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

Jay A. Gunderson and Gary C. Hughes

Montana Bureau of Mines and Geology

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Cover photo: Spherical concretions eroded out of the Hell Creek Formation, Fort Peck Reservoir, Montana. Photo by Jay Gunderson, MBMG.

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PURPOSE

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

While subsurface formation tops are available from the Montana Board of Oil and Gas (MBOG) and some petroleum data vendors, they are mostly derived from well completion reports and are inconsistently picked and use inconsistent nomenclature. Users must spend considerable time and effort editing and normalizing 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 basis. This dataset allows users to more quickly advance to the interpretation phase of subsurface geological projects.

INTRODUCTION

The Glasgow 1° x 2° (1:250,000) quadrangle in northeastern Montana is situated on the western flank 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).

The surface geology of the Glasgow quadrangle consists almost entirely of Late Cretaceous sands and shales, covered in places by Tertiary gravels (fig. 2; Vuke and others, 2007). A remnant of the Tertiary Fort Union Formation (Fm) crops out in the northeast portion of the quadrangle.

Subsurface geologic units range from Precambrian to Tertiary in age and consist primarily of cyclic marine sediments deposited during Paleozoic and Mesozoic time. Williston 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). Subsurface units in the eastern half of the quadrangle dip gently eastward toward the center of the basin. The Bowdoin Dome, a broad basement-cored structure, occupies the western half of the quadrangle (fig. 2).

Only one significant oil discovery has been made in the Glasgow quadrangle. The Lustre field, discovered in 1982, produces oil from the Charles and Mission Canyon Formations. Bowdoin Dome, however, is one of the State's top producing gas regions. Over the past 5 years, nine natural gas fields situated on the domal structure have produced a combined average of 7.2 billion cubic feet (BCF) of gas per year from Upper Cretaceous sandstones. Bowdoin field, the largest of these gas fields, has produced roughly 475 BCF of gas since its discovery in 1913 (Raforth, 1985; MBOG, 2024). The major oil- and gas-producing zones within the Glasgow quadrangle are highlighted on the stratigraphic column in figure 3.

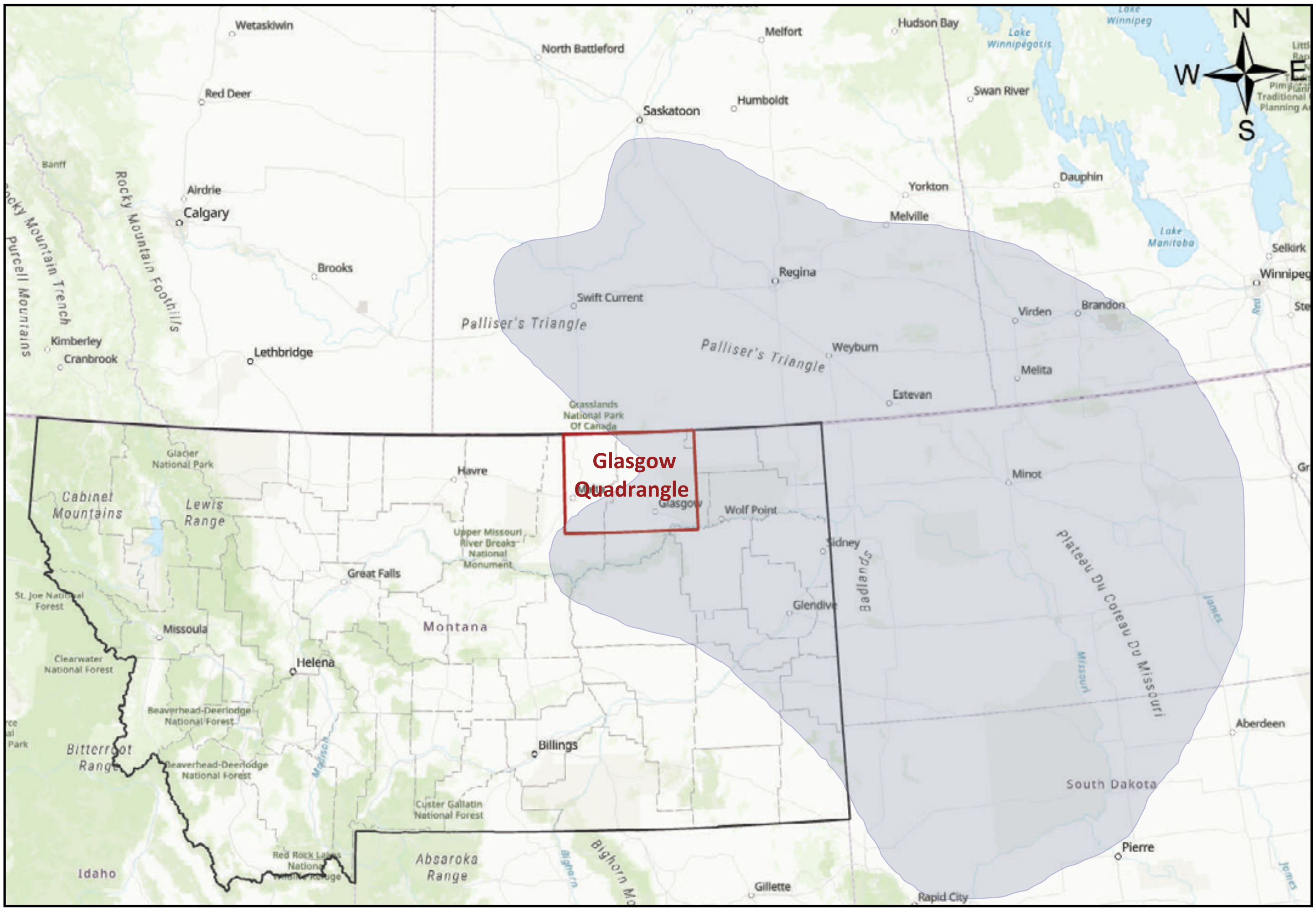

Figure 1. Index map showing the location of the Glasgow 1° x 2° quadrangle. The gray shaded area is the approximate extent of the Williston Basin.

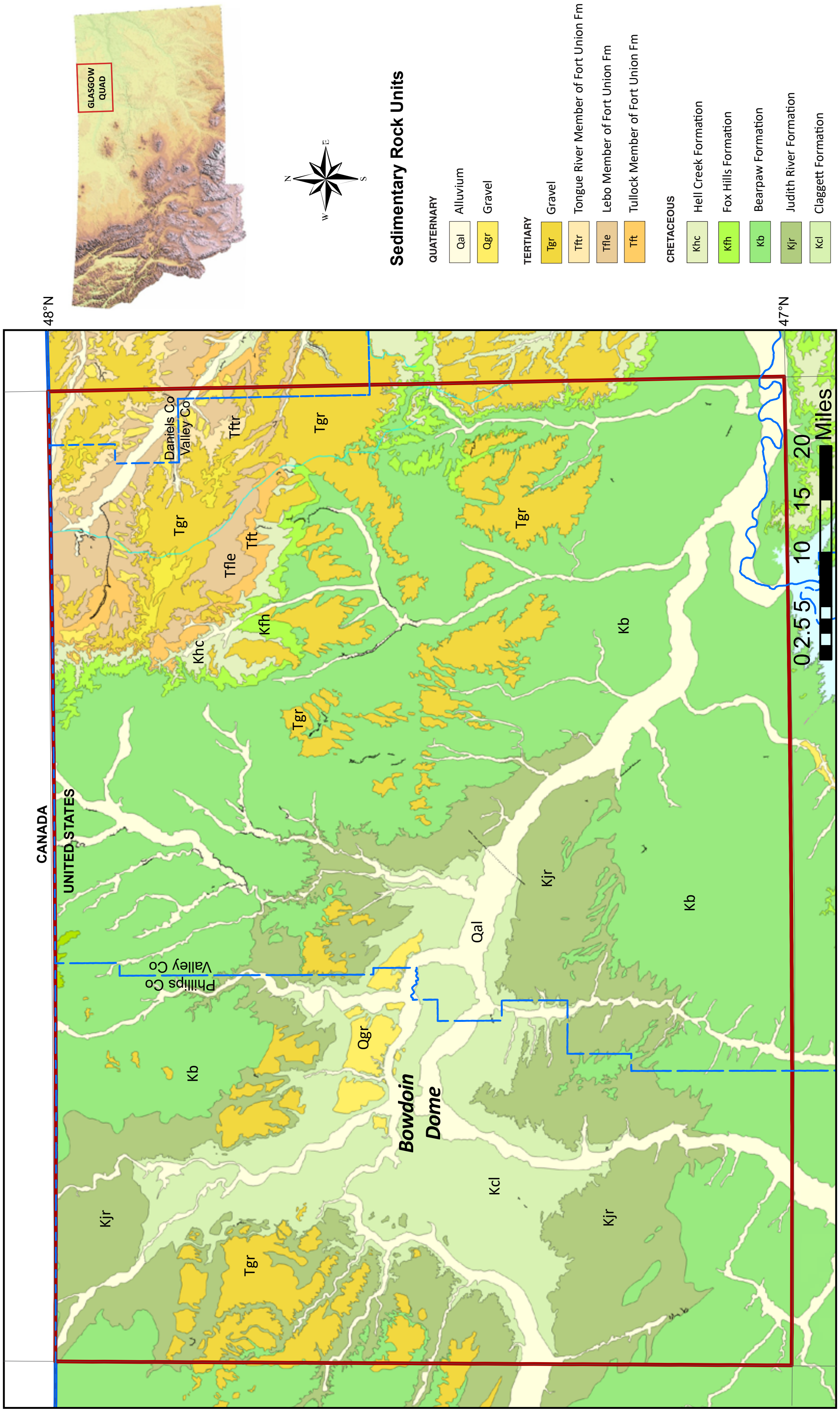

Figure 2. Surface geologic map of the Glasgow 1° x 2° quadrangle (modified from Vuke and others, 2007).

DATA AND METHODS

Approximately 3,000 petroleum exploration wells have been drilled in the Glasgow quadrangle since the early 1900s. About 2,400 of these are shallow gas wells drilled within the Bowdoin Dome. Only 15 wells in the vicinity of the dome reached drilling depths greater than 3,500 ft. Thus, deep well log data are sparse, particularly in the western half of the quadrangle.

Well header and location data were acquired from the MBOG. Raster images of geophysical logs and mudlogs (if available) were obtained from MJ Systems of Calgary, Alberta. Sample logs of the Northwest Geological Society 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.

Stratigraphic picks were made by correlating geophysical log signatures on a well-by-well basis; all are lithostratigraphic correlations. Where possible, lithology descriptions from sample logs and from geological reports in the MBOG well files (MBOG, 2023) were used to correlate lithologic units to geophysical log signatures. For deviated wells, formation tops were identified from true vertical depth logs. Most of our stratigraphic picks are formation tops, but we also include the tops of some stratigraphic groups, formation members, and a few intraformational marker beds (fig. 3). 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.

Structure and isochore maps were created for selected formations and intervals using our stratigraphic picks. Structural elevation and formation thickness data were gridded using PETRA's "Least Squares Method" interpolation algorithm with square grid spacings 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 illustrating our stratigraphic picks are provided in figures 4 through 9. Additional comments are provided 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 Glasgow quadrangle, and are generally consistent with the geophysical log interpretations of other authors for this area (e.g., Rice, 1976, 1981; Condon, 2000; Gunderson and Furer, 2017). Nomenclature for the interval between the top of the Fall River Fm and the top of the Mowry Fm varies, and is discussed in detail by Condon (2000).

Triassic–Jurassic

One Triassic and four Jurassic age tops are included in this study (fig. 5). Jurassic strata are primarily composed of thick marine limestones and shales that unconformably overlie Triassic strata. Our correlations for the Jurassic Piper and Nesson Fms follow Nordquist (1955).

- The Triassic Spearfish Fm is 100–150 ft thick in the northwestern portion of the Glasgow quadrangle, and thins to the southwest. It is absent west and southwest of the eastern edge of the Bowdoin Dome. The top of the Spearfish Fm is truncated by the Early Jurassic unconformity, resulting in removal of the Spearfish Fm southwest of its zero line shown in plate 7.

- We picked the informal "Piper limestone" [Firemoon Member (Mbr) of the Jurassic 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 where the Nesson and Piper Formations pinch out due to depositional onlap onto an eastward extension of the Belt Island high (Imlay and others, 1948). In the southwestern corner of the quadrangle, the Rierdon Fm rests unconformably on dolomites and limestones of the Mississippian Mission Canyon Fm.

- The top of the Swift Fm is a difficult stratigraphic pick and should be used with caution. It is identified as the top of a gradually increasing resistivity log profile, just below

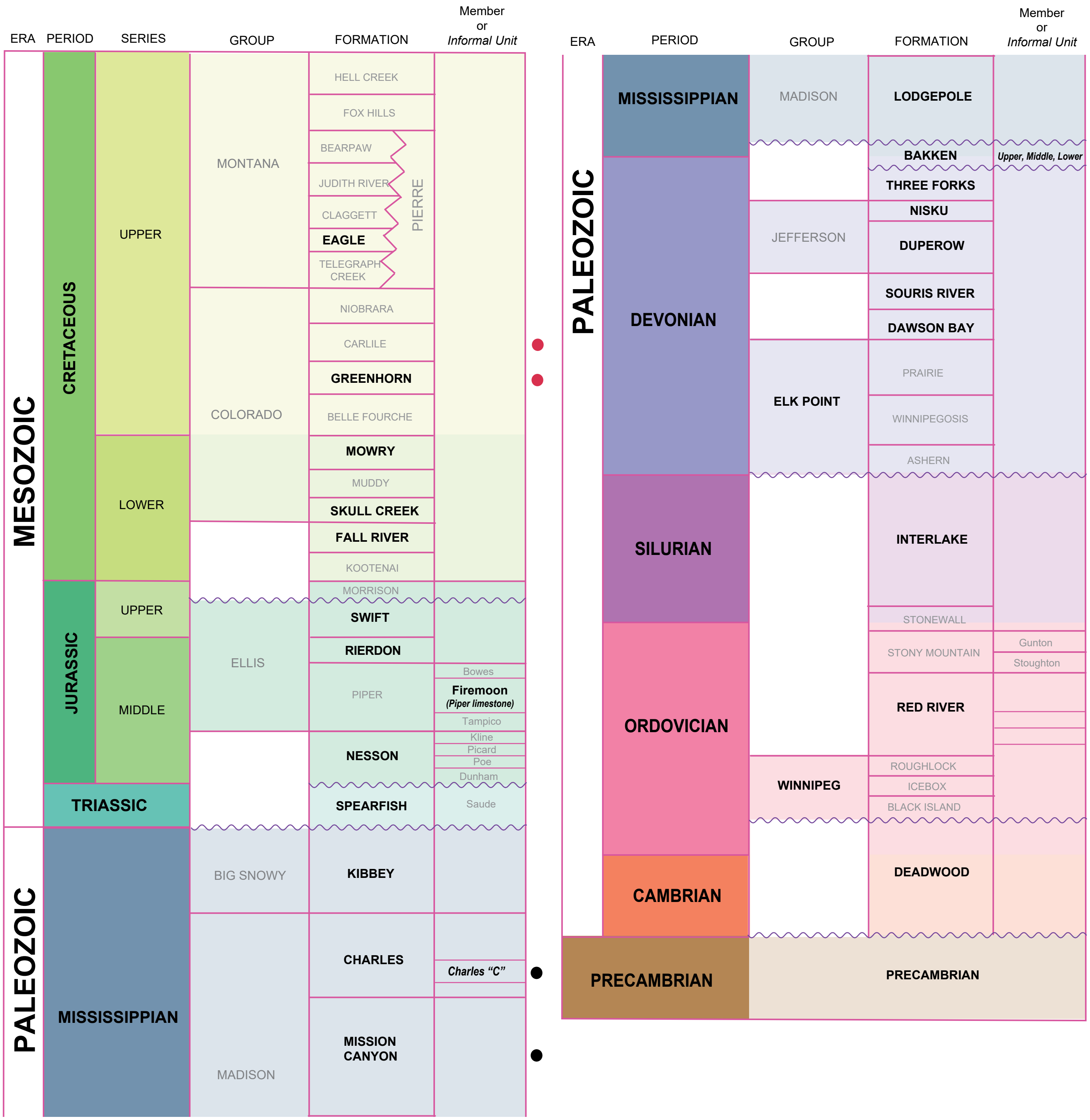

Figure 3. Stratigraphic column for the Glasgow quadrangle (modified from Sandberg, 1962; Balster, 1980; and Murphy and others, 2009). The stratigraphic tops identified in this study are bolded in black type, and include formal groups, formations, formation members, and informal subunits. Group and formation names that are grayed out were not analyzed, but are presented here for stratigraphic context. Dots to the right of the stratigraphic column indicate the major oil-producing (black) and gas-producing (red) zones within the quadrangle.

the thick Lower Cretaceous channel sands. Indications of glauconite on sample logs help to identify the top of the Swift Fm, but sample logs can be inaccurate.

Pennsylvanian–Permian

There are no known Pennsylvanian or Permian strata present in the subsurface of the Glasgow quadrangle.

Mississippian

Stratigraphic picks of Mississippian age in this study belong primarily to the Madison Group. Although the overlying Big Snowy Group comprises, in ascending order, the Kibbey, Otter, and Heath Fms (fig. 3), the Heath, Otter, and the upper portion of the Kibbey Fms were removed by multiple erosional events from Early Pennsylvanian to Early Triassic time; only the lower part of the Kibbey Fm remains along the southeastern border of the quadrangle. It can be difficult to distinguish between clastic sediments of the Kibbey Fm and the overlying Spearfish Fm on geophysical logs (fig. 5).

Stratigraphic picks within the Madison Group are the top of the Charles Fm, Charles C, Mission Canyon Fm, and the Lodgepole Fm (fig. 6). The Charles Fm thins rapidly near the Williston Basin margin and is absent in the western half of the quadrangle. Our Charles C (also known as Ratcliffe) and Mission Canyon picks follow those of Longman and Schmidtman (1985) for the Lustre oil field, located along the eastern border of the Glasgow quadrangle. Accordingly, we put the top of the Mission Canyon Fm at the top of the clean (low gamma-ray), massive limestone (fig. 6). We recognize that many operators continue to use the traditional pick for the top of the Mission Canyon, placing it just below the “Richey shale.” The top of the Lodgepole Fm is picked on a subtle increase in the gamma-ray log reflecting an increase in argillaceous micrite, and signifying a change from clean, platformal carbonate deposition to deeper water, distal muddy carbonate deposition. The Mission Canyon and Lodgepole Fms can be difficult picks; they should be used prudently.

Devonian

Our Devonian correlations (figs. 7, 8) can be traced across most of the Glasgow quadrangle. The entire Devonian section thins from north to south onto the sporadically emergent Central Montana Platform, but the thinning is not consistent for all of the Devonian formations.

- The Bakken Fm is informally subdivided into lower, middle, and upper lithologic units (fig. 7). The upper and lower shales of the Bakken Fm have a distinctively high gamma-ray signature due to the organically enriched black shales. The Bakken Fm is absent in the southern portion of the Glasgow quadrangle due to depositional onlap and truncation by the Late Devonian–Early Mississippian unconformity (at the base of the Lodgepole Fm).

- We identified the top of the Elk Point Group rather than its constituent formations in the Glasgow quadrangle. The Elk Point Group comprises, in ascending order, the Ashern, Winnipegosis, and Prairie Fms (Ballie, 1955). While these three formations are readily distinguishable in the central portion of the Williston Basin, they become more difficult to separate westward, due in part to dissolution of the Prairie Fm evaporites and stratigraphic thinning and facies changes (dolomitization) of the Winnipegosis Fm (Sandberg and Hammond, 1958; Sandberg, 1962).

- Correlations of the Elk Point Group and the overlying Dawson Bay Fm are aided by the presence of “red shales” above and within the interval (fig. 8; Rader, 1953; LeFever, 2014). The Dawson Bay Fm consists of a carbonate unit overlying the “2nd red shale,” but southwest of the approximate limit of Elk Point deposition, the Dawson Bay Fm appears to be represented by a single 40- to 50-ft-thick dolomitic shale (sometimes with a very thin overlying carbonate).

- Both the Dawson Bay Fm and Elk Point Group thin to the southwest and may be absent in the southwestern corner of the Glasgow quadrangle. Because of the lack of well control, it is difficult to identify an exact location of the termination of these strata, but the depositional limits of the Dawson Bay Fm likely extend further west than those for the Elk Point Group (Sandberg and Hammond, 1958; Sandberg, 1961).

Precambrian–Cambrian–Ordovician–Silurian

The type log showing Cambrian, Ordovician, and Silurian formation picks is shown in figure 9.

- The top of the Interlake Fm is an unconformity that truncates progressively older strata to the southwest. In the southwestern corner of the quadrangle, the Interlake Fm is absent and the Late Silurian–Early Devonian unconformity truncates Ordovician strata (Sandberg, 1962).
- In the central portion of the Williston Basin, the top of the Red River Fm is typically a robust stratigraphic pick, defined in part by an overlying shale (Stoughton Mbr of the Stony Mountain Fm). As the Stoughton Mbr thins and disappears to the west toward the basin margins, the Red River top becomes increasingly difficult to correlate. Without this shale marker, dolomites of the overlying Stony Mountain and Stonewall Fms are not easily distinguished from dolomites of the Red River Fm (Sandberg, 1962). Our Red River Fm picks rely, in part, on the interpretations of well operators, NWGS logs, and various published and unpublished maps and cross-sections. They should be used with caution.
- The Winnipeg Group, about 150 ft thick along the quadrangle's eastern border, thins westward to a zero edge just east of the Bowdoin Dome. The medial shale (Icebox Fm of Carlson, 1960) undergoes a westward facies change from shale to sand, so the Winnipeg Group consists primarily of sandstone in the Glasgow quadrangle (Sandberg, 1962).
- The top of the Cambrian–Ordovician Deadwood Fm (Emerson Fm of Knechtel, 1956) typically exhibits markedly higher gamma-ray log readings than either the sandstone of the overlying Winnipeg Group or the carbonates of the Red River Fm when the Winnipeg Group is absent. A key lithologic component of Cambrian–Ordovician shales is the presence of glauconite. We relied on the presence of limestone and green glauconitic shale in lithologic descriptions to help identify the top of the Deadwood Fm.
- Only five wells in the quadrangle penetrated Precambrian rocks. The top of Precambrian can be a difficult pick; sample descriptions do not always appear to match log responses. Our Precambrian top picks are from Gunderson (2024).

RESULTS

The primary product from this study is a high-quality database of formation top depths for more than 800 petroleum exploration wells located in the Glasgow quadrangle. These data are contained in the Glasgow_tops_v1.xlsx file. The number of formation tops picked per well varies based on well depth and the availability of geophysical logs, but as many as 25 formation picks were made for the deepest wells. In the western half of the Glasgow quadrangle, only 25 wells were drilled deep enough to reach Paleozoic formations; 20 of these were drilled prior to 1990 and have poorer quality geophysical logs for interpretation. Both the lack of deep wells and the lack of modern log data make it difficult to correlate Paleozoic units with confidence in the western half of the quadrangle.

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 have 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 have impacted formation distribution and thickness in the Glasgow quadrangle. The most apparent are the sequence boundaries that occurred during the Late Silurian–Early Devonian, Late Mississippian–Early Pennsylvanian, and the Early Jurassic (Carlson and Anderson, 1965). For example, the regional cross-section in plate 11 illustrates stratigraphic thinning of Mississippian, Triassic, and Jurassic formations to the southwest. This happened first by truncation of the Spearfish Fm and the Madison Group beneath the Early Jurassic Unconformity, followed by depositional onlap of Middle Jurassic strata onto the erosional surface. Plate 12 shows the corresponding subcrops beneath the Early Jurassic

Unconformity (colored areas). Dashed lines represent the approximate depositional limits of the Jurassic Nesson Fm and "Piper limestone." The cross-section line for plate 11 is also indicated.

Excel files containing the grid data used to generate structure and isochore maps (plates 1–10) are provided in a single zipped file (Glasgow_grid_files.zip). 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 the NAD83 datum.

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 provided here to generate additional subsurface maps and interpretations.

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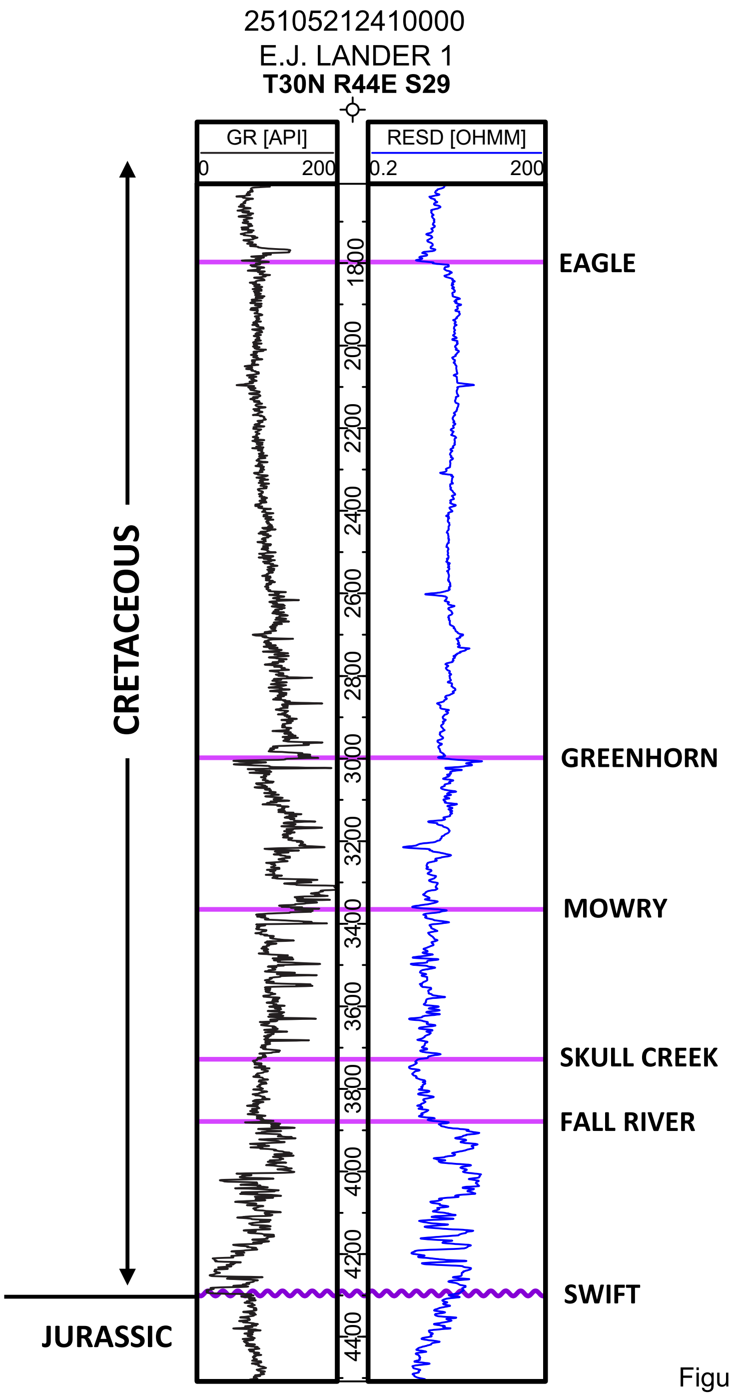

Figure 4. Type log for selected Cretaceous formation tops.

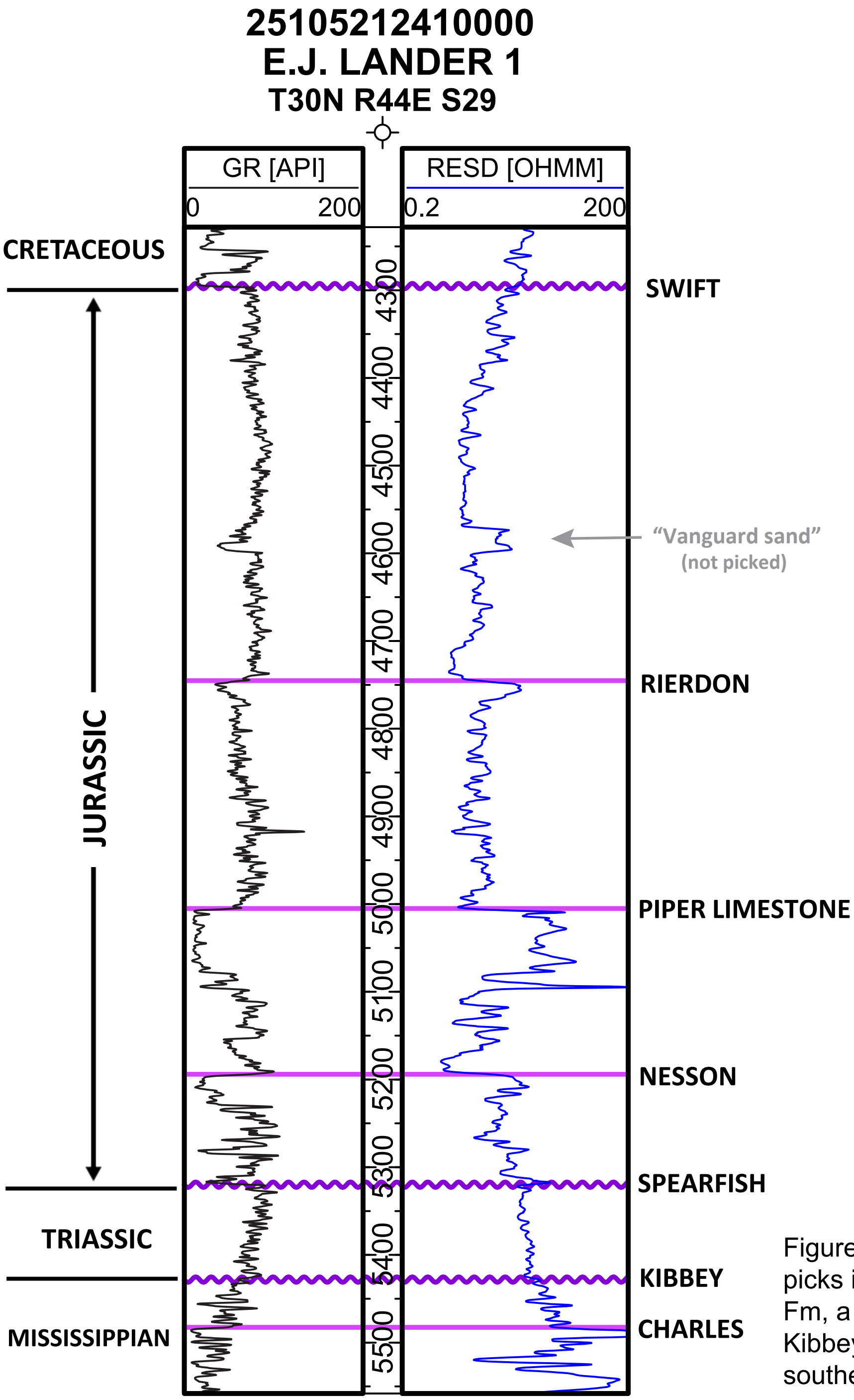

Figure 5. Type log for the Triassic and Jurassic picks in this study. Below the Triassic Spearfish Fm, a thin remnant of the lowermost portion of the Kibbey Formation (Mississippian) exists along the southeastern border of the quadrangle.

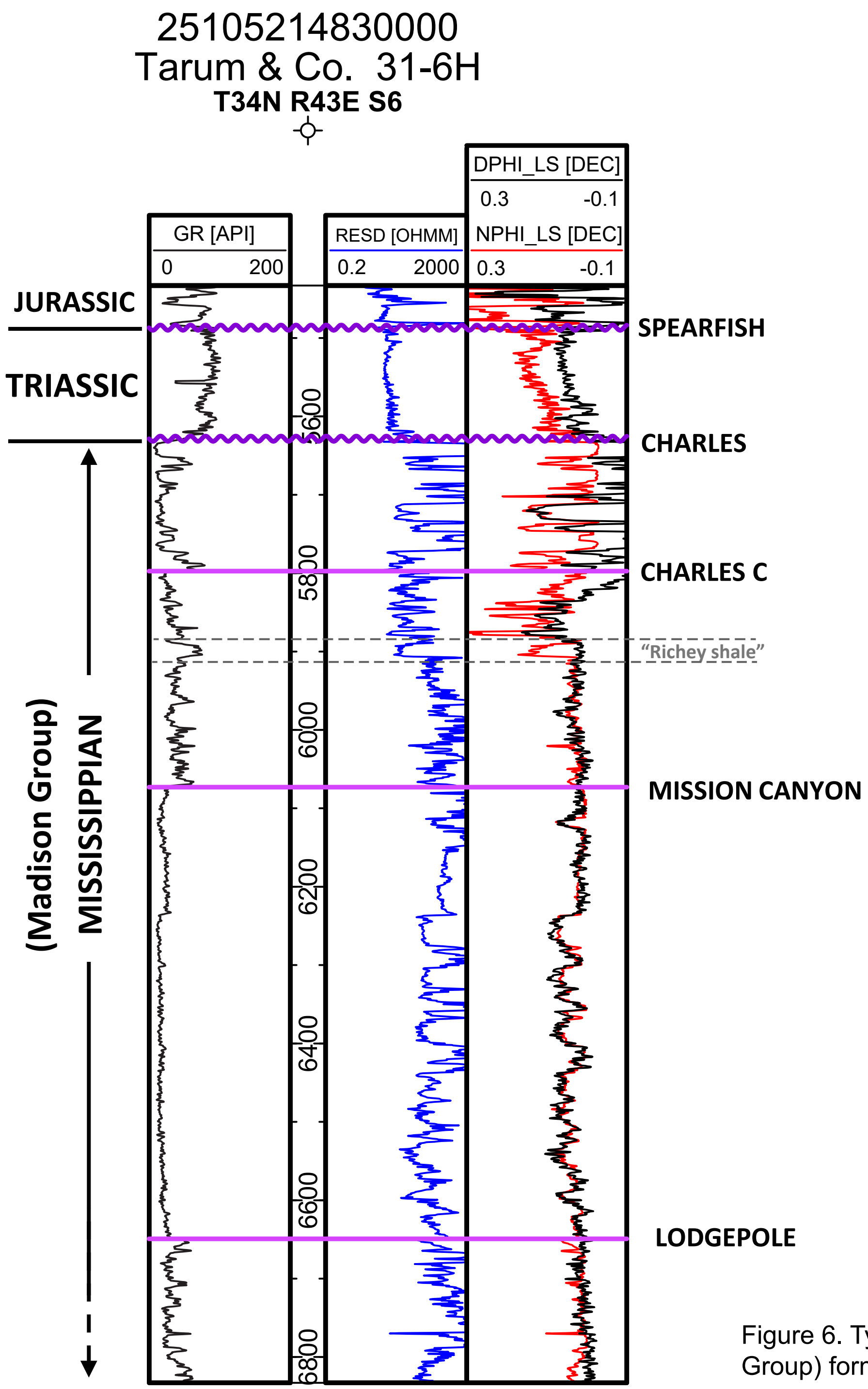

Figure 6. Type log for Mississippian (Madison Group) formation tops.

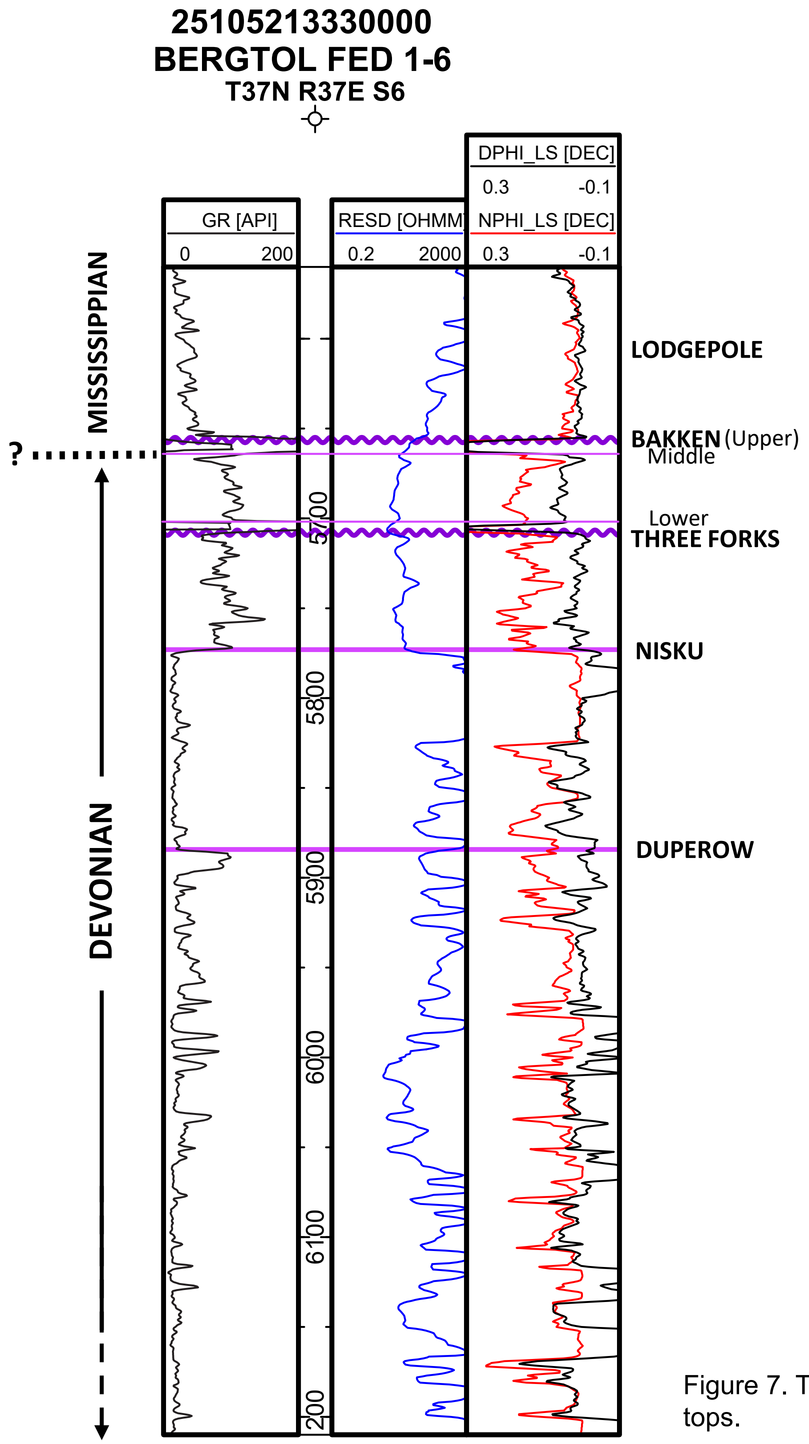

Figure 7. Type log for Upper Devonian formation tops.

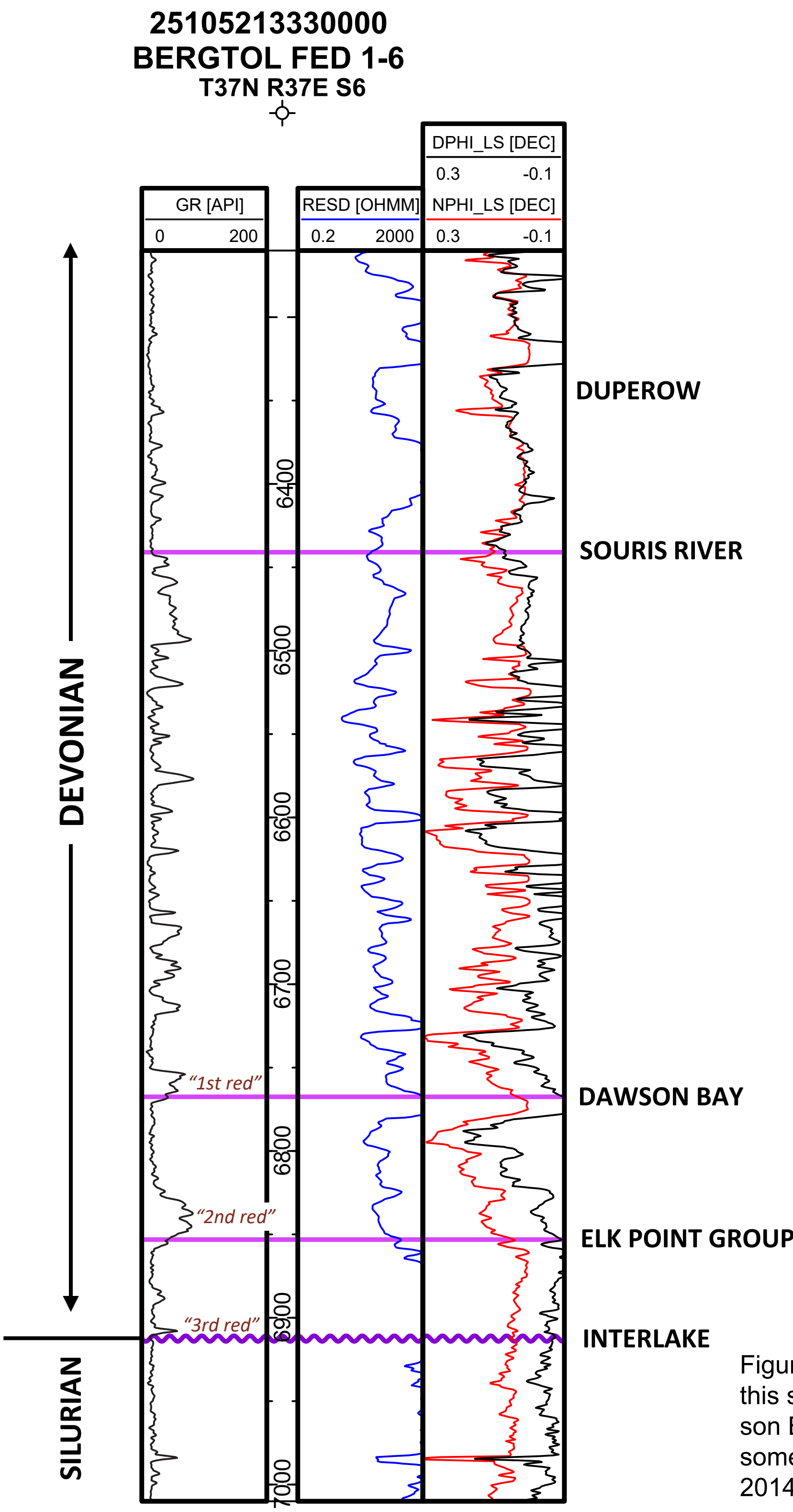

Figure 8. Type log for the Middle Devonian picks in this study. The "red shales" at the base of the Dawson Bay Formation and Elk Point Group help identify some formation boundaries (Radar, 1953; Lefever, 2014).

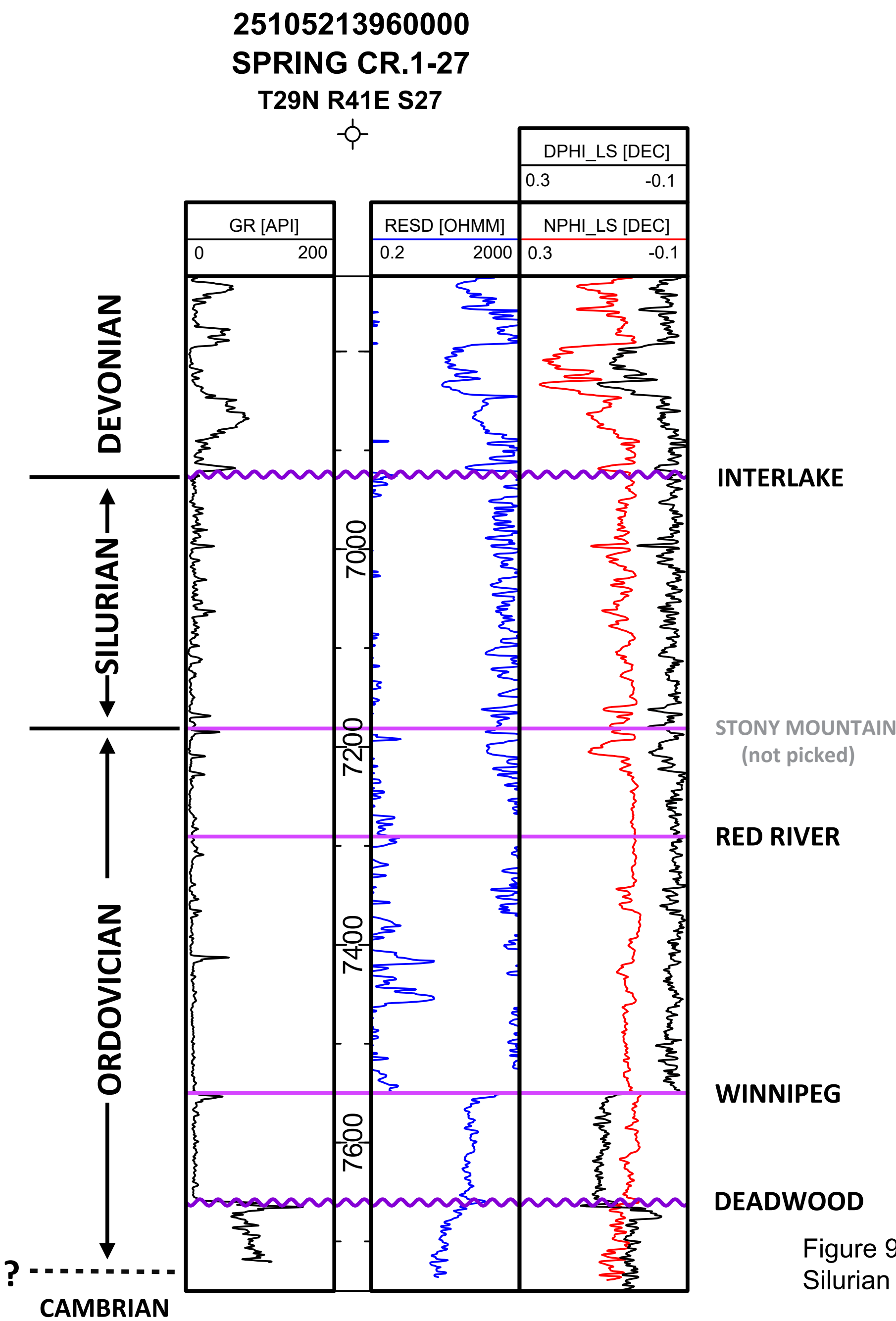

Figure 9. Type log for Cambrian, Ordovician, and Silurian formation tops.

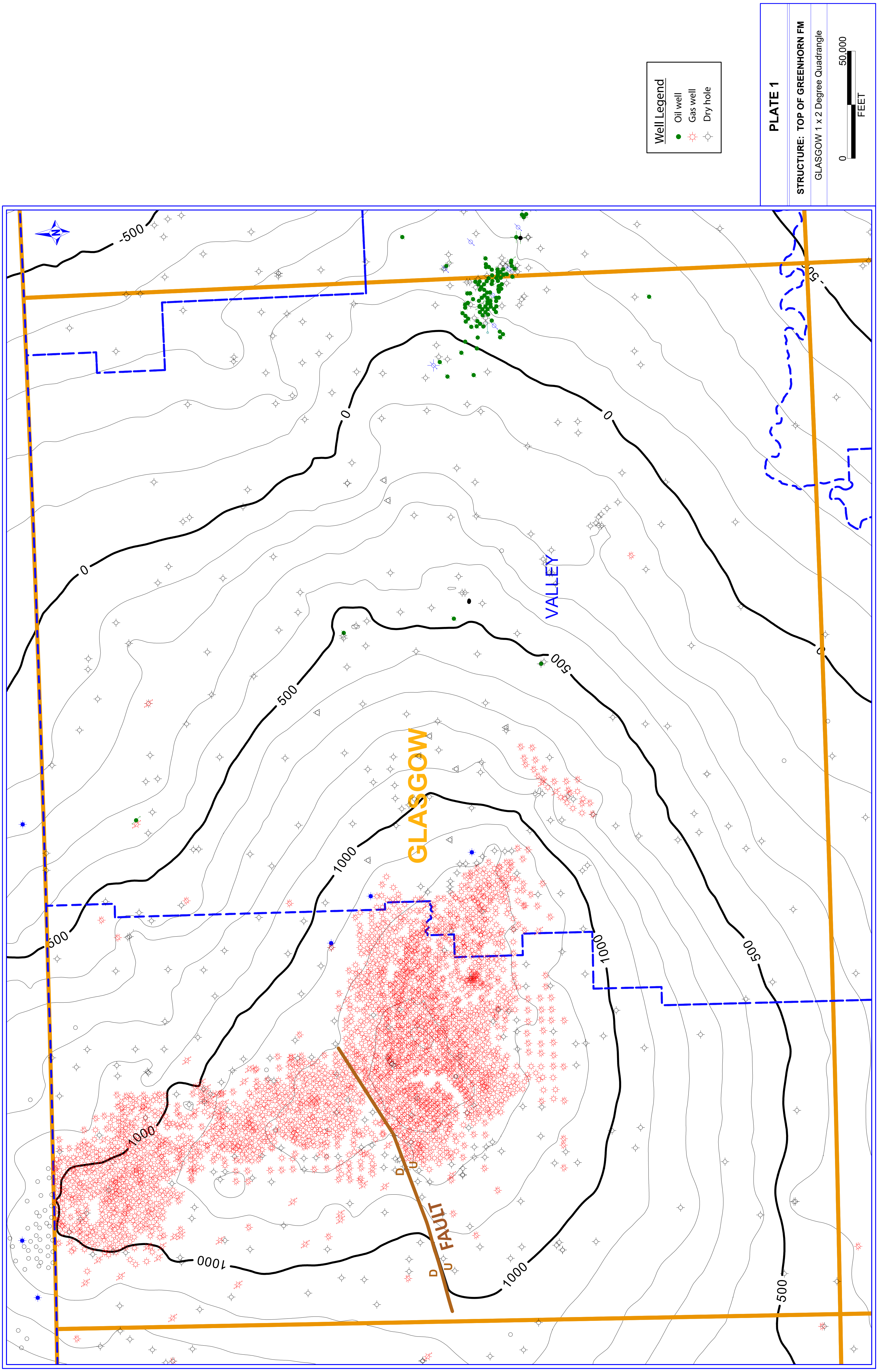

Plate 1. Structure map on the top of the Greenhorn Formation. The surface trace of a fault on the west side of Bowdoin Dome is shown as a thick brown line (Raforth, 1985).

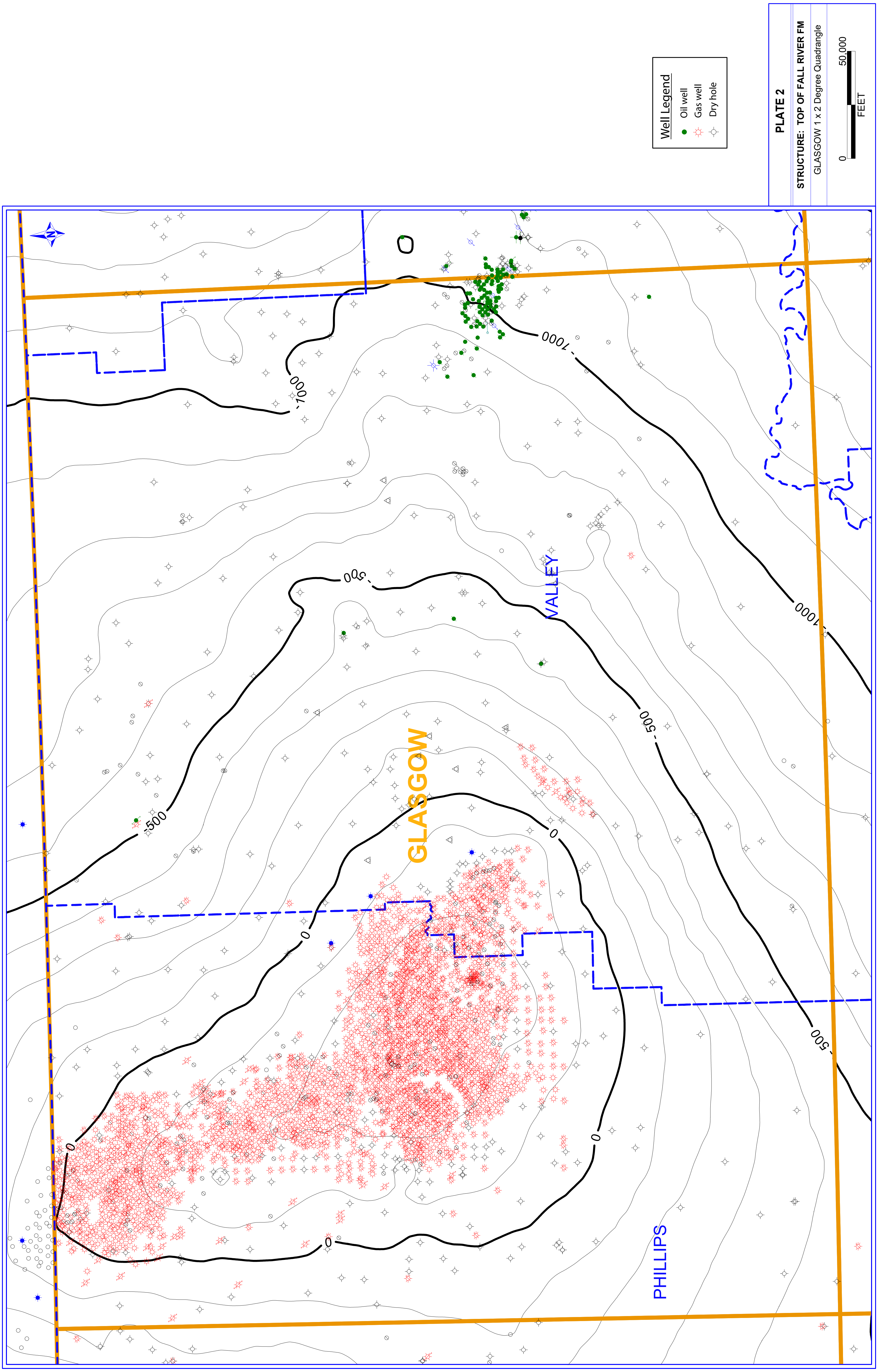

Plate 2. Structure map on the top of the Fall River Formation.

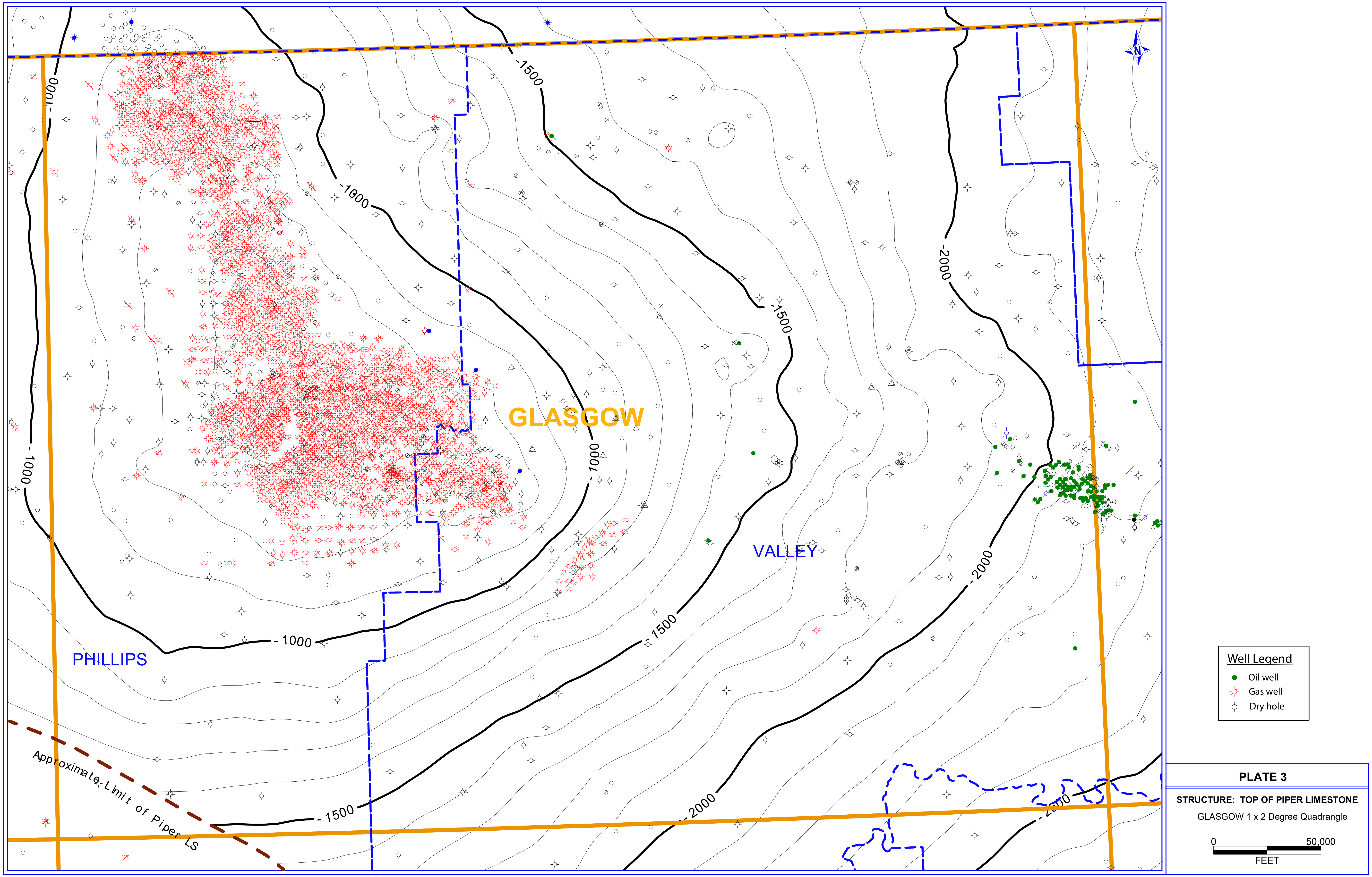

Plate 3. Structure map on the top of the “Piper limestone” (Firemoon Member of the Piper Formation). The Piper Formation is absent in the southwestern corner of the Glasgow quadrangle.

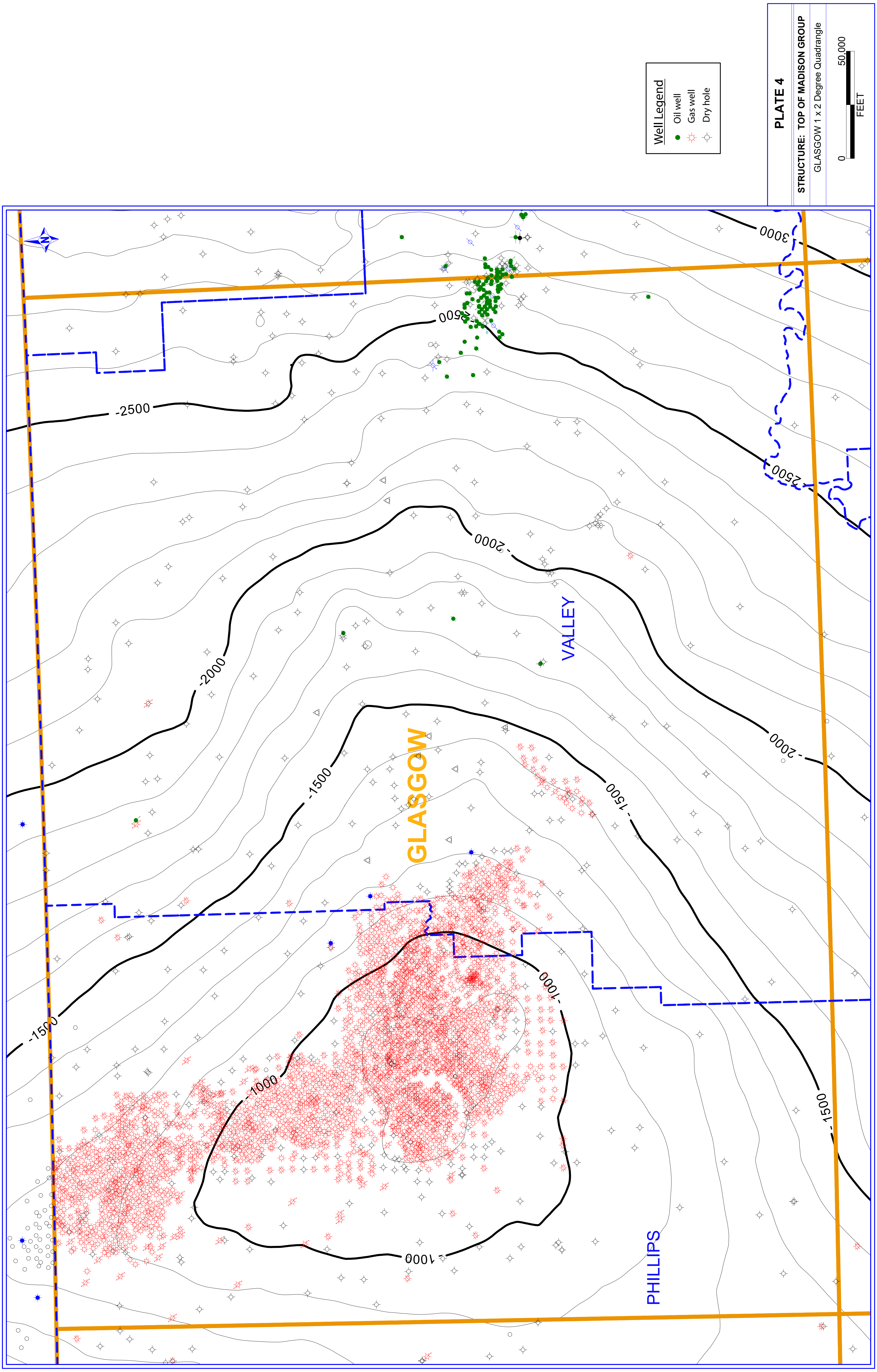

Plate 4. Structure map on the top of the Madison Group.

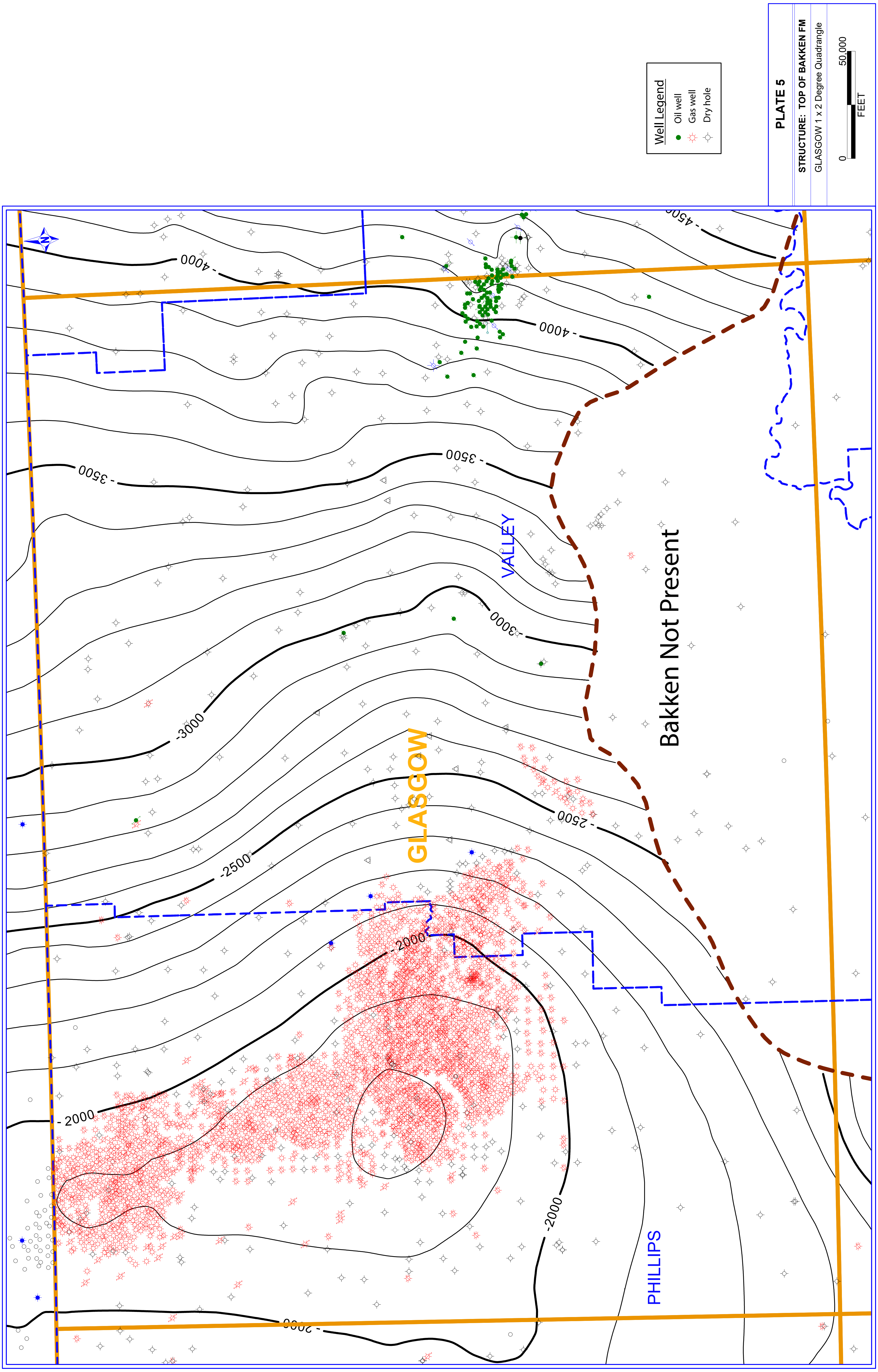

Plate 5. Structure map on top of the Bakken Formation. The Bakken Formation pinches out to the south and is not present in the southern portion of the Glasgow quadrangle.

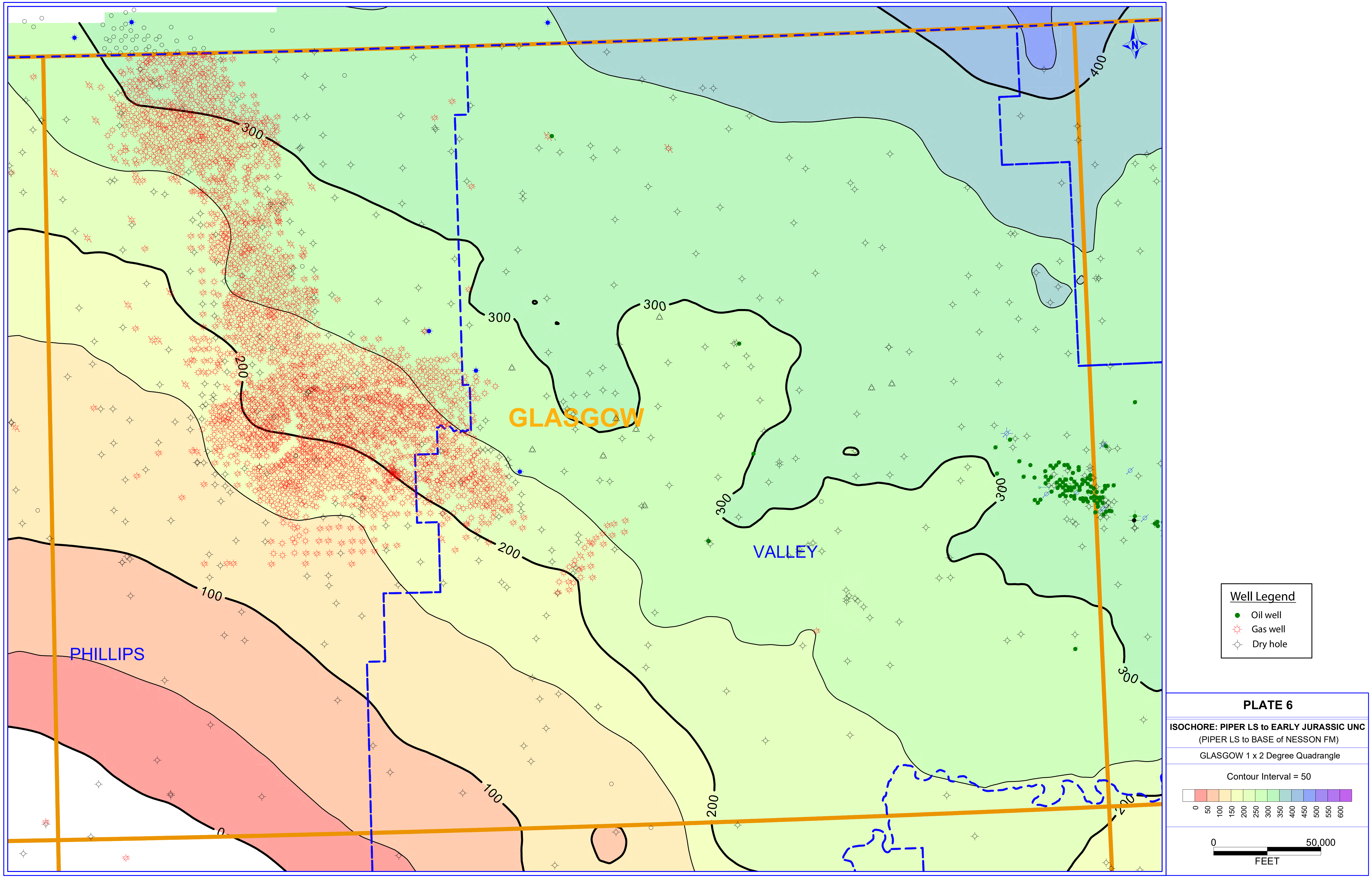

Plate 6. Isochore of the top of the “Piper limestone” to the Early Jurassic Unconformity (i.e. base of Nesson Fm). Thinning to the southwest is due to onlap of Jurassic sediments onto the Belt Island high (Imlay, 1948).

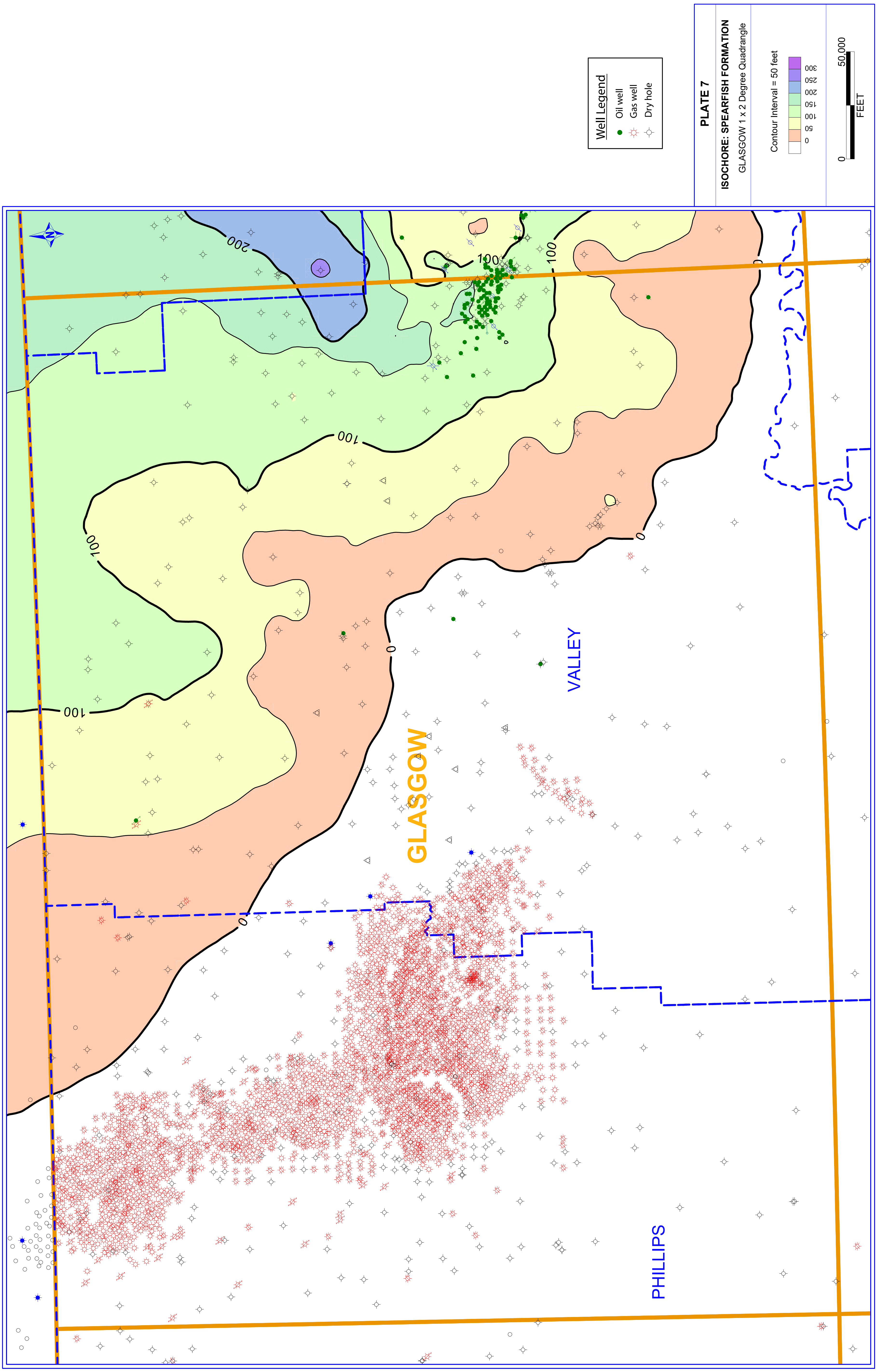

Plate 7. Isochore of the Spearfish Formation. The Spearfish Formation pinches out to the southwest due to onlap at the base and subsequent truncation at the top by the Early Jurassic Unconformity.

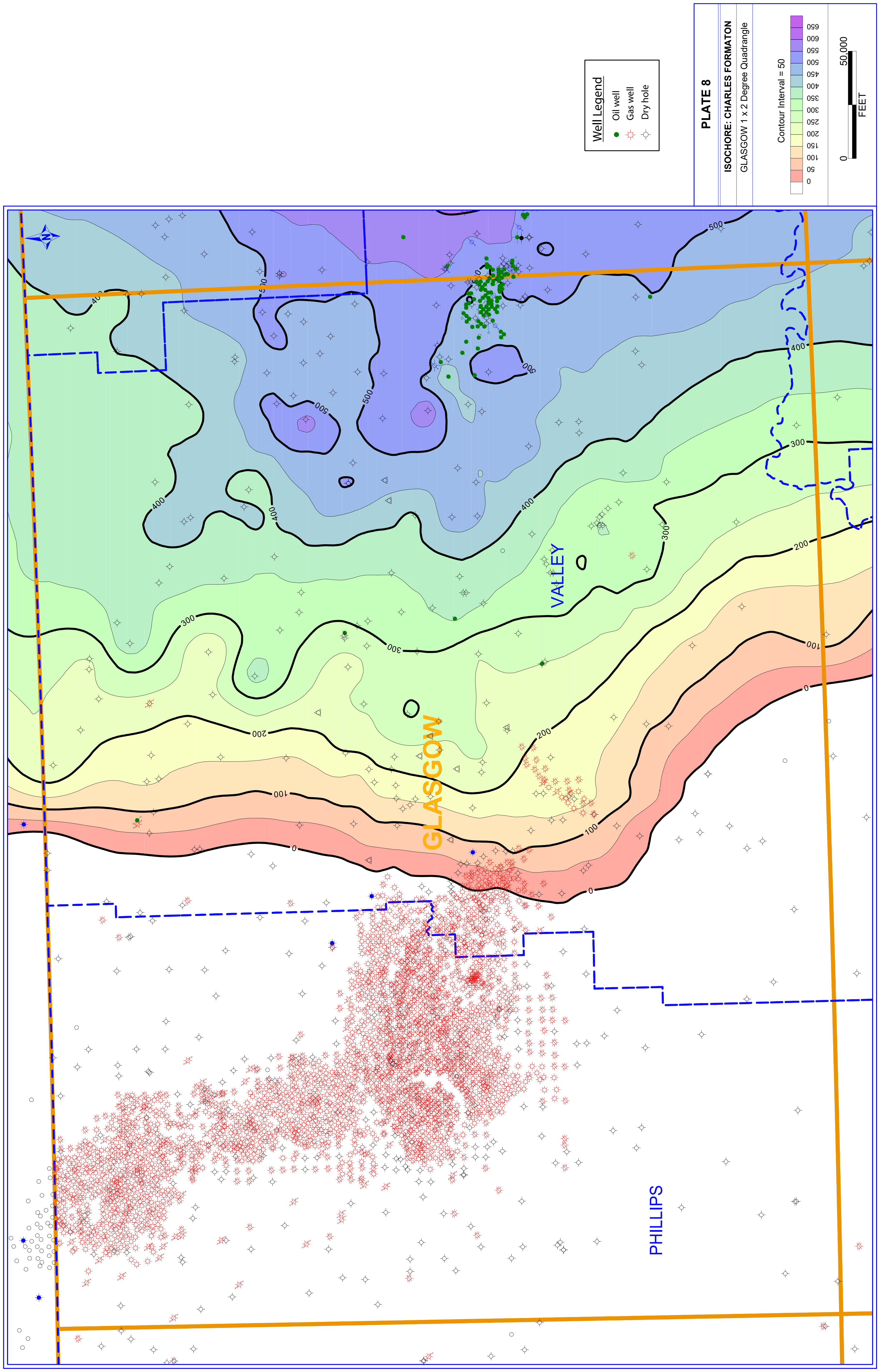

Plate 8. Isochore of the Charles Formation. The Charles Formation has been removed in the western half of the quadrangle, where Triassic and Jurassic strata directly overlie the Mission Canyon Formation.

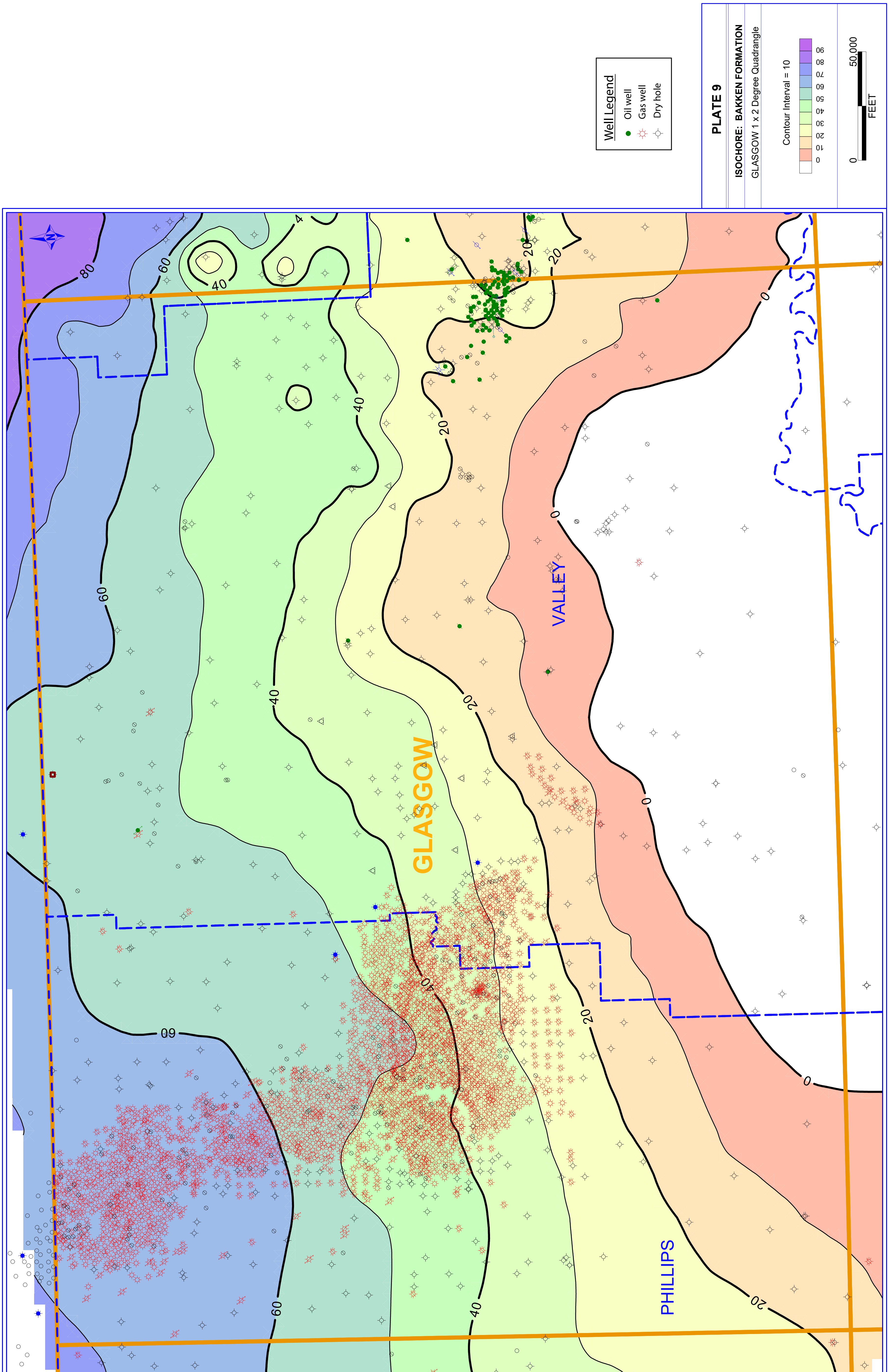

Plate 9. Isochore of the Bakken Formation.

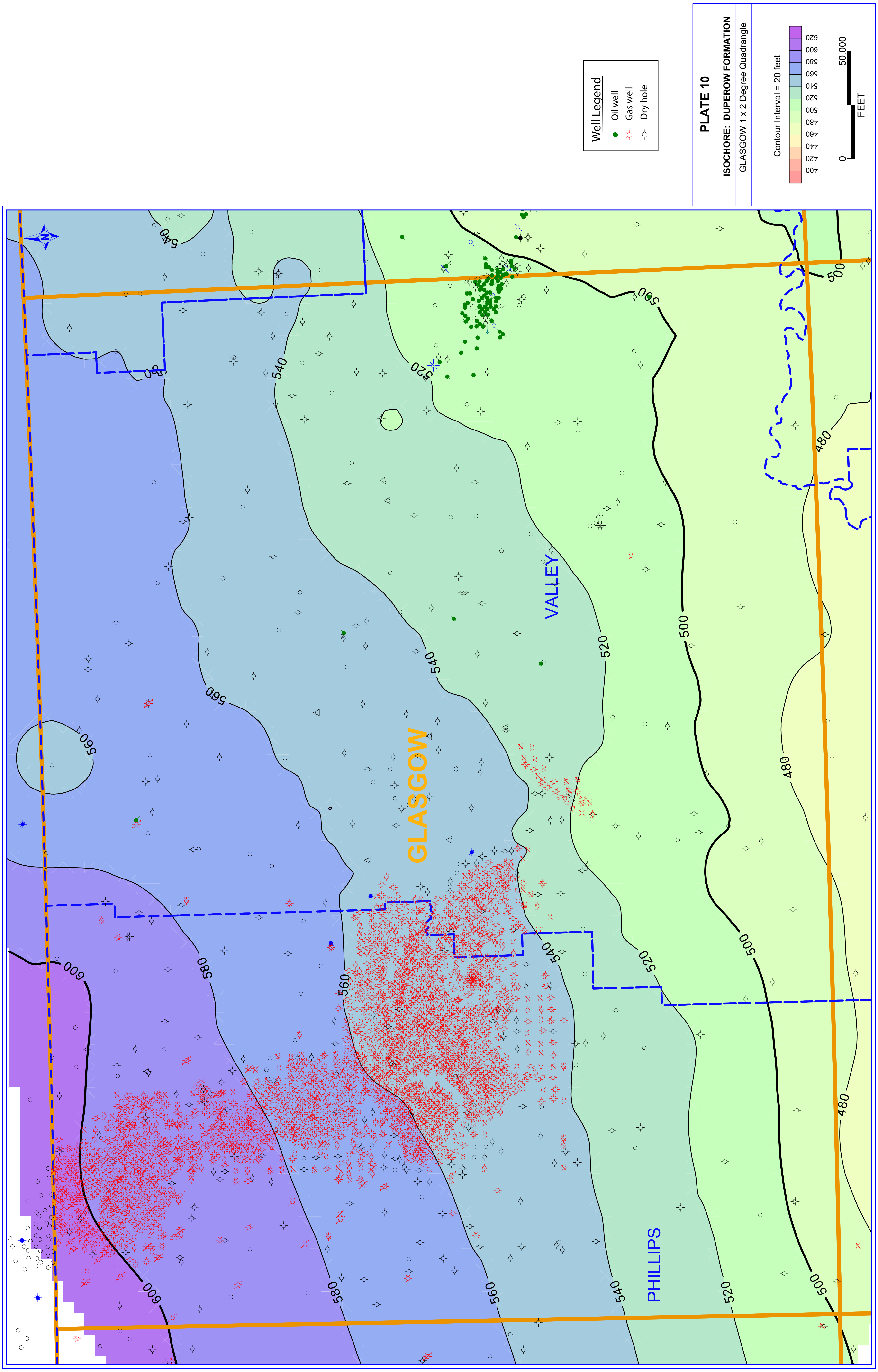

Plate 10. Isochore of the Duperow Formation.

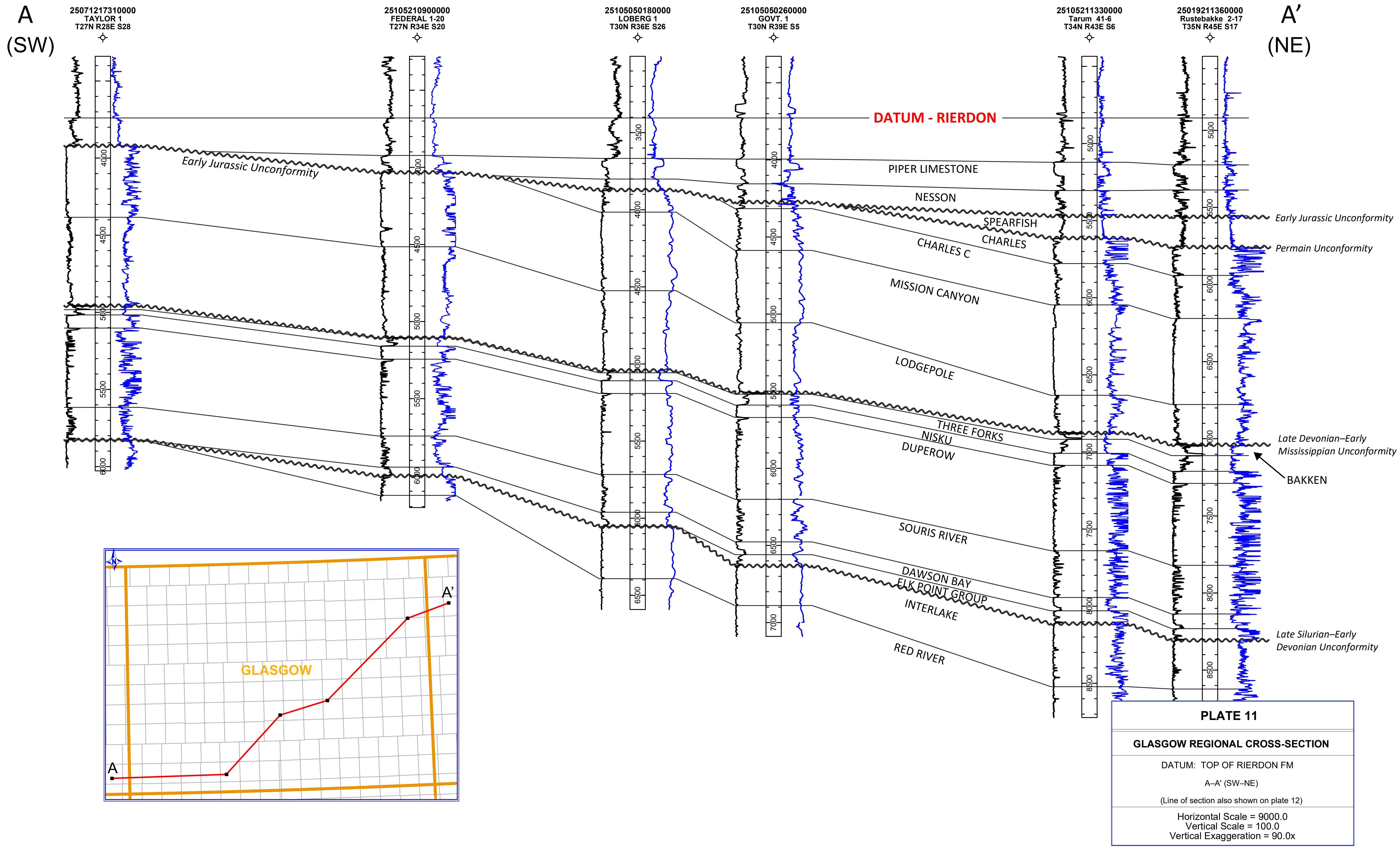

Plate 11. Southwest–northeast cross-section showing thinning of units to the southwest due to truncation of strata below major unconformities and onlap of the units immediately above the unconformities. The line of section is shown on plate 12.

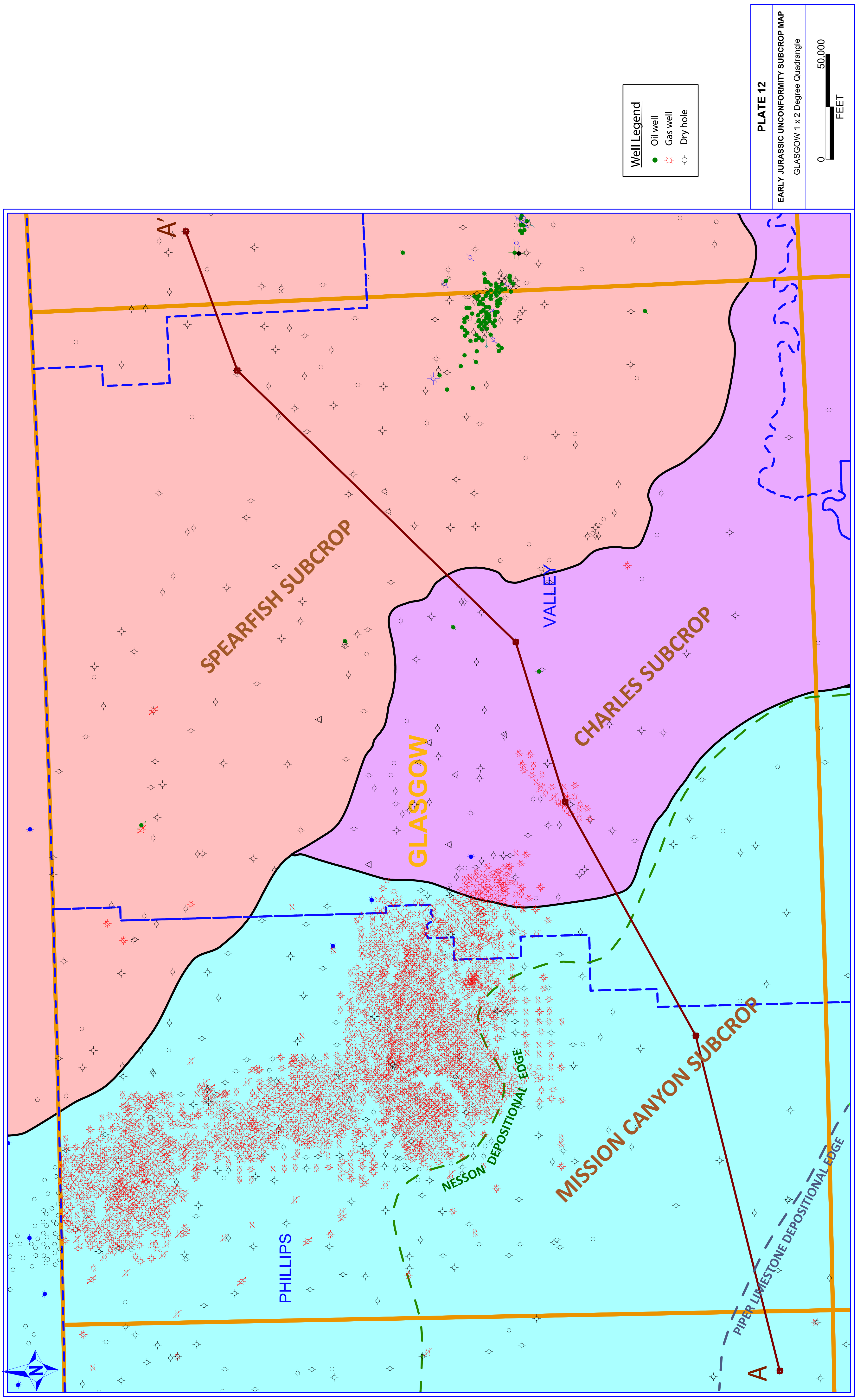

Plate 12. Subcrop map depicting the stratigraphic units beneath the Early Jurassic Unconformity (colored areas). The dashed lines indicate the depositional edges of Middle Jurassic units above the unconformity as they onlap onto the Belt Island high to the southwest (Imlay, 1948).