picks,* or *stratigraphic picks* in this report as a general term that includes these data.

Structure and isochore maps (plates 1–14) were created for select formations to demonstrate the usefulness of these data. 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 were used to guide the gridding process to reflect our interpretations.

Type logs that document our stratigraphic picks are provided in figures 4 through 16. Explanations and a few additional comments are included for clarification of nomenclature, illustrations of stratigraphic picks on logs, and/or observations about formation thickness and extent.

The authors have strived for consistency in our formation tops database. However, we recognize that errors can occur for many reasons. We may periodically update these data with corrections and additions as warranted.

Cretaceous

Five stratigraphic horizons were picked within the Cretaceous section (fig. 4). They can be correlated across the entire Glendive quadrangle, and are generally consistent with the interpretation of other authors for this area (e.g., Rice, 1976; Condon, 2000; Gunderson and Furer, 2019).

Jurassic

Five tops of Jurassic age were selected as part of this database (fig. 5) and follow the correlations of Zieglar (1956), Nordquist (1955), and Carlson (1993). Jurassic strata are primarily composed of thick marine limestones, shales, and basal evaporite deposits (e.g., informal "Dunham salt") that unconformably overlie Triassic and older strata. Note that the Dunham salt is only observed in the eastern portion of the Glendive quadrangle. It can be very discontinuous due to post-depositional dissolution (LeFever and LeFever, 2005; Stolldorf, 2021).

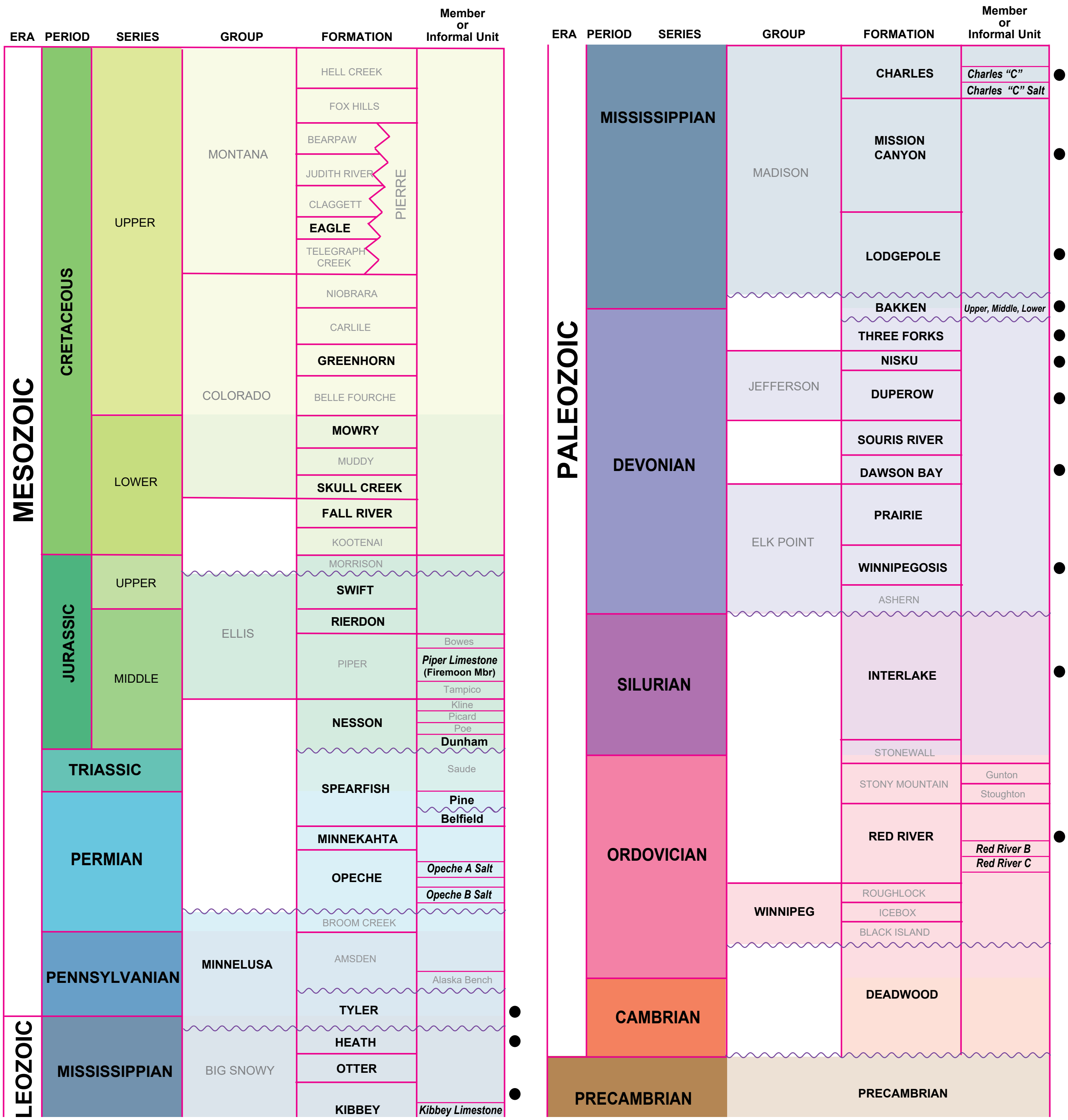

Figure 3. Stratigraphic column for the Glendive quadrangle (modified from Murphy and others, 2009). Stratigraphic tops stored in the database are in bolded black type, and include formal groups (e.g., Minnelusa, Winnipeg), formations, and formation members. Also included are several informal subunits. Common group and formation names that are grayed out were not included in the database, but are presented here for stratigraphic context. Black dots indicate major oil-producing zones within the quadrangle.

Permian–Triassic

A total of eight horizons within the Permian–Triassic interval are stored in the database. Stratigraphic names used here follow those used by the North Dakota Geological Survey (Murphy and others, 2009). The Spearfish Fm is of Triassic age above the top of the Pine Member (Mbr) and Permian age below (fig. 6; see also NDGS, 2025). Other items of note are:

- A Spearfish marker bed designated "SPRF_MKR_1" was picked to facilitate correlations within the Spearfish Fm.
- The Pine Mbr of the Spearfish Fm (informal "Pine salt") only occurs in the eastern portion of the Glendive quadrangle. Like the Jurassic-age Dunham salt, log correlations show that more than 50 ft of salt can disappear over distances of less than 0.5 mi (Stolldorf, 2022).
- The Permian Unconformity is picked at the base of the Pine salt. It progressively truncates younger to older strata to the west (fig. 7). We chose to use the name "Permian Unconformity" because the erosional surface occurs at the base of the Pine salt (when present), which is considered to be Permian age (Murphy and others, 2009; Carlson, 1993; LeFevre and LeFevre, 2005). This unconformity is not well documented in the literature, but Zieglar (1956, fig. 4, p. 174) also recognized the unconformity at the base of the Pine salt. The unconformity can be difficult to identify when the Pine salt is absent, but subtle changes in log character hint at its presence.
- Within the Glendive quadrangle, the Opeche Fm contains one salt bed designated Opeche A. While an additional salt termed Opeche B occurs just over the border in North Dakota, it was not observed in the project area (LeFever and LeFever, 2005; Chittick, 2024a,b). Both salts are discontinuous.

Pennsylvanian

Two stratigraphic picks of Pennsylvanian age are the Minnelusa Group and the Tyler Fm (fig. 8). Although we include the Minnelusa Group here as Pennsylvanian, the uppermost portion may, in fact, be Permian age (Murphy and others, 2009). We did not delineate the Amsden or Broom Creek Fms.

The Tyler Fm top is placed at the base of the lowermost thick limestone thought to belong to 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 Fms (fig. 9). We also include the "Kibbey limestone" top because it is a distinctive and useful stratigraphic marker and datum. Big Snowy Group strata are bounded by unconformities, making regional correlations difficult.

The top of the Heath Fm is an unconformity and consequently can be difficult to pick. Generally, Heath strata are characterized by a higher gamma ray and resistivity profile that contrasts with the lower, more sporadic gamma profile of overlying Tyler deposits. High gamma spikes within the Heath interval can be correlated over tens of miles or more. The more persistent high gamma spikes are designated marker beds Heath_Mkr_1, Heath_Mkr_2, and Heath_Mkr_3 in ascending order. The "hot" gamma ray Heath markers we picked correlate with those described by Bottjer and others (2020). The Heath Fm top is an unconformity, and when some or all of the Heath markers are absent, it is very likely that they were eroded and replaced by younger Tyler sediments (fig. 10).

The horizons within the Madison Group that were picked for inclusion in this database are illustrated in figures 11 and 12. Note that:

- The Charles C salt only occurs in the eastern portion of the project area.
- The Lower Lodgepole marker was picked in wells within the southern half of the quadrangle (fig. 12). This marker helps delineate the underlying Late Devonian–Early Mississippian Unconformity documented by Clement (1986).

- The Late Devonian–Early Mississippian Unconformity (abbreviated as “LDEM Unconf” for convenience) is picked at the abrupt change in log signatures. Limestones of the Lodgepole Fm lie above the LDEM Unconf, while Silurian or Devonian dolomites and shales are preserved beneath the unconformity (fig. 12). Density-Neutron logs aid greatly in making this distinction. In the southernmost portion of the quadrangle along the axis of the Cedar Creek anticline, the entire Devonian section has been eroded, leaving basal Lodgepole Fm lying on the Silurian Interlake Fm. Clement (1986) discussed this unconformity in detail.

Devonian

The 11 Devonian stratigraphic picks are shown in figures 13 and 14. All of the Devonian formations can be identified across the central and northern parts of the Glendive quadrangle. However, in the southern portion, the upper part of Devonian strata (Bakken, Three Forks, Nisku, and Duperow) are progressively truncated southward by the Late Devonian–Early Mississippian Unconformity (Clement, 1986).

The Bakken Fm is informally subdivided into lower, middle, and upper members, (LeFever and others, 2013). The upper and lower shales of the Bakken Fm have a very distinctive high gamma-ray response (fig. 13). The entire Bakken Fm pinches out to the south and is absent in the southern portion of the quadrangle.

In addition, our log correlations indicate southward depositional(?) thinning, and pinchout occurs within the Dawson Bay, Prairie, and Winnipegosis Fms.

The thick salt beds that characterize the Prairie Fm are only observed in the northeastern portion of the quadrangle. When salt beds are not present, the interval is generally 50 ft thick or less and is represented by shaley log profiles.

Silurian

The top of the Interlake Fm and an Interlake marker are the only Silurian picks stored in this database (fig. 15). The Interlake marker was picked in wells in the southern half of the Glendive quadrangle. In this area, the marker was useful in identifying the top of the Interlake Fm where truncation occurred.

Precambrian–Cambrian–Ordovician

Six stratigraphic picks from Precambrian through Ordovician age were included in the database and are illustrated in figure 16. Our terminology follows that of Murphy and others (2009).

Six wells within and immediately adjacent to the Glendive quadrangle penetrate Precambrian rocks. The Precambrian top picks in this database were taken from Gunderson (2024).

RESULTS

The primary product from this study is a high-quality database of formation top TVD depths for more than 2,000 petroleum exploration wells located in the Glendive quadrangle. The number of formations picked per well varies based on well depth and the depth range of available geophysical logs. As many as 50 formation picks were made for the deepest wells.

These data can be used to generate a myriad of geologic structure and isopach 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 the Greenhorn Fm, Piper limestone, Charles C (Ratcliffe) horizon, Bakken Fm, and Red River Fm (plates 1–5).

Five isochore maps were generated for specific intervals that have implications for petroleum exploration and/or depositional and tectonic history: namely, the top of the Spearfish Fm to the Permian Unconformity, the Permian Unconformity to the top of the Minnelusa Group, and the Tyler Fm, Heath Fm, and Bakken Fm (plates 6–10).

Plate 11 is a subcrop map of the Permian unconformity and shows the locations of three cross-sections. Plates 12 and 13 are cross-sections that show the truncation of Permian strata to the northwest beneath the Permian Unconformity. Truncation of the entire Devonian section to the southwest on the Cedar Creek Anticline is illustrated in plate 14.

Excel data files are provided for the structure and isochore grids illustrated by plates 1–10. Structure grids are in XYZ format, where X is longitude, Y is latitude, and Z is elevation of the top of the formation or horizon 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 (Glendive_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 use the formation tops data to accelerate geological research.

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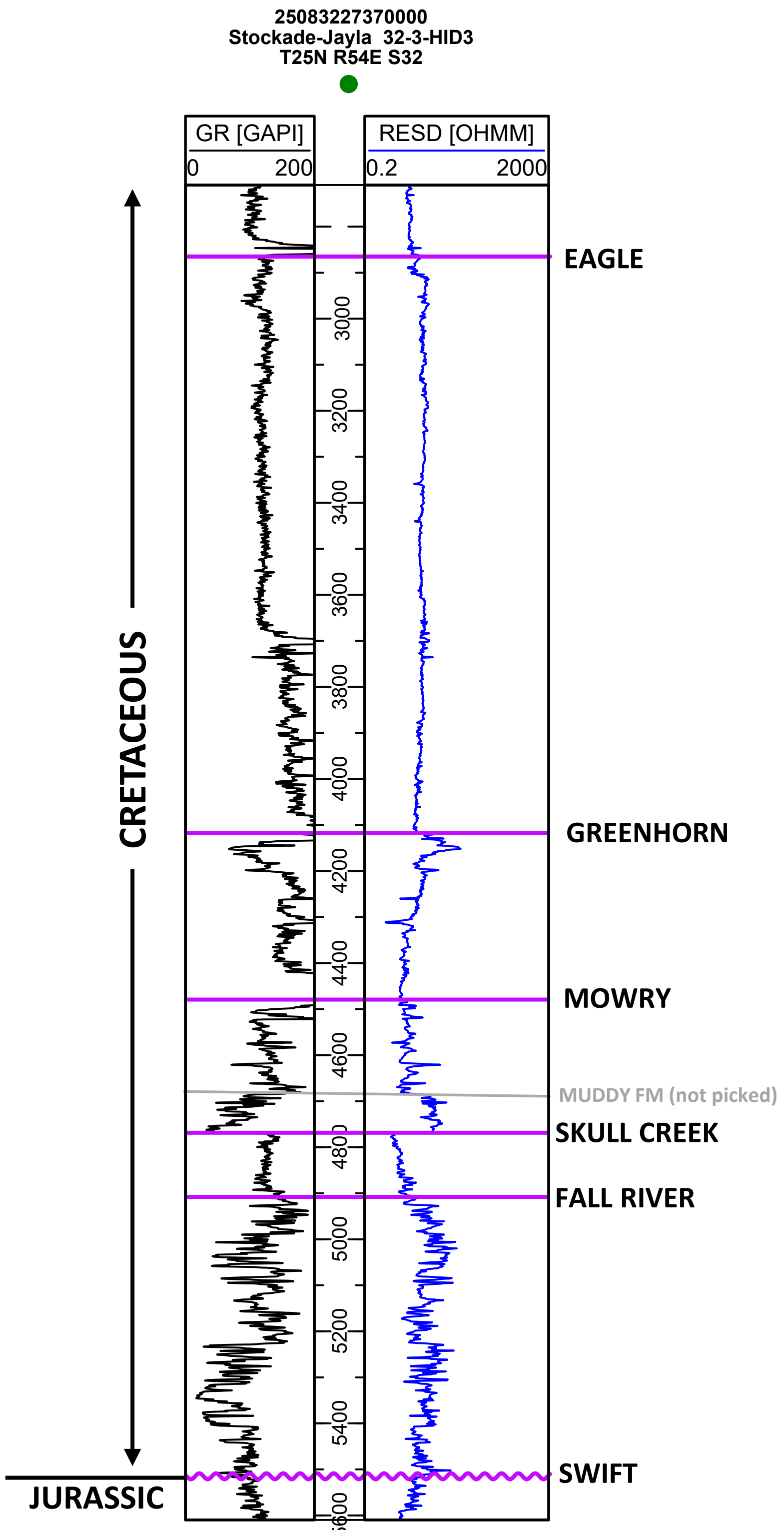

Figure 4. Type log illustrating the Cretaceous formation tops stored in the database.

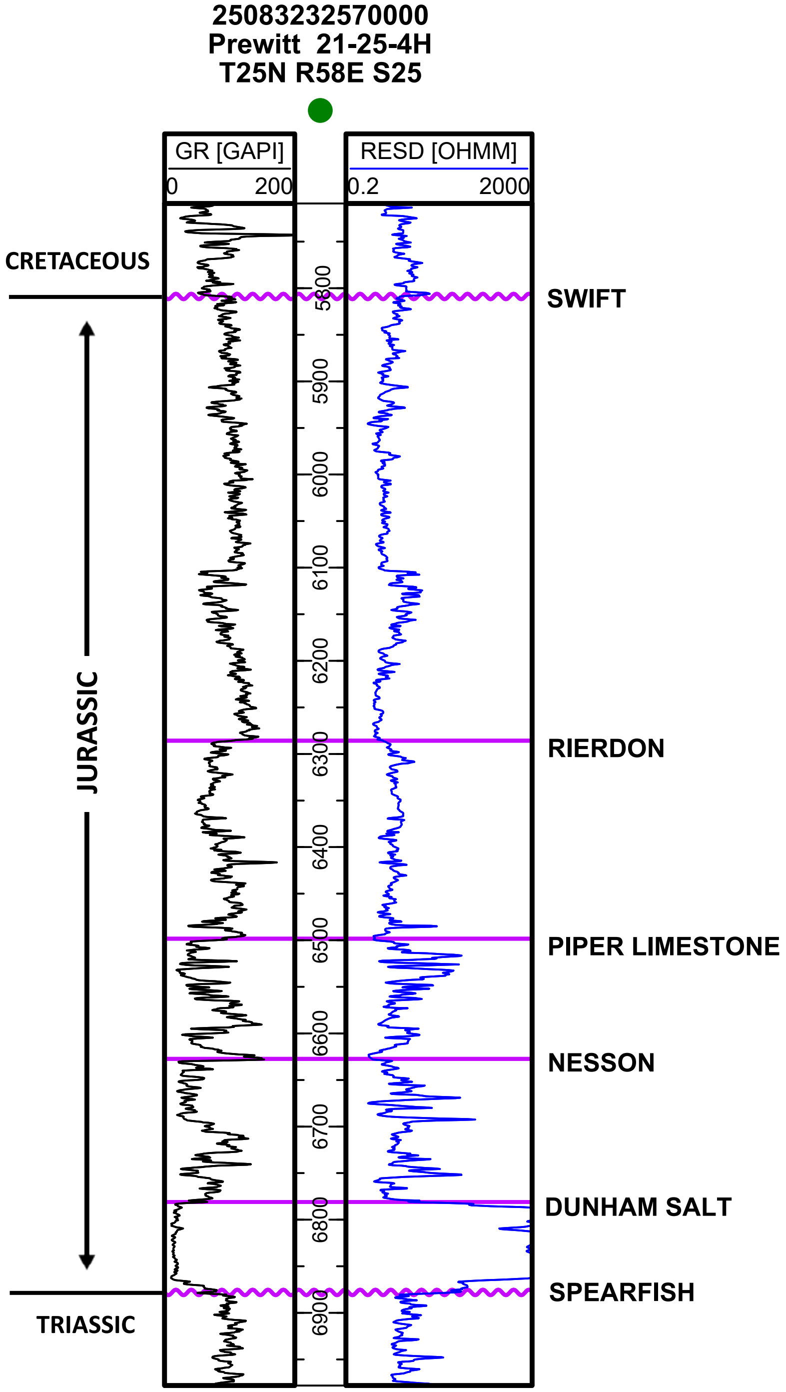

Figure 5. Type log showing Jurassic tops included in the database.

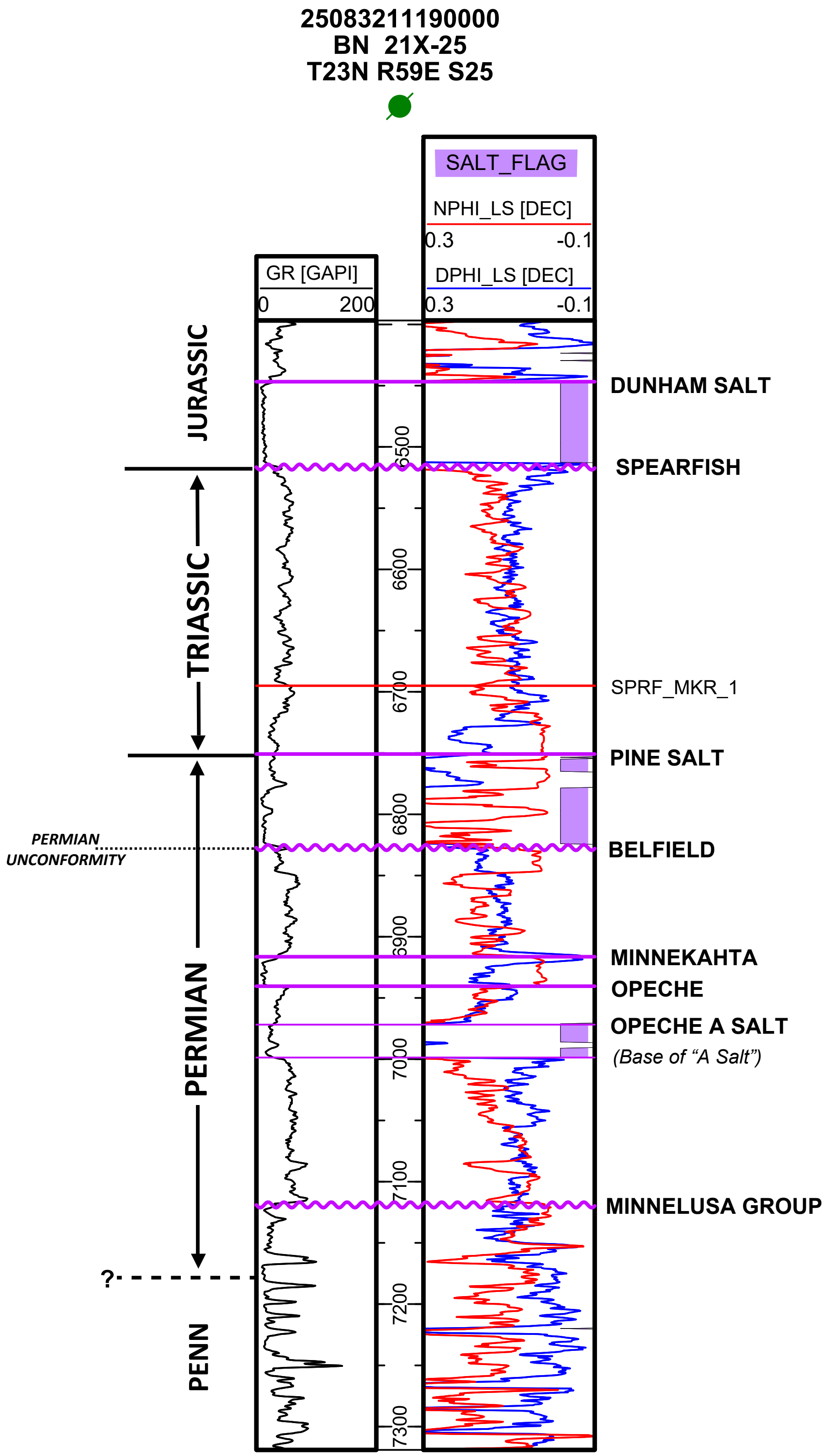

Figure 6. Type log highlighting stratigraphic picks within the Permian–Triassic interval. The salt intervals can be very discontinuous due to post-depositional dissolution.

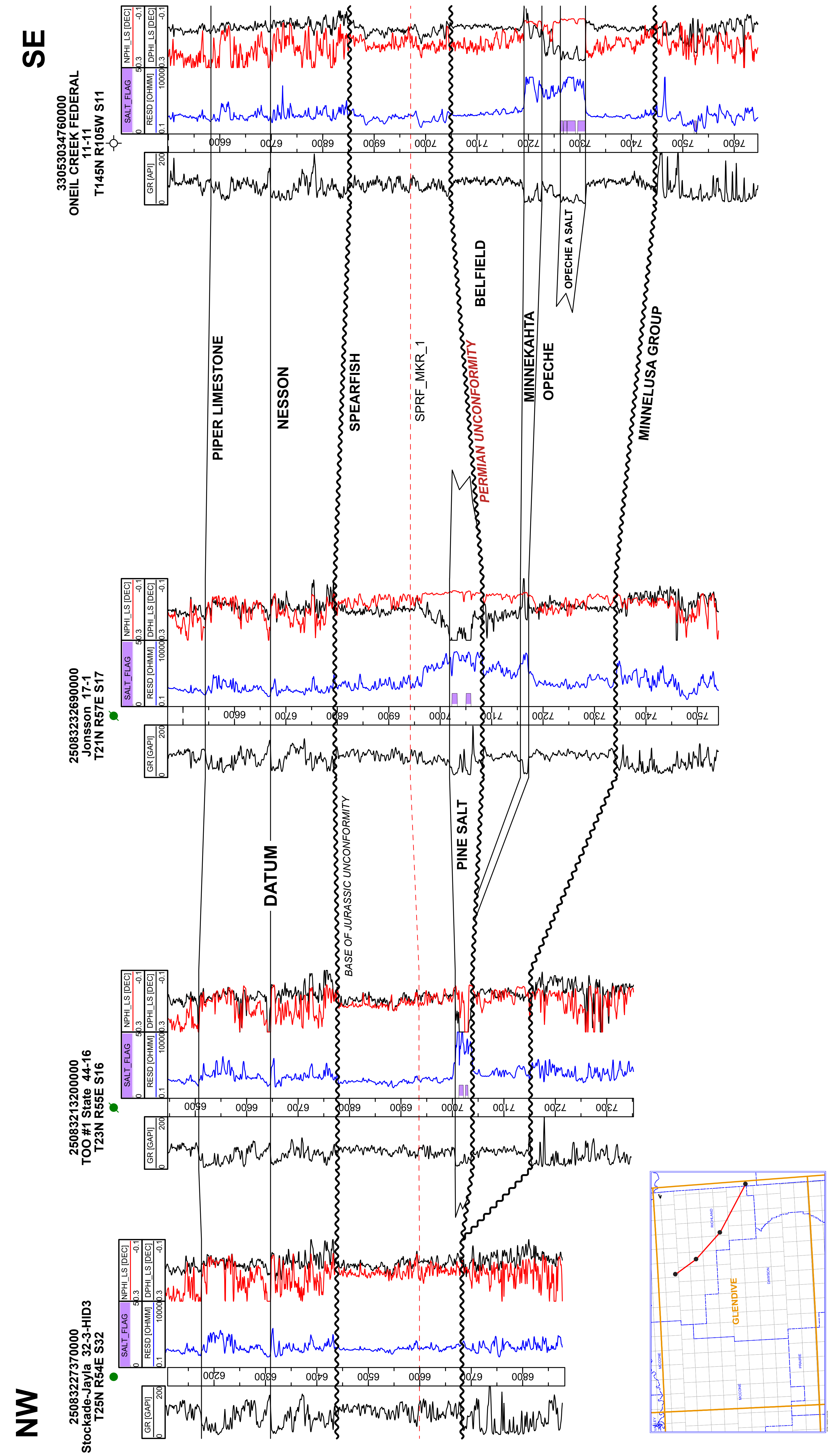

Figure 7. Stratigraphic cross-section illustrating the truncation of Permian strata beneath the Permian Unconformity.

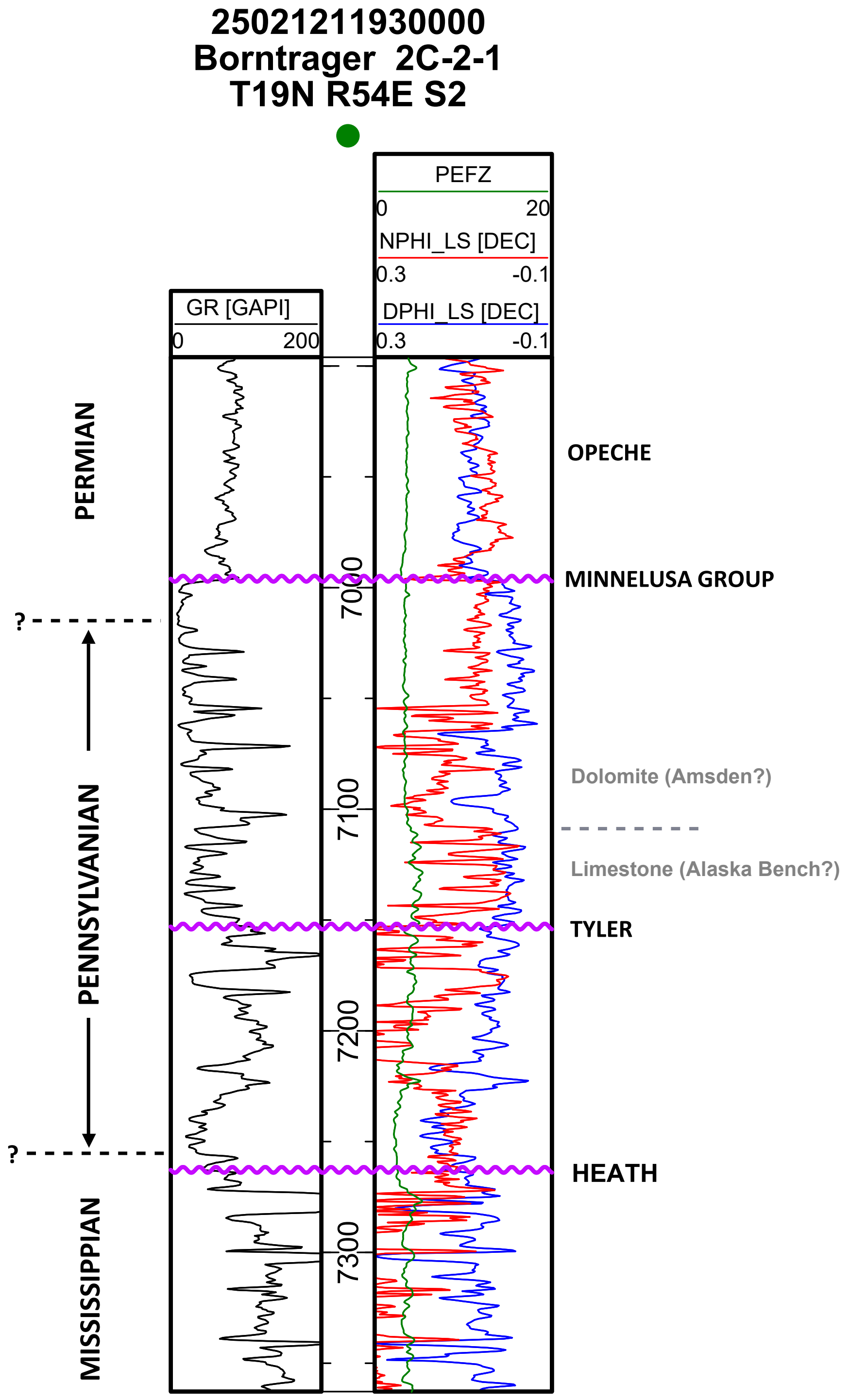

Figure 8. Type log illustrating the two Pennsylvanian picks stored in the database. Note that the upper portion of the Minnelusa Group may be early Permian in age as shown in Murphy and others (2009).

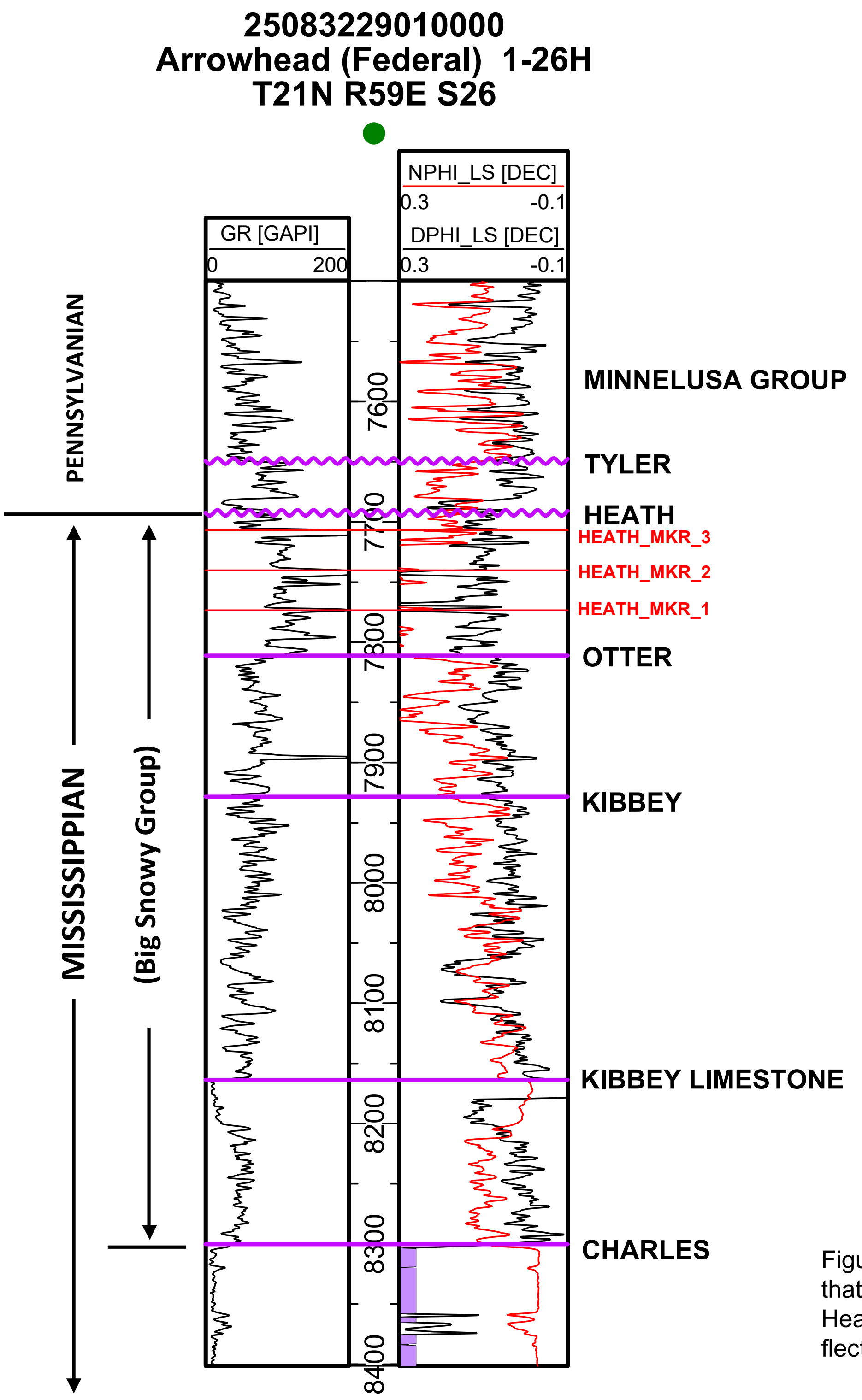

Figure 9. Type log showing formation tops picked within the Big Snowy Group. Note that the Big Snowy Group is bounded by unconformities. The marker beds within the Heath Formation are very useful in picking the Heath top because their absence reflects erosion prior to Tyler deposition.

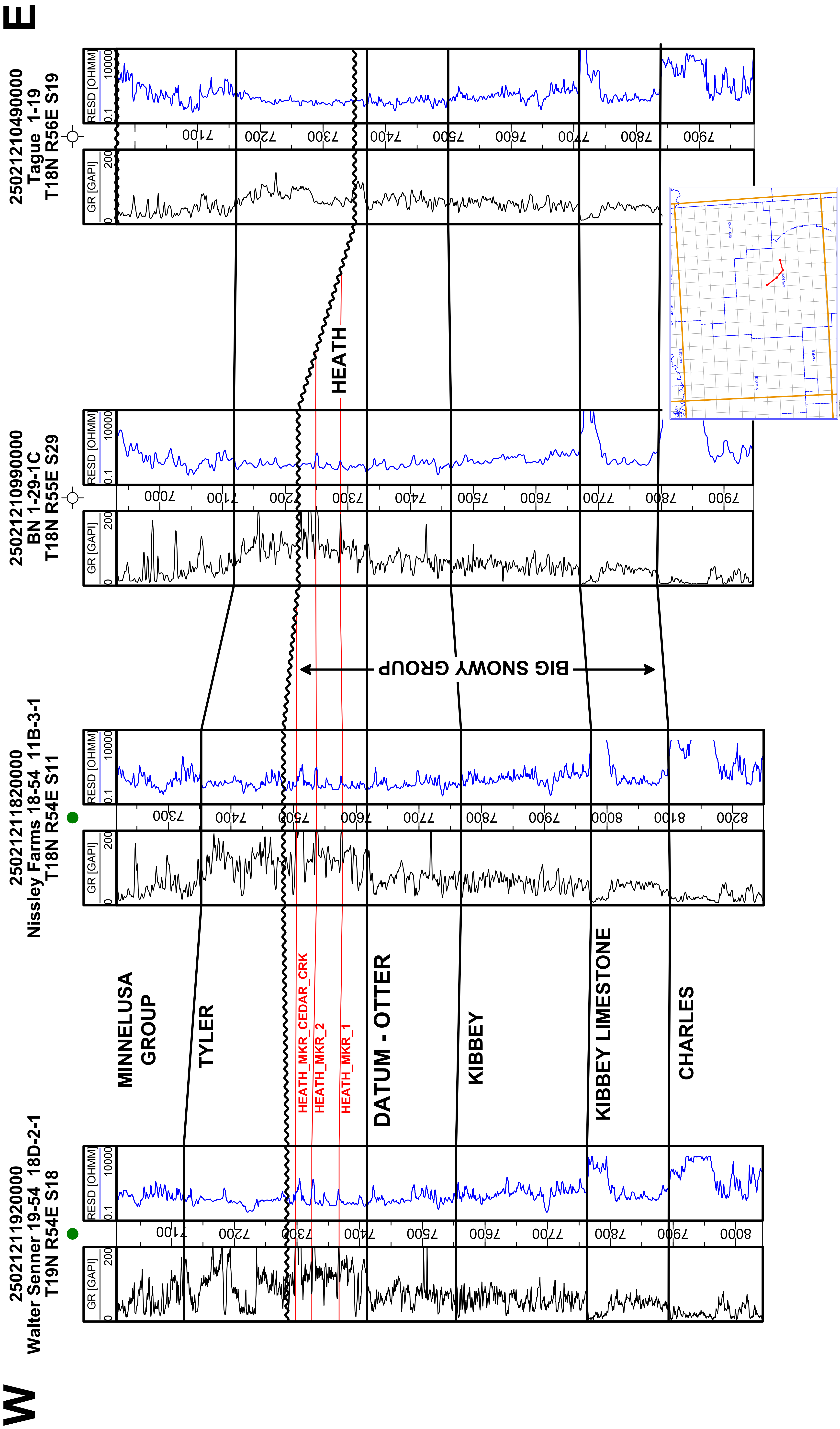

Figure 10. Stratigraphic cross-section illustrating the truncation that occurs at the top of the Heath Formation.

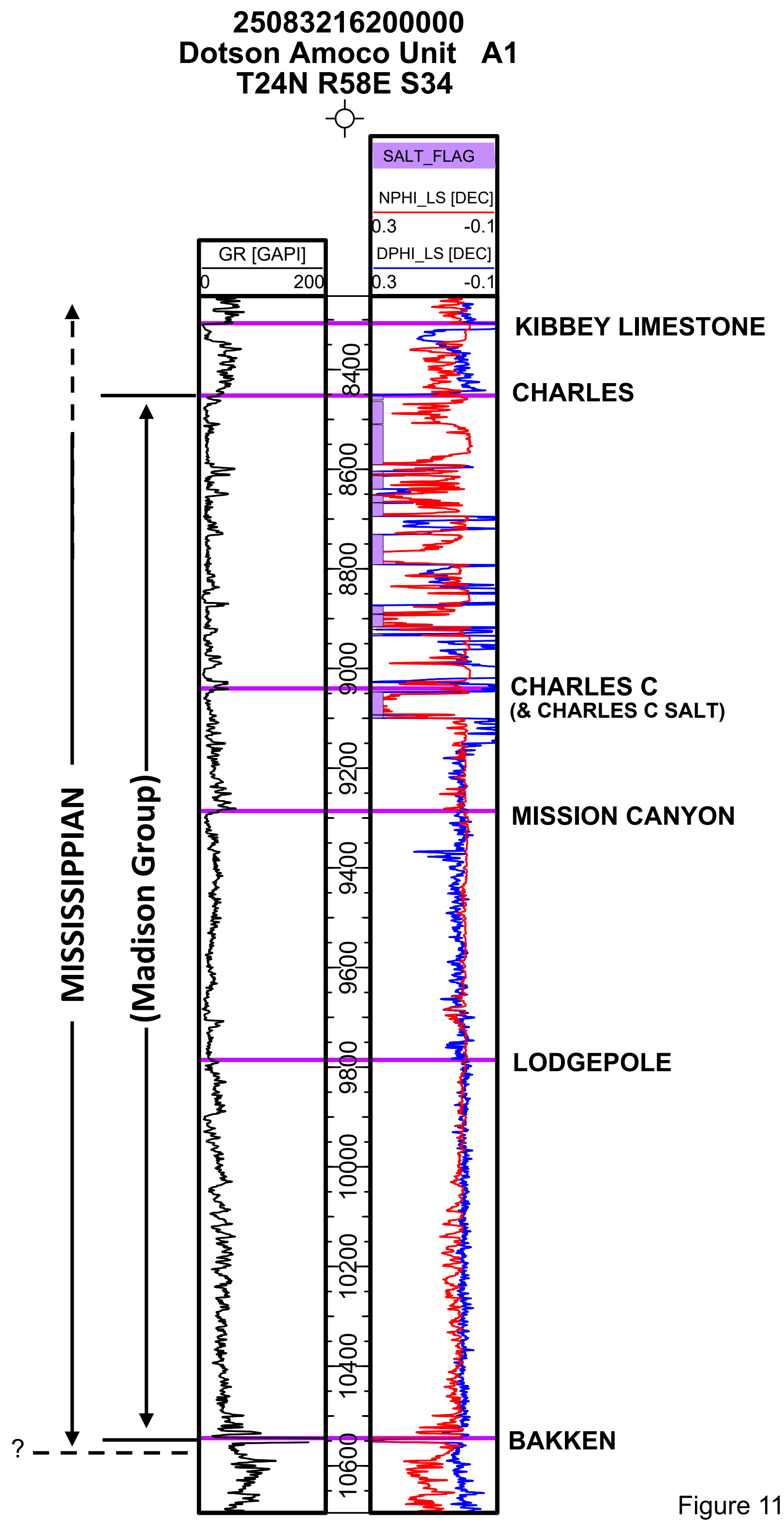

Figure 11. Type log section illustrating the formation tops picked within the Madison Group.

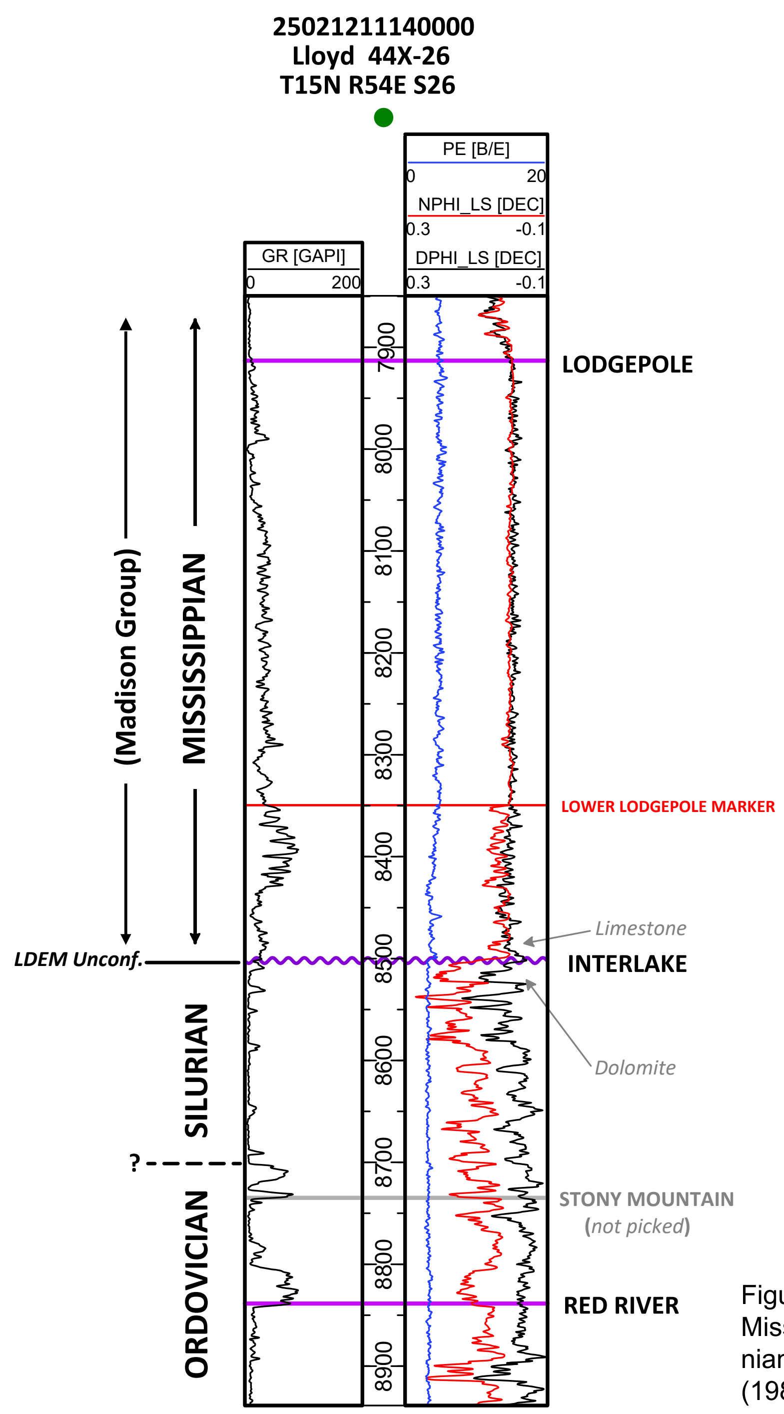

Figure 12. Type log illustrating how the Lower Lodgepole Marker and the Late Devonian–Early Mississippian (LDEM) Unconformity were picked. Note that at the location of this type log, Devonian formations have been completely removed prior to deposition of Lodgepole strata. Clement (1986) discussed the LDEM unconformity in detail.

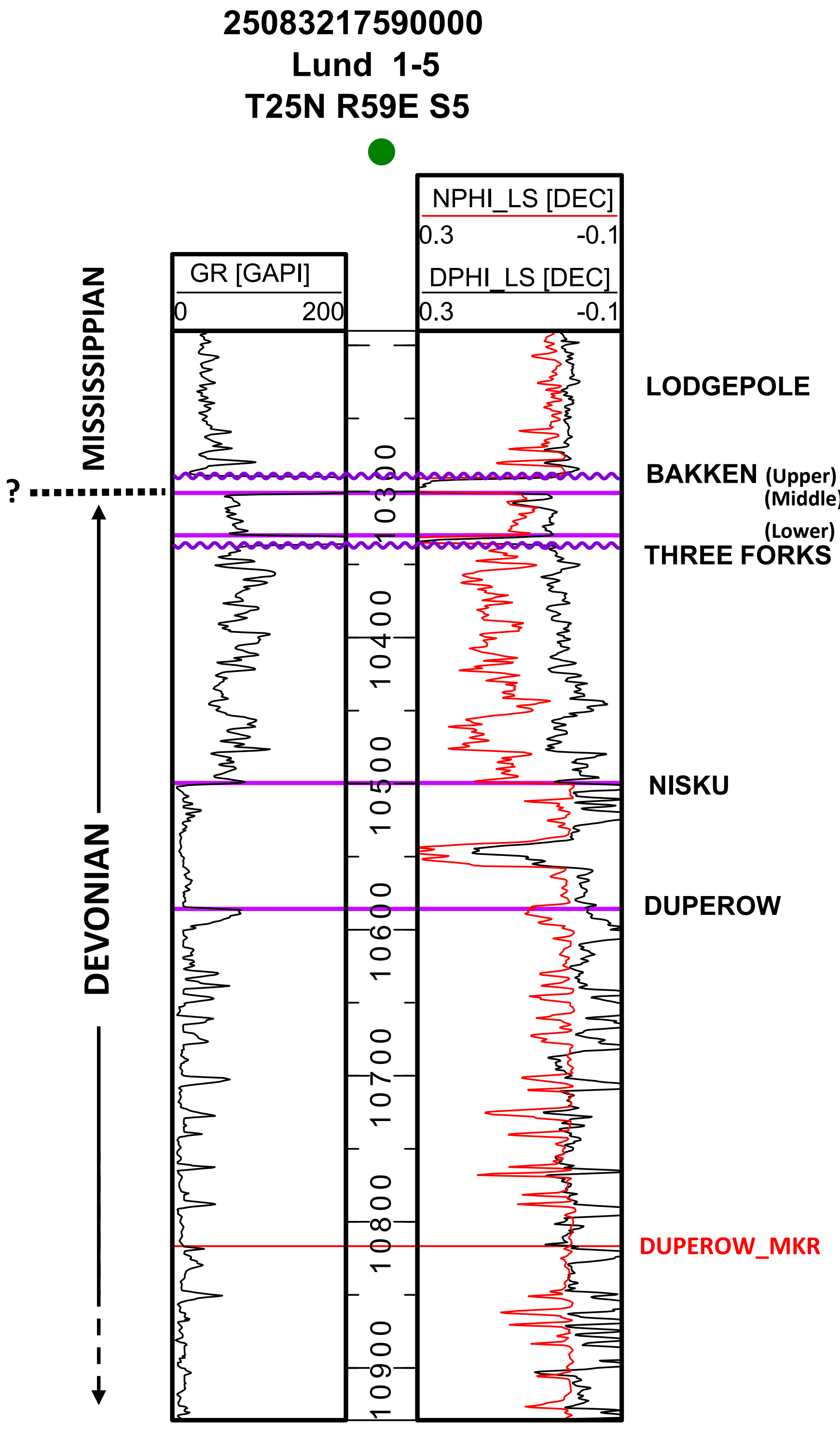

Figure 13. Type log section showing the Bakken, Three Forks, Nisku, and Duperow Formation tops that are stored in the database.

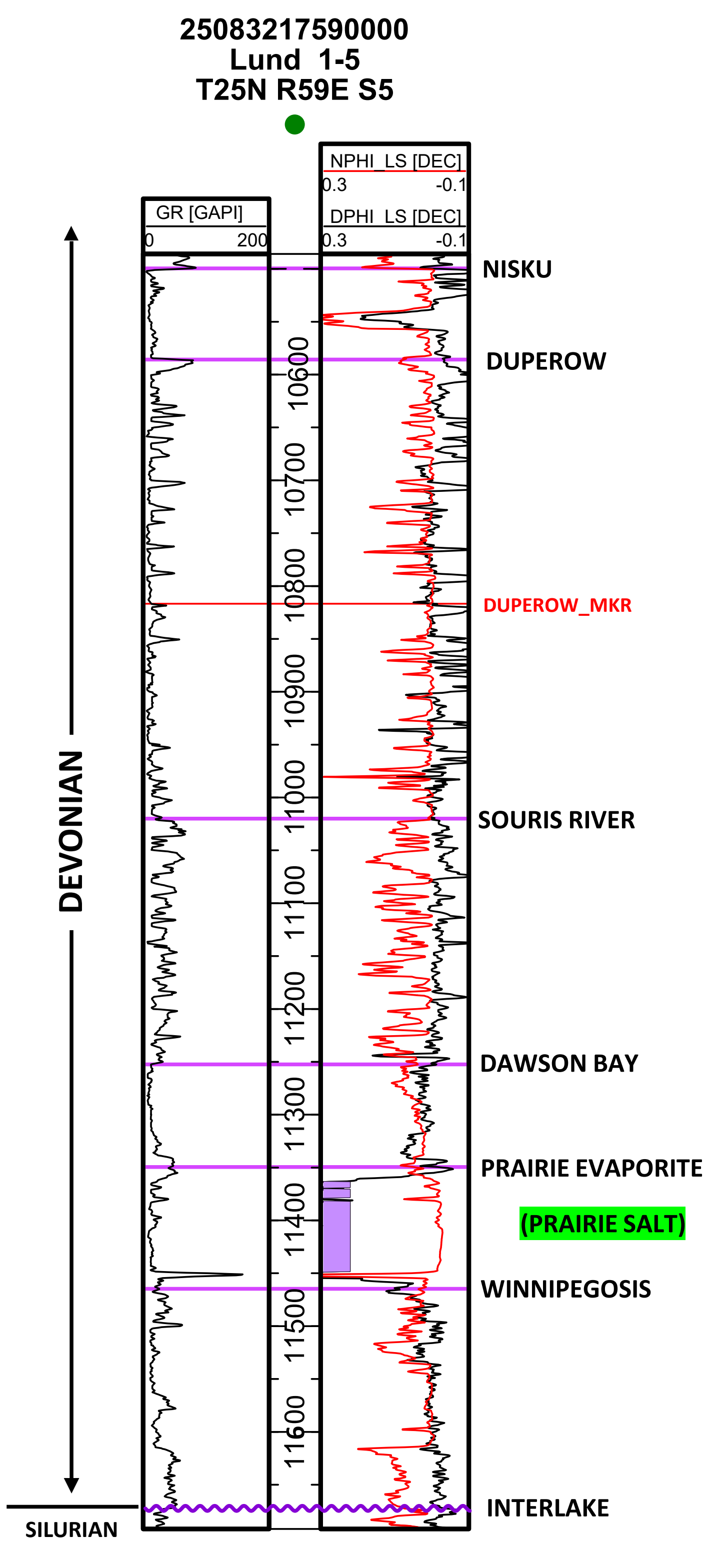

Figure 14. Type log for Devonian strata below the top of the Duperow Formation.

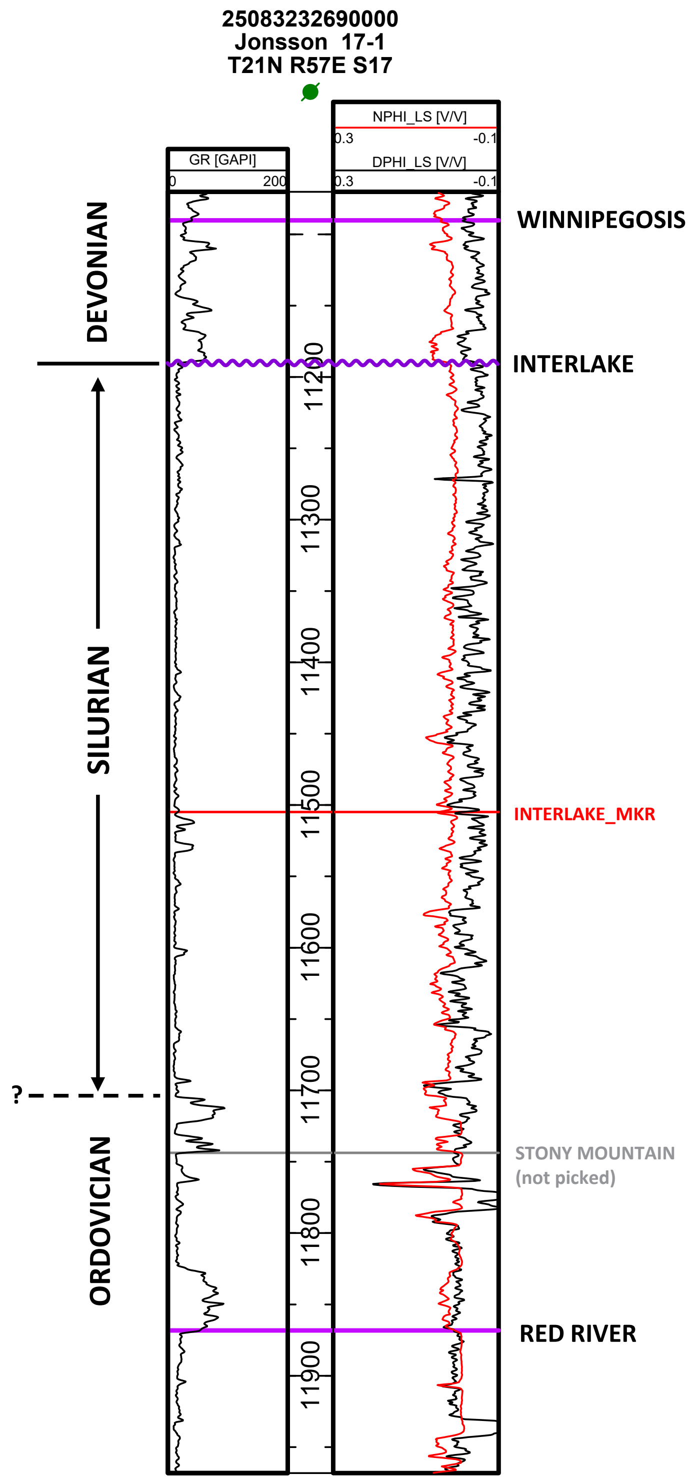

Figure 15. Type log section of the Interlake Formation.

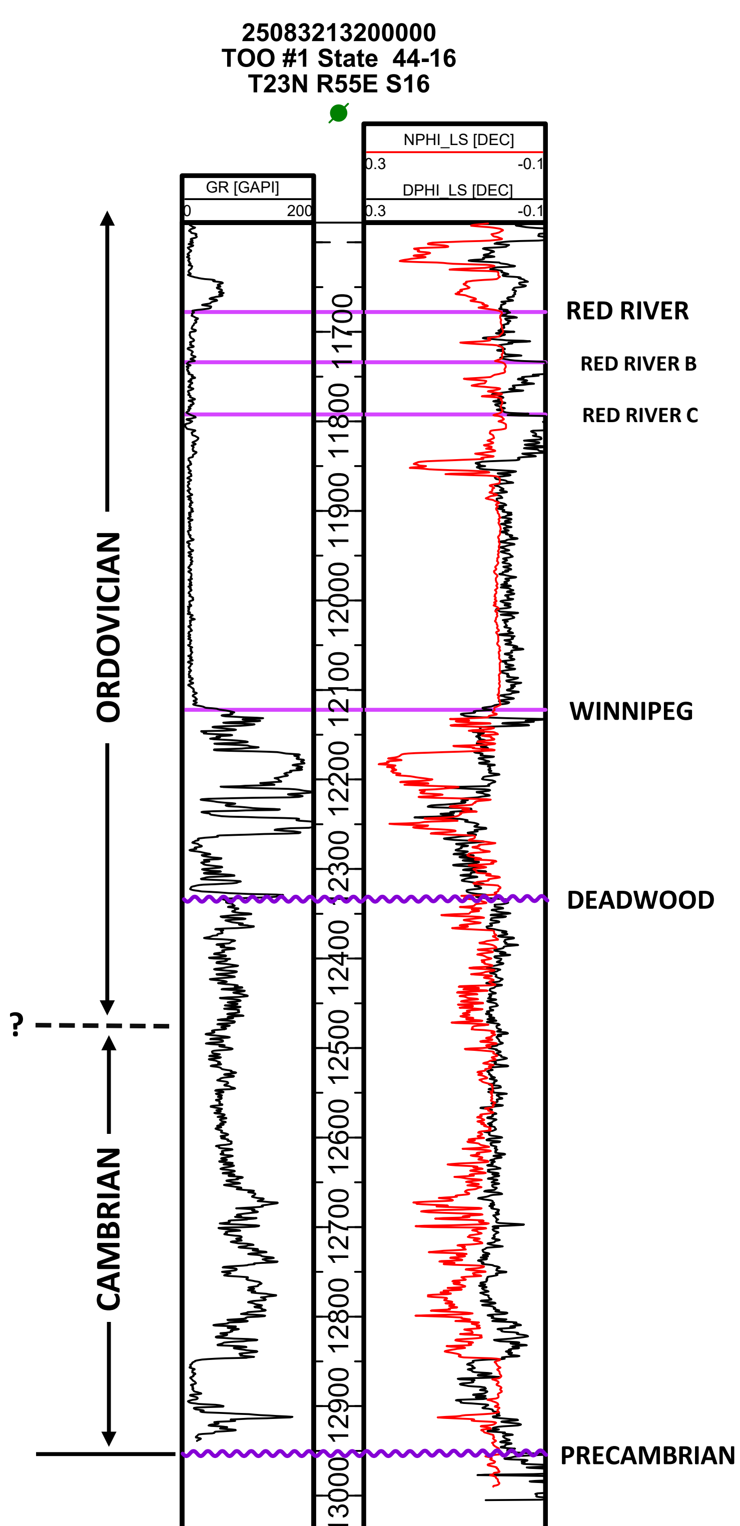

Figure 16. Type log section showing Precambrian, Cambrian, and Ordovician age formation tops stored in the database.

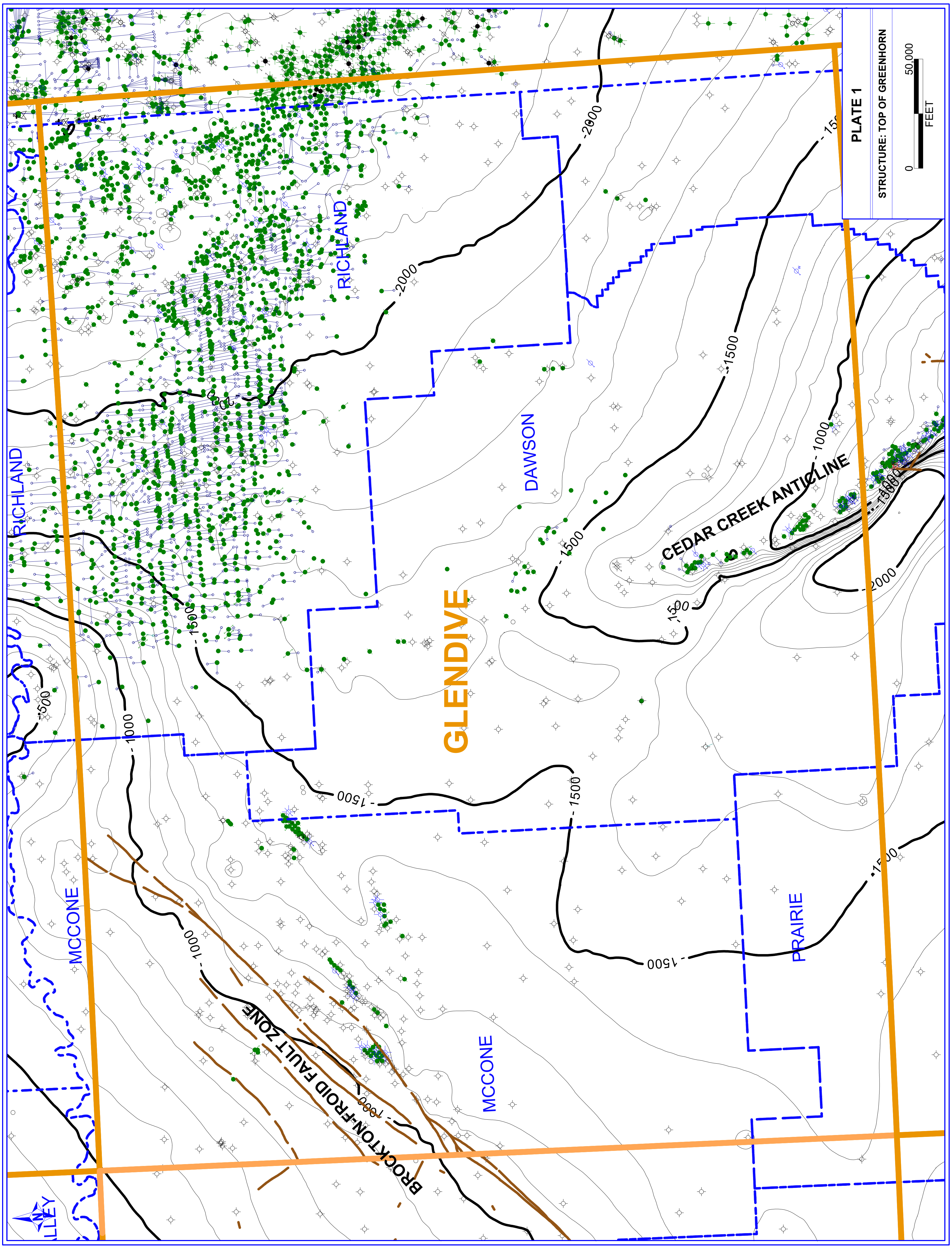

Plate 1. Structure map on the top of the Greenhorn Formation. The faults shown are surface traces from Vuke and others (2007).

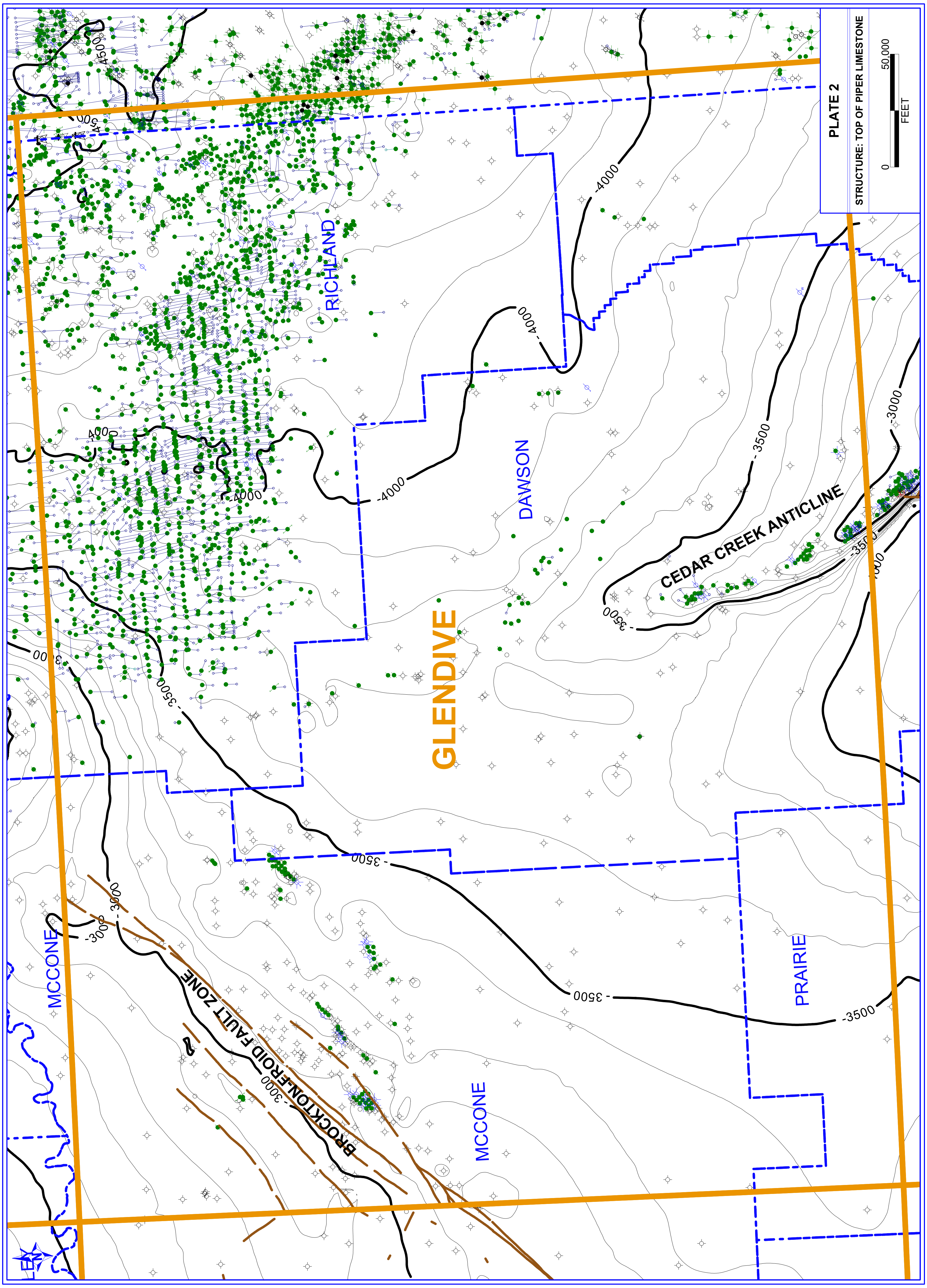

Plate 2. Structure map on the top of the Piper limestone. The faults shown are surface traces from Vuke and others (2007).

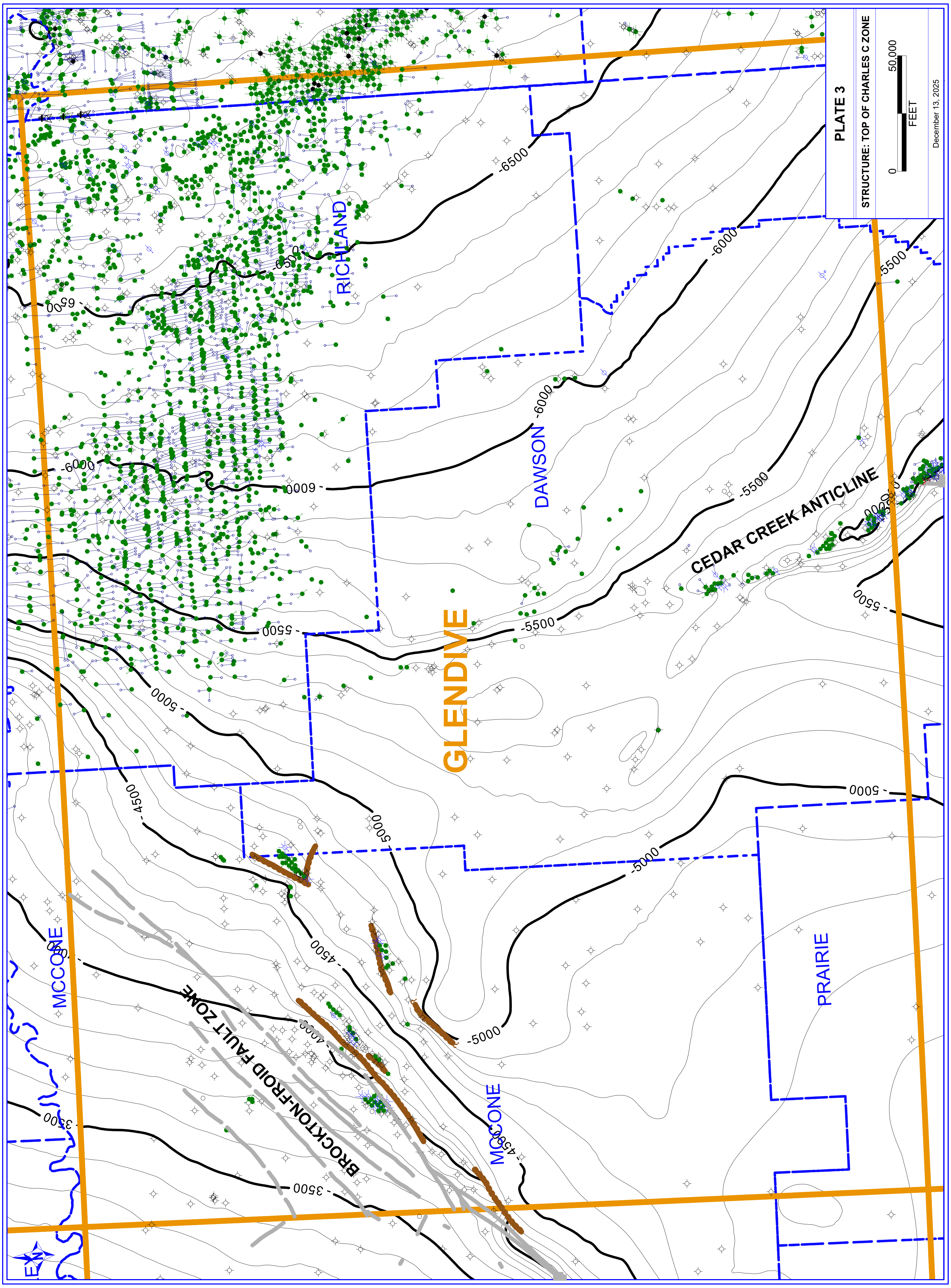

Plate 3. Structure map on the top of the Charles C (Ratcliffe) Formation. The faults shown as thick brown lines are those that cut the contoured horizon as identified by Edmisten and Foster (1969), Hicks (1985a,b,c). There is also a fault cut found in the NPRR 1-A well in sec. 11, T. 21 N., R. 47 E., showing more than 120 ft of missing section in the upper Duperow. The trend and the extent of this fault are unknown and we assume a northeasterly trend similar to the others. The surface traces of faults are shown in gray.

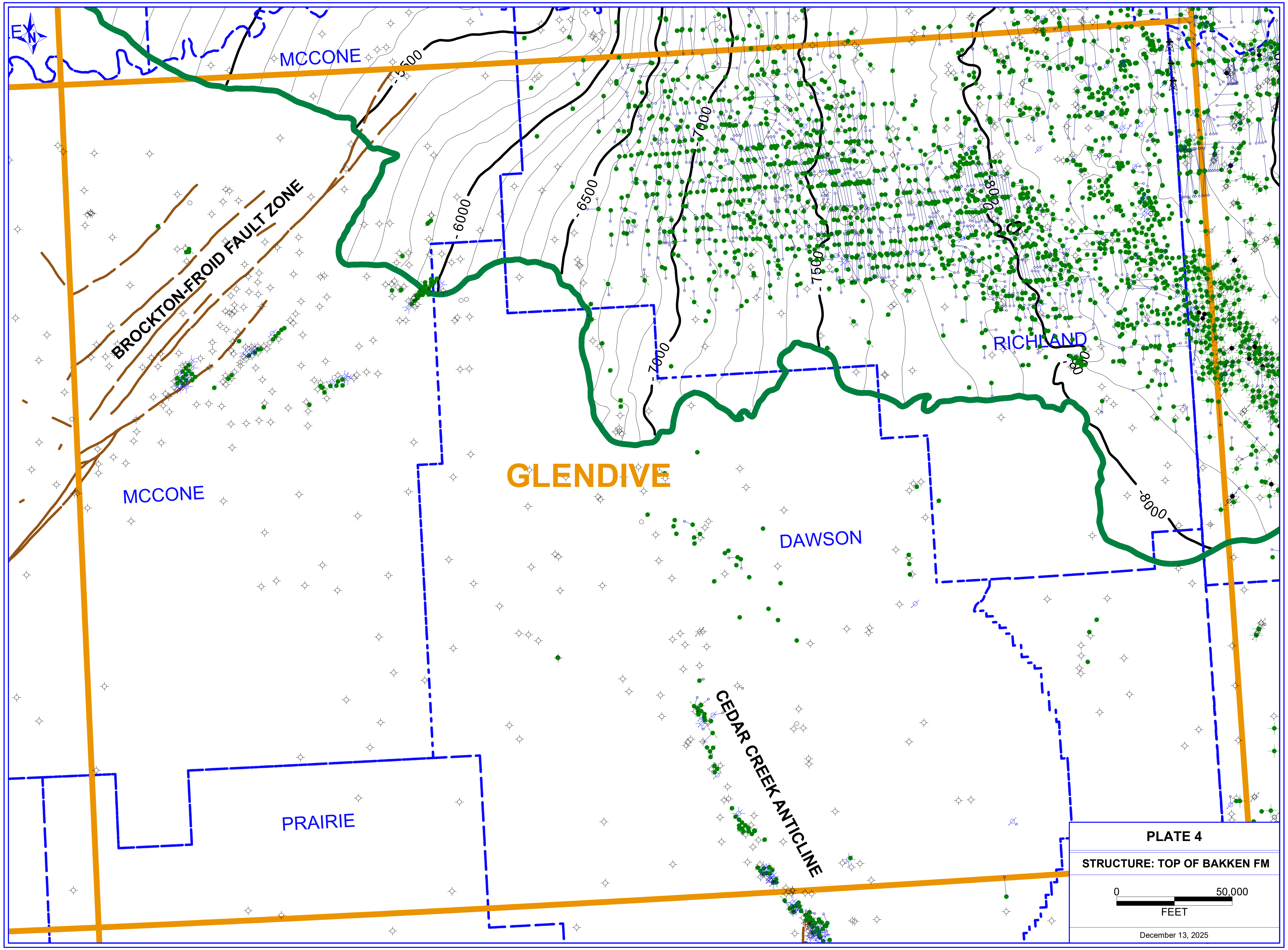

Plate 4. Structure map on top of the Bakken Formation. The faults shown are surface traces from Vuke and others (2007). The Bakken pinches out to the south and is not present in the southern half of the Glendive quadrangle.

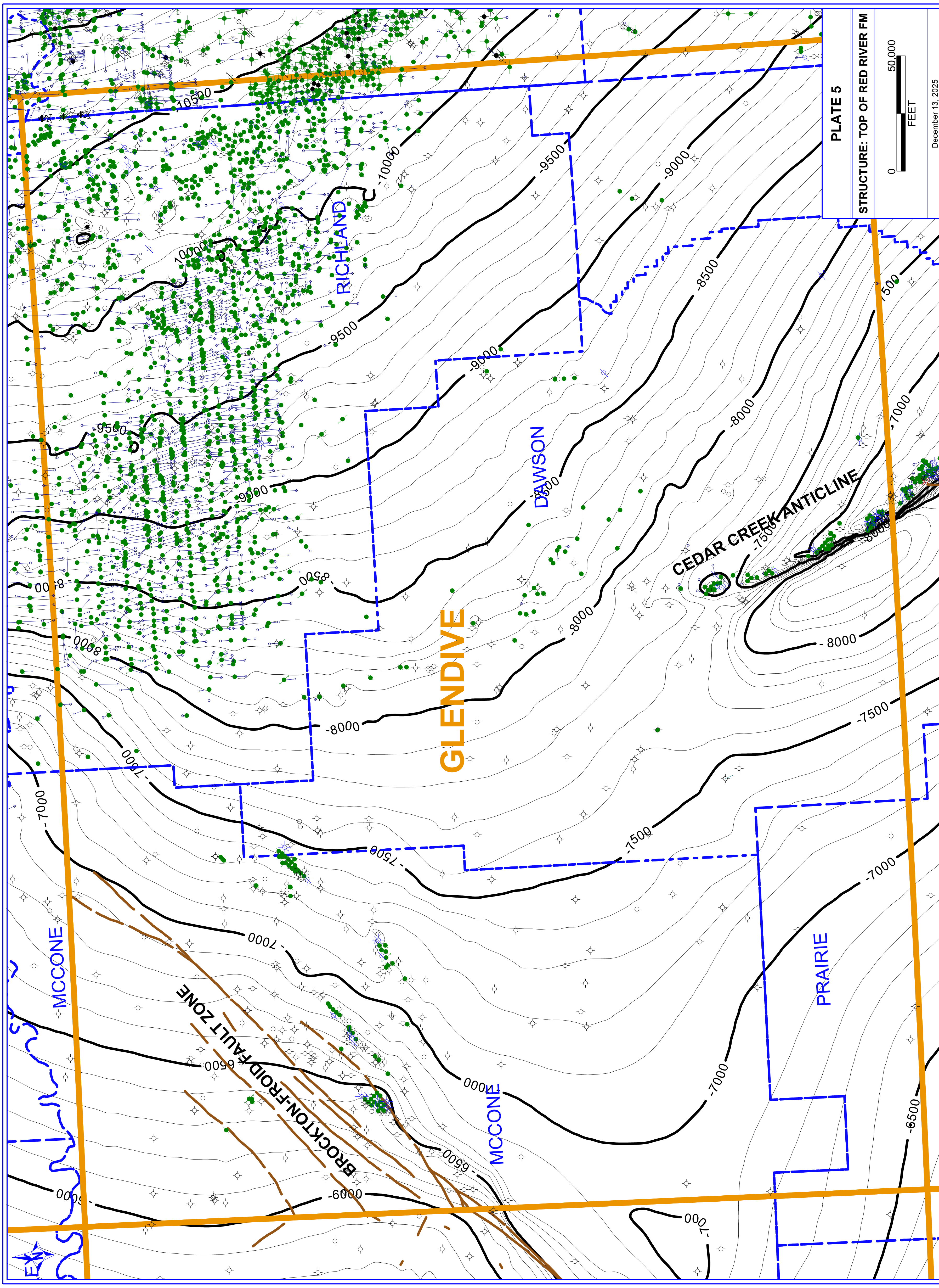

Plate 5. Structure map on the top of the Red River Formation. The faults shown are surface traces from Vuke and others (2007).

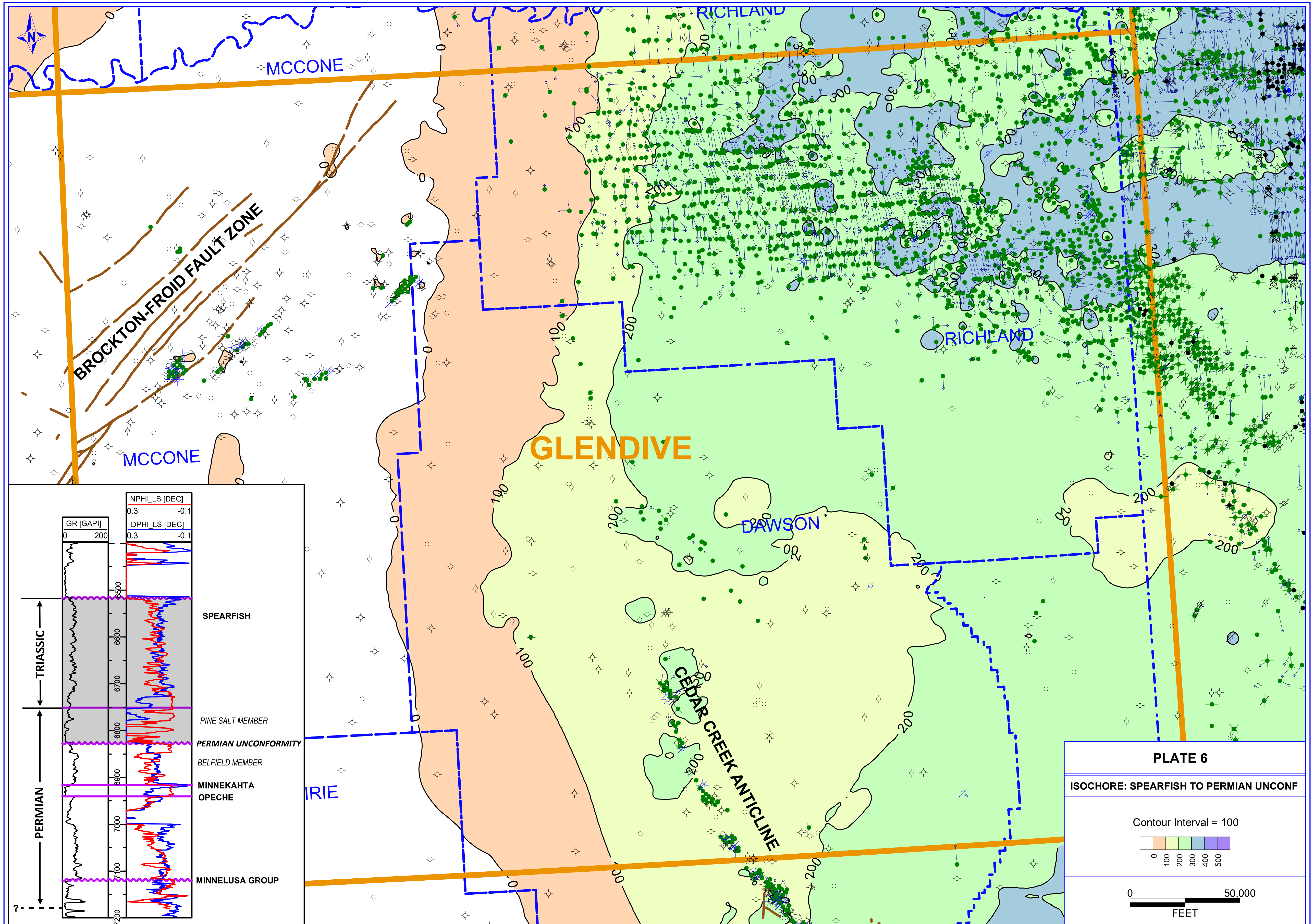

Plate 6. Isochore of the Spearfish Formation to the Permian Unconformity. The Spearfish Formation pinches out to the west by onlap and subsequent erosion prior to the deposition of Jurassic strata. Note the type log inset that indicates the isochore interval in gray.

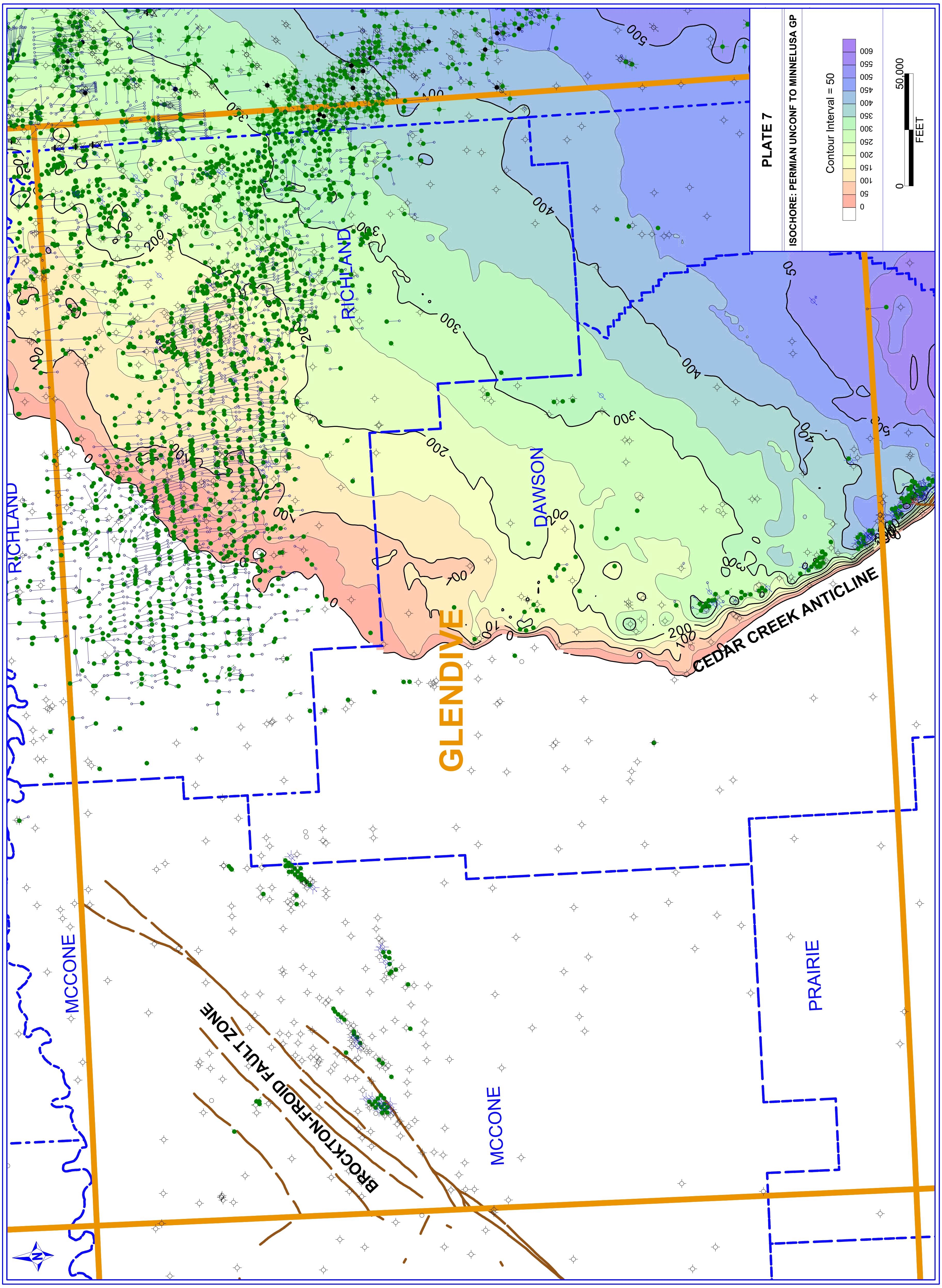

Plate 7. Isochore of the Permian Unconformity to the top of the Minnelusa Group. Note the abrupt thinning that occurs on the southwest flank of the Cedar Creek Anticline caused by fault movement in late Perm-ian–early Triassic time (Clement, 1986). The isopach interval is shown on the inset type log shaded in gray.

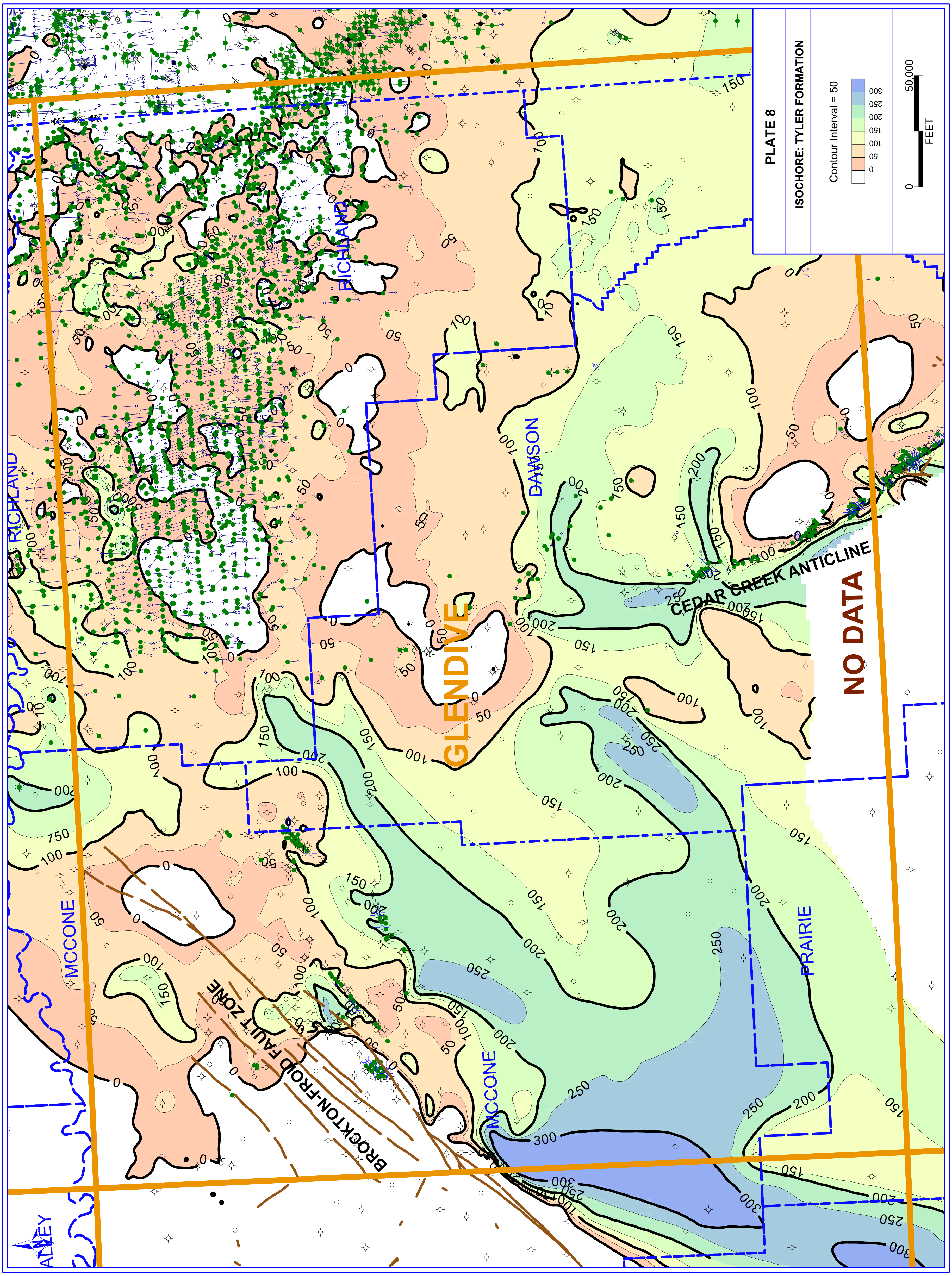

Plate 8. Isochore of the Tyler Formation.

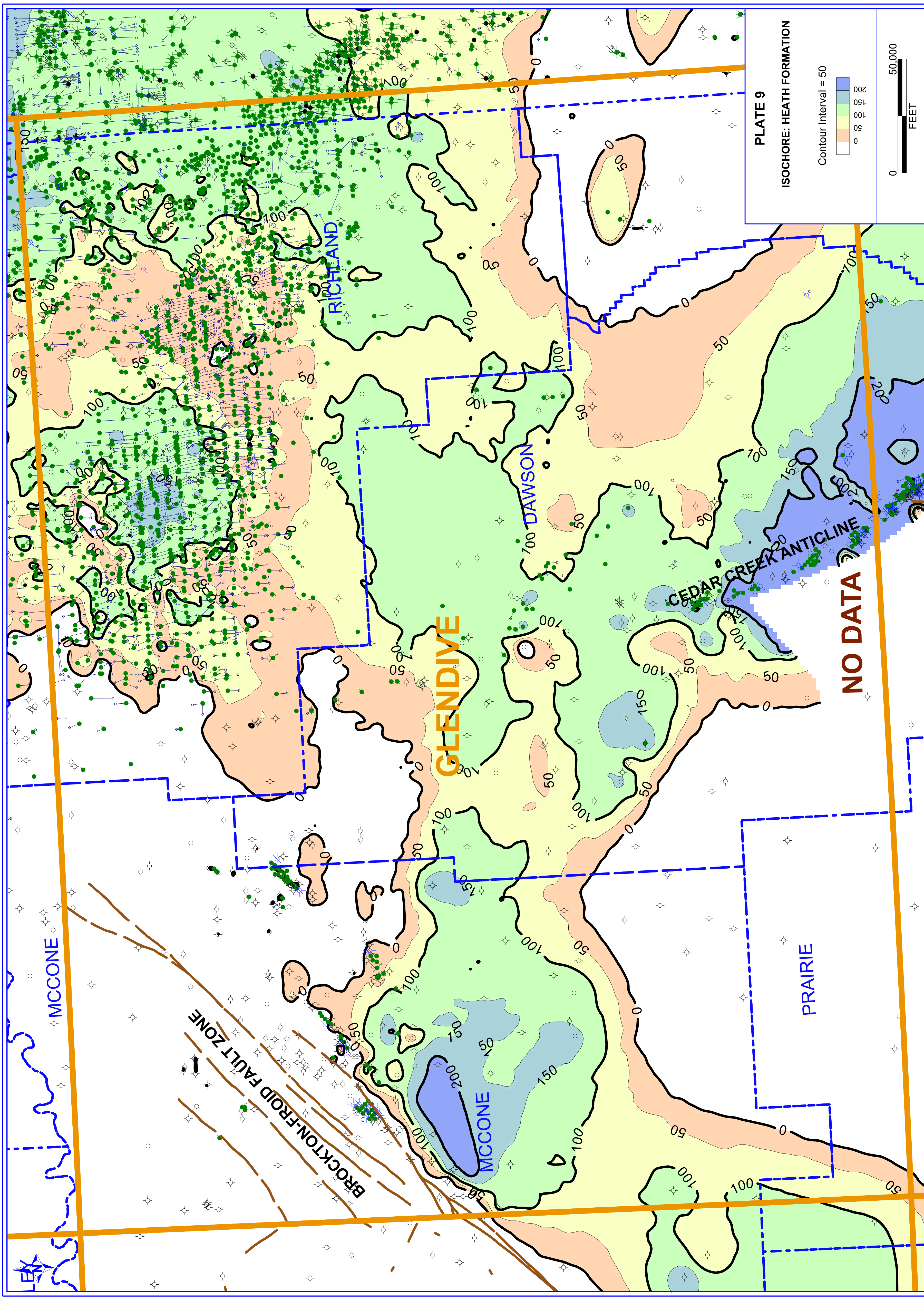

Plate 9. Isochore of the Heath Formation.

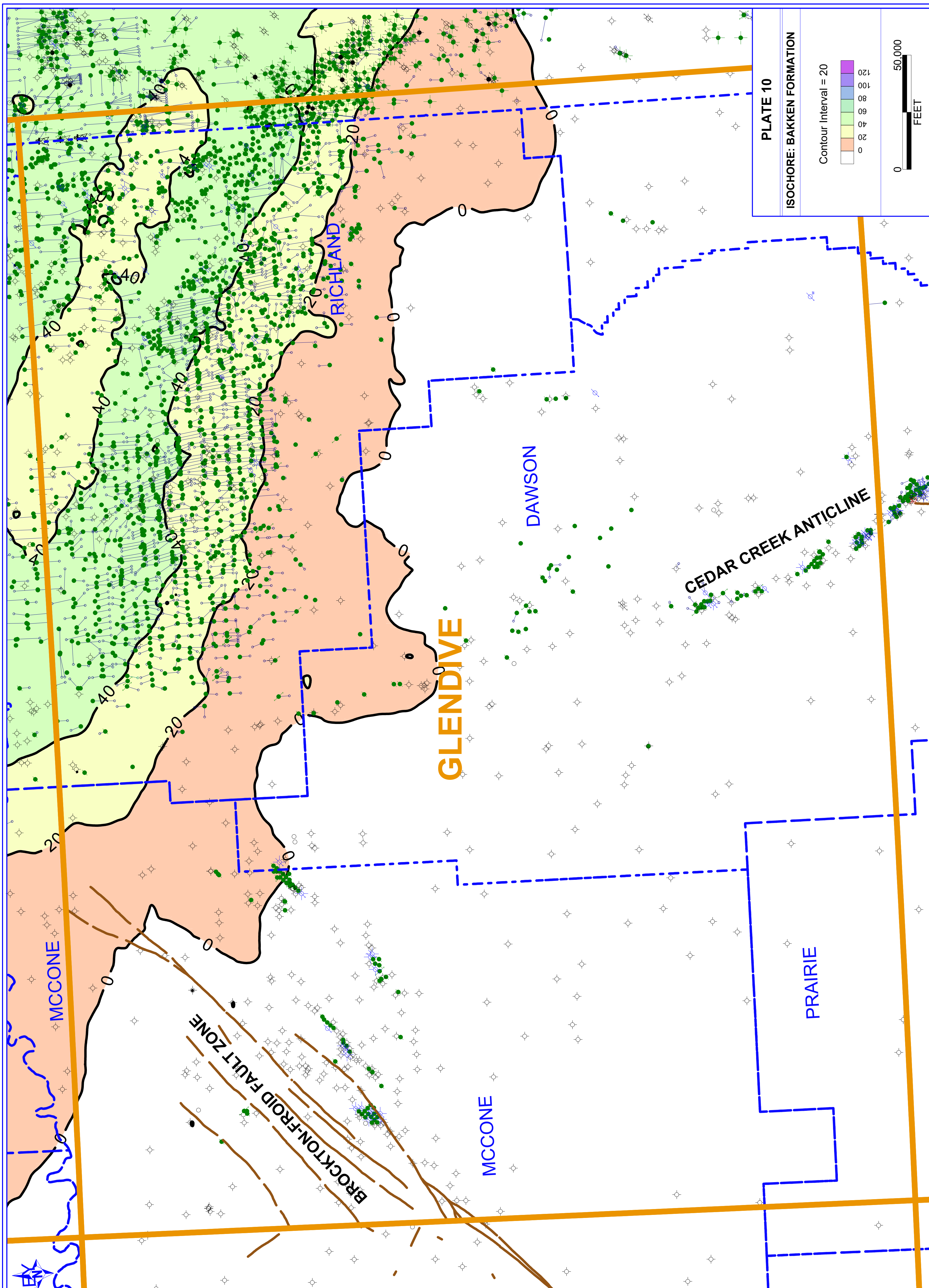

Plate 10. Isochore of the Bakken Formation.

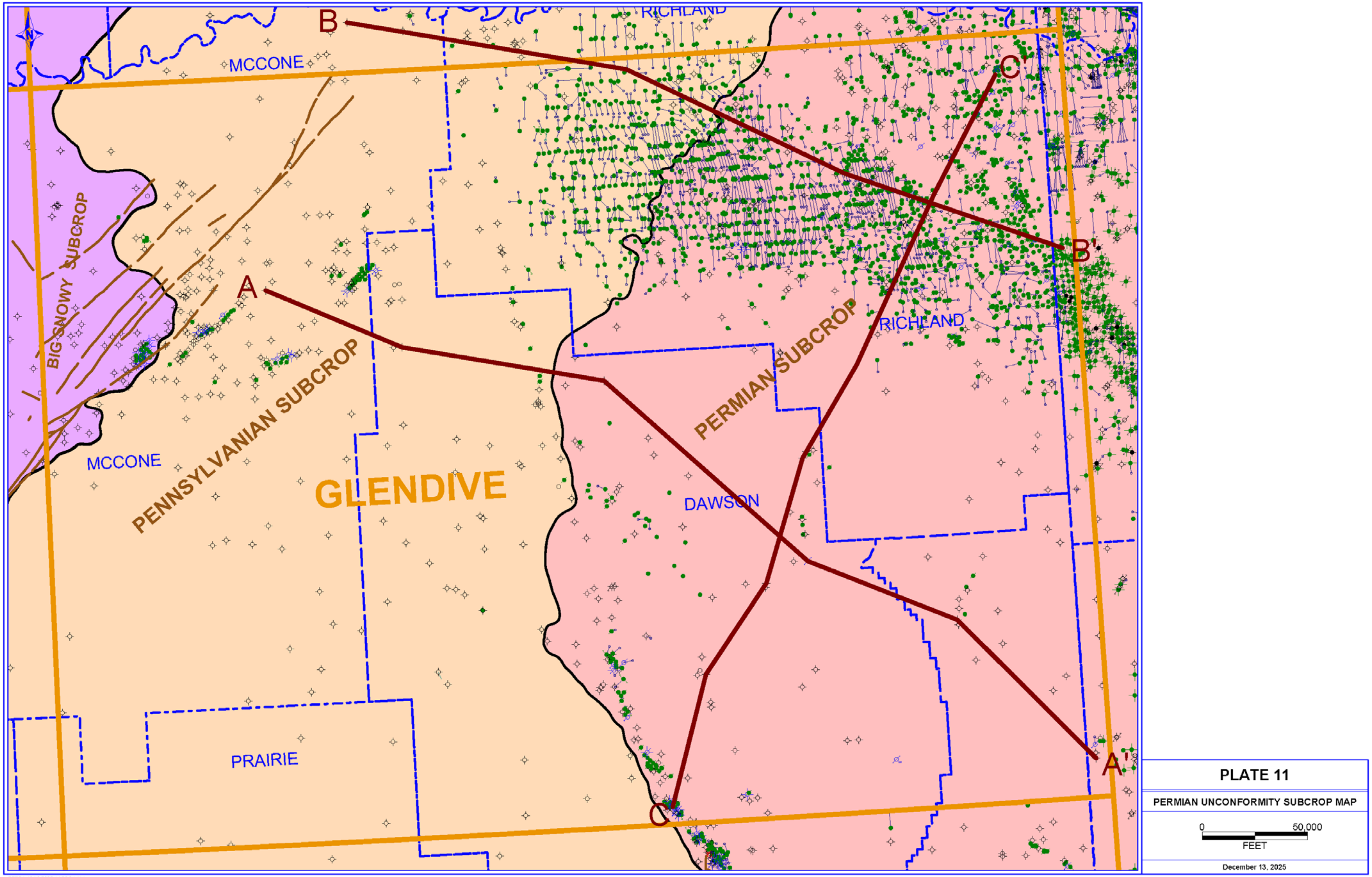

Plate 11. Subcrop map illustrating the units that are truncated by the Permian Unconformity. Note that while upper portions of the Minnelusa Group may be Permian in age, the entire Minnelusa Group section is included within the Pennsylvanian subcrop area.

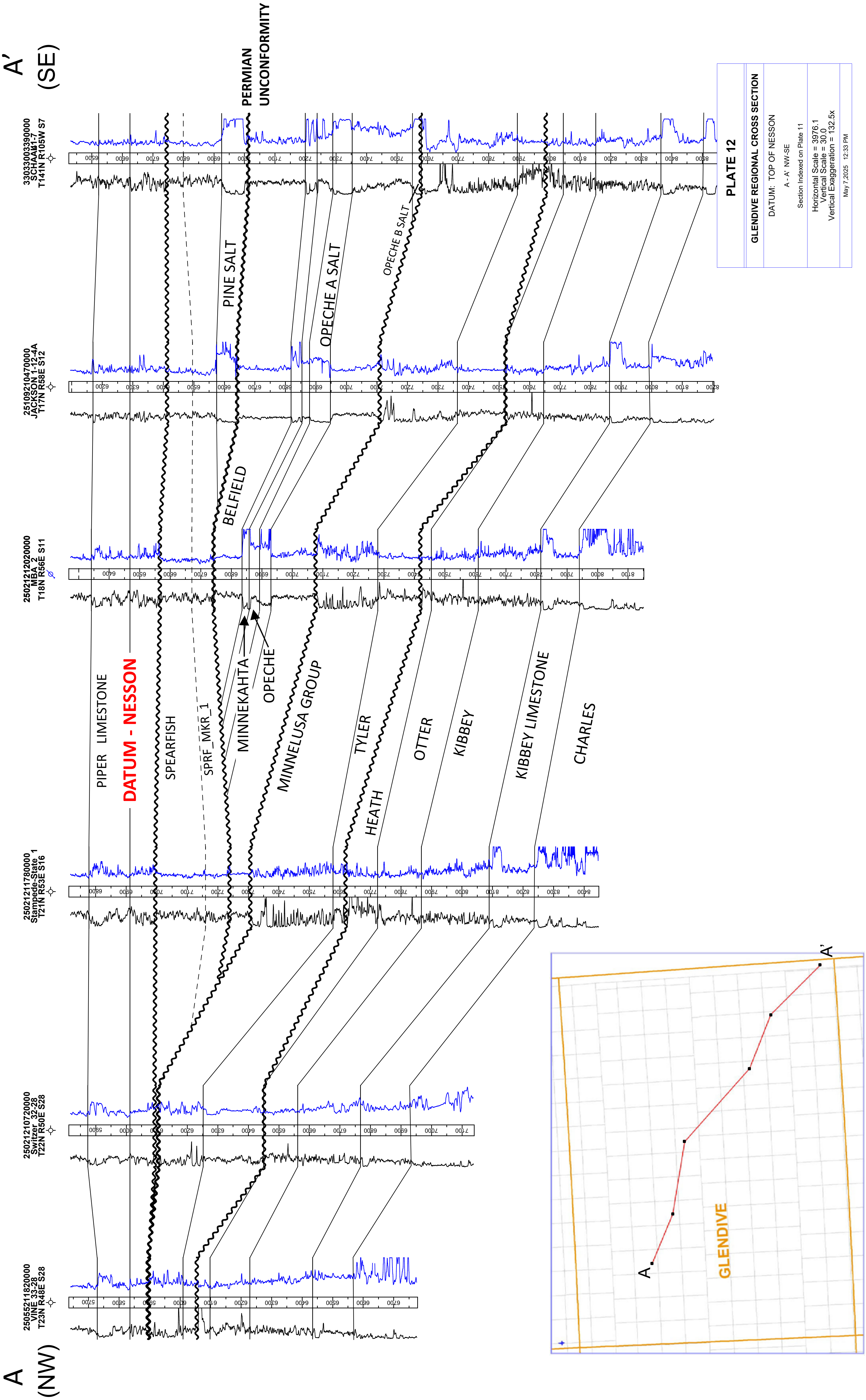

Plate 12. Northwest–southeast cross-section illustrating truncation of units beneath the Permian Unconformity.

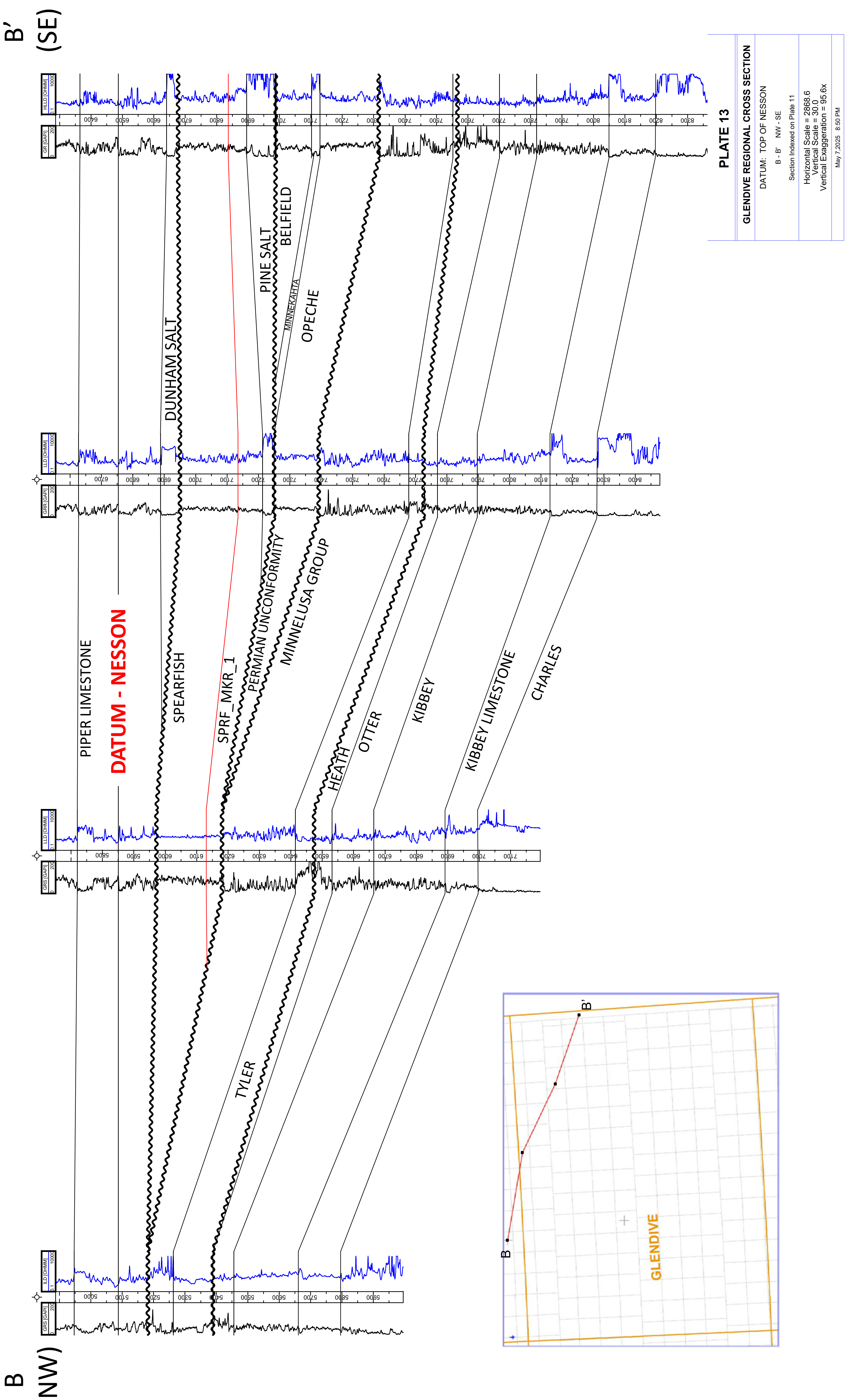

Plate 13. Northwest–southeast cross -section showing the truncation of Permian and Pennsylvanian strata below the Permian Unconformity.

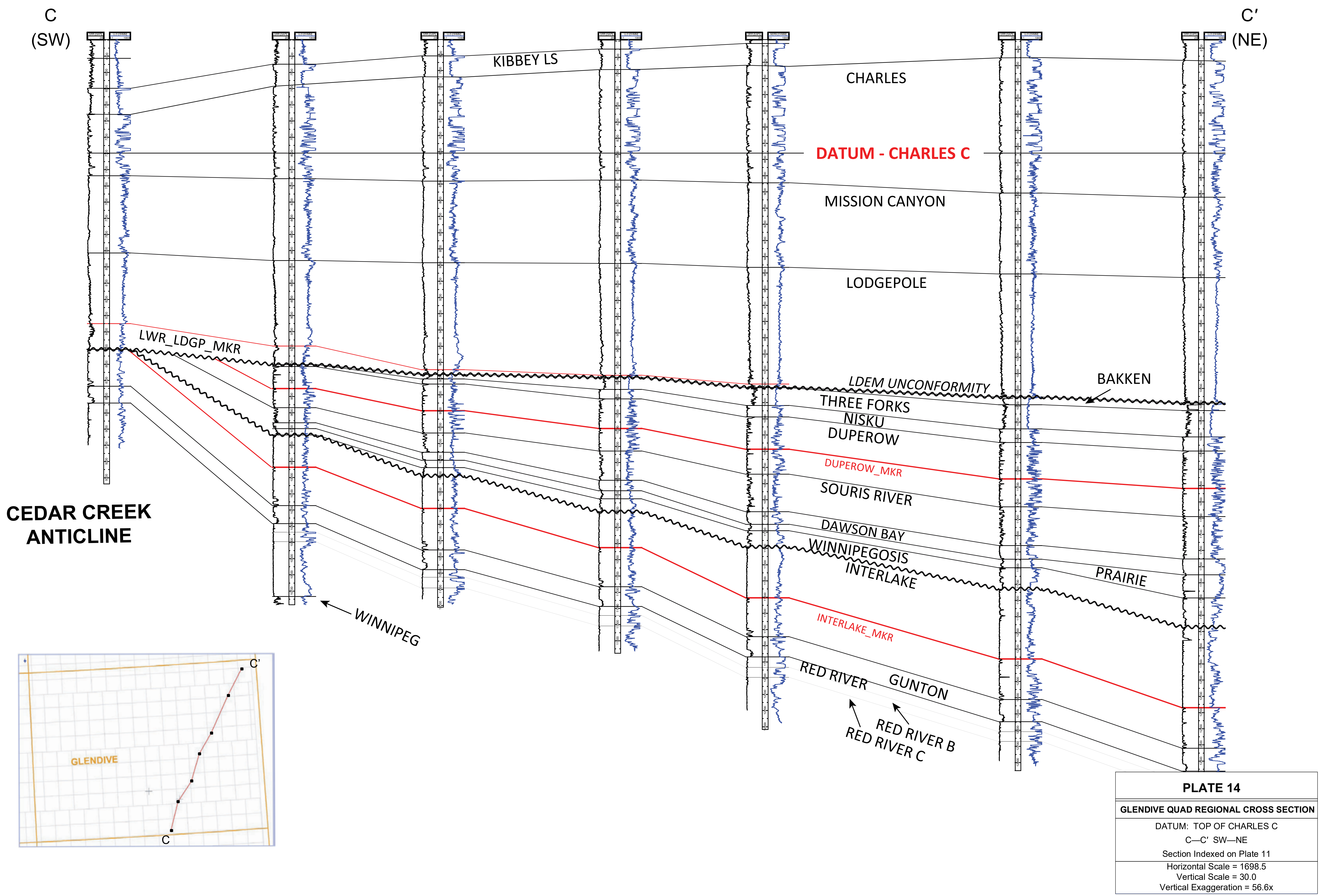

Plate 14. Southwest–northeast cross-section showing the truncation of Devonian strata below the Late Devonian–Early Mississippian (LDEM) Unconformity (see Clement, 1986).