Report of Investigation 25

COAL RESOURCES OF THE LATE CRETACEOUS JUDITH RIVER AND EAGLE FORMATIONS, NORTH-CENTRAL MONTANA

Jay A. Gunderson

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MBMG
Montana Bureau of Mines and Geology

Cover photo: Coalbed in the upper Judith River Formation partially exposed north of Winifred, Montana (photo courtesy of Clay Schwartz, MBMG).

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INTRODUCTION

Coal-bearing formations blanket about two-thirds of eastern Montana (fig. 1). For the past 50 years, nearly all coal-exploration drilling, mapping, resource assessment, and mining in Montana have focused on the Tertiary Fort Union Formation located in the Powder River Basin, Bull Mountain Basin, and Fort Union Region (fig. 1). Coalbeds within the Fort Union Formation are thick, low-sulfur, and easily accessible for surface mining. Meanwhile, other coal-bearing regions have generally been ignored because their coal deposits are considered uneconomic and/or because we lack data to properly evaluate resources in those areas. The purpose of this investigation is to identify coalbeds and estimate the amount of coal resources in Montana's north-central coal region—an area that includes portions of Blaine, Hill, Liberty, Chouteau, Fergus, and Phillips Counties (fig. 1).

Coal in Montana's north-central region has not been studied since the early 20th century reconnaissance mapping by Pepperburg (1910, 1912), Bowen (1914a, 1914b, 1914c), and Pierce and Hunt (1937). They identified coalbeds in the Eagle and Judith River Formations but concluded the beds were too thin and lenticular for commercial operations. Based on these early maps, Combo and others (1949) reported just 120 million short tons of subbituminous coal reserves for the region.

Today we have subsurface data that allow us to re-evaluate the coal resources in north-central Montana. Thousands of oil and gas exploration wells have been drilled in the region during the past several decades, and we can use geophysical log data from these wells to identify coal in the subsurface. In southwestern Saskatchewan, Frank (2006) used geophysical logs to identify 48 x 109 m^3—or about 69 billion short tons—of coal resources in the Belly River Formation (equivalent to the Judith River Formation of Montana). The Belly River coalbeds lie along a 70-mi north–south trend just north of the U.S.–Canadian border and are likely to extend southward into Montana.

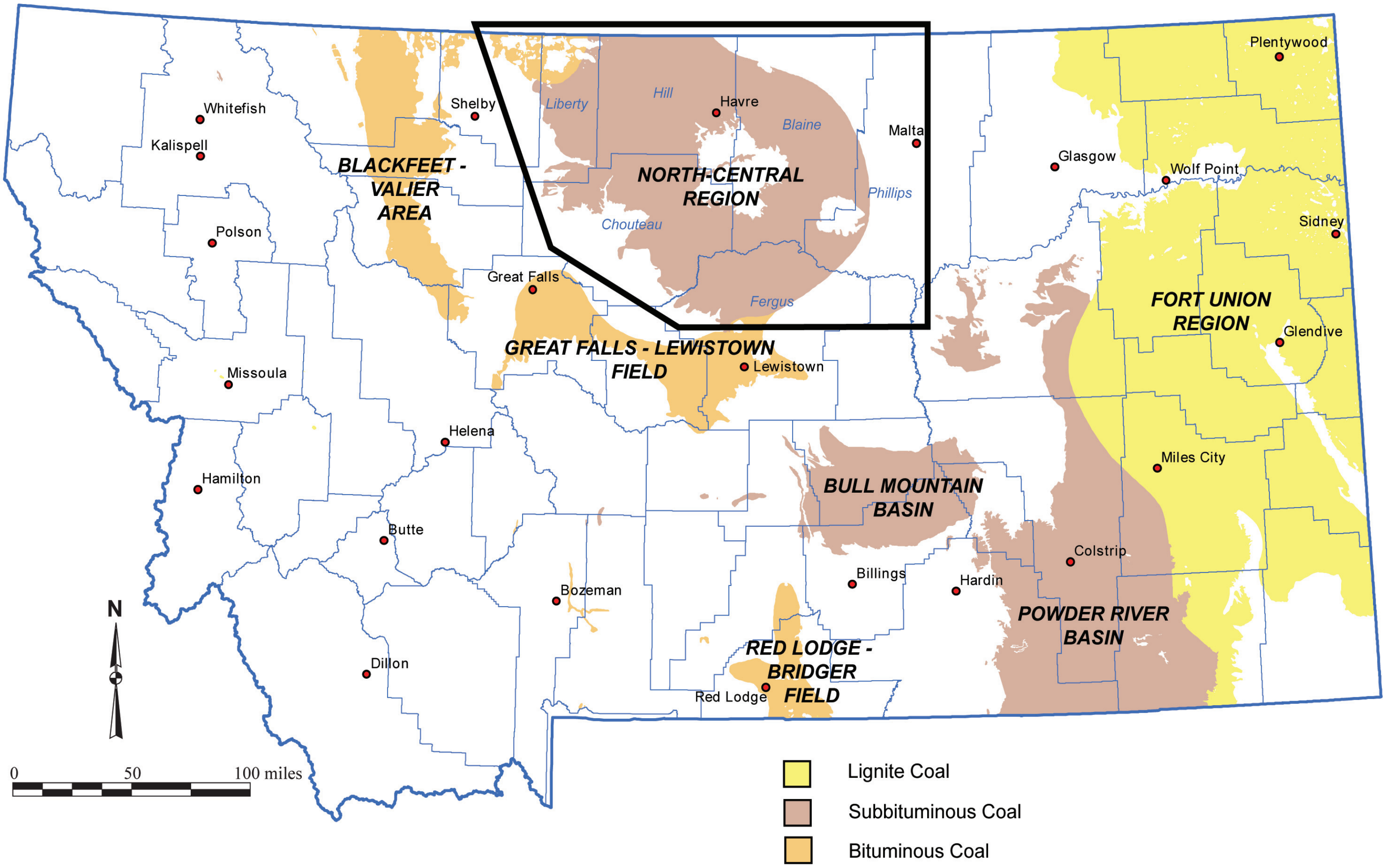

Figure 1. Coal regions of Montana (modified from Cole and others, 1982). The study area is outlined in black.

GENERAL GEOLOGY

The study area includes about 16,000 mi^2 of north-central Montana centered on the Bearpaw Mountains (fig. 2). The area is bounded on the south by the Highwood, Moccasin, and Judith Mountains and extends north to the Canadian border. Its western and eastern limits coincide with two prominent geologic structures: the Sweetgrass Arch and Bowdoin Dome, respectively.

Late Cretaceous sedimentary rocks dip gently eastward off the flank of the Sweetgrass Arch, exposing progressively younger geologic units from west to east (fig. 2). Sedimentary rocks of the Montana Group formed along the margins of the Western Interior Seaway and record at least two major cycles of marine regression and transgression (fig. 3; Gill and Cobban, 1973; Catuneanu and others, 2000). The Claggett and Bearpaw Formations are marine shales deposited in relatively deep water during periods of sea level rise and flooding of the mid-continent region (marine transgression to highstand). The intervening Eagle and Judith River Formations are primarily near-shore and continental deposits (marine regression to lowstand). As the epicontinental sea retreated, eastward prograding deltas deposited alternating layers of marine and non-marine sandstone, siltstone, shale, and coal (Gill and Cobban, 1973; Mclean, 1971; Rice, 1980). Coalbeds formed in near-shore environments that remained at or near water table levels for long periods during marine transgressions and regressions. Coalbeds in both the Eagle and Judith River Formations tend to be thin (generally 2–3 ft thick), with a greater number of beds and thicker beds occurring in the Judith River Formation (Pepperburg, 1910, 1912; Bowen, 1914a,b,c; Pierce and Hunt, 1937). Coals are primarily subbituminous with heating values ranging from 7,500 to 9,500 Btu/lb on an as-received basis (Gilmour and Dahl, 1967).

The Bearpaw Mountains (fig. 2) are the erosional remnants of a large volcanic pile created by Eocene extrusive and intrusive igneous activity. They are cored by an elongate northeast–southwest-trending dome that probably formed from basement uplift during Laramide time (Baker and Johnson, 2000). Large blocks of sedimentary and igneous rocks slid off the central uplift, creating a series of shallow thrust faults concentrically arranged around the mountains (Reeves, 1924, 1946; Hearn, 1976). Faulted strata include the Eagle and Judith River Formations and the coalbeds they contain. Thus, faulting has a significant impact on coalbed distribution. The gravity-slide thrust faults surrounding the Bearpaw Mountains also form important structural traps for gas accumulations in the Eagle Formation (Maher, 1969; Baker and Johnson, 2000). Most wells within the study area were drilled in known gas fields.

Quaternary glacial till conceals bedrock geology over most of the study area other than immediately south and southeast of the Bearpaw Mountains (fig. 2). In the plains, away from mountains and fault blocks, coal exposures are limited to stream cuts, ravines, and other topographic lows.

METHODS

More than 8,000 petroleum exploration wells have been drilled in the study area since the 1970s. Raster images of geophysical well logs were obtained from MJ Systems of Calgary, Alberta, and basic well data (location, elevation, formation tops, etc.) from the Montana Board of Oil and Gas (MBOG, 2013). These data were imported into IHS Markit's PETRA software for analysis.

Nearly one-half of the 8,000 wells were excluded from final analysis because they either lacked the proper geophysical logs for interpretation or had such poor quality logs that coalbeds could not be picked reliably. For the remaining 4,300 wells, logs were analyzed from the bottom of surface casing to the base of the Eagle Formation up to 2,500 ft deep. Coalbeds were identified on the basis of low gamma ray, low density, high neutron porosity, and high resistivity log readings (fig. 4). True vertical depth (TVD) logs were used for approximately 50 directionally drilled (i.e., non-vertical) wells. The locations, depths, and thicknesses for coalbeds identified during this study are available from the MBMG Data Center (COAL database: http://www.mbmg.mtech.edu/datacenter/datacenter.asp).

Coal resources can be classified in several ways depending on coal rank (heating value), thickness, depth, reliability category (distance from point of measurement), and whether or not they are considered

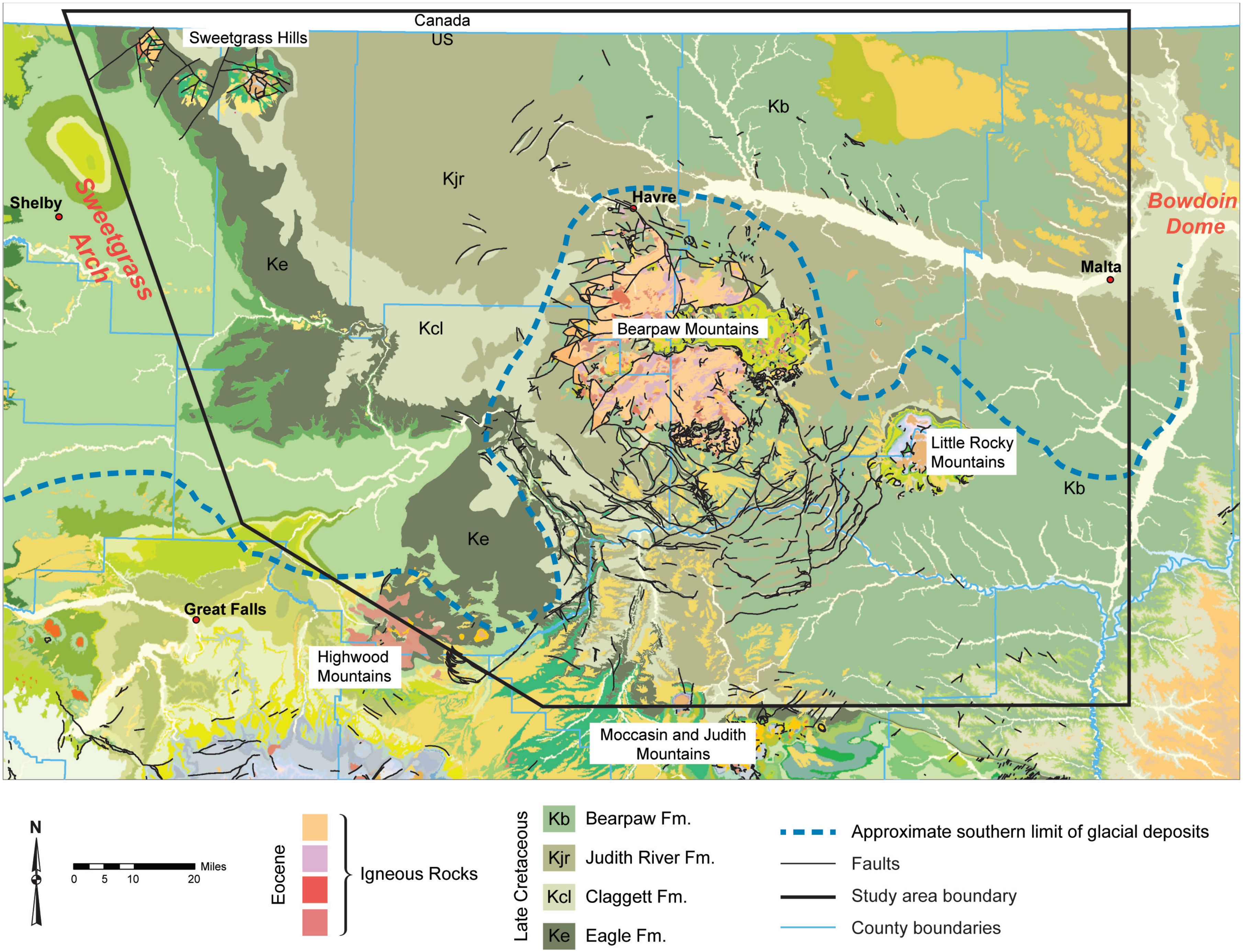

Figure 2. Geologic map of the study area (modified from Vuke and others, 2007).

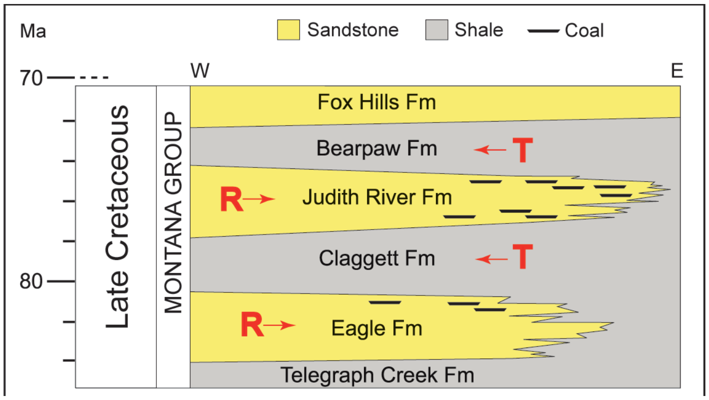

Figure 3. Stratigraphic and depositional schematic of Late Cretaceous Montana Group. Direction of shoreline migration during marine transgressions (T) and regressions (R) shown in red.

economically producible at the time of classification (see sidebar below). The goal of this investigation was to assess the distribution and amount of coal resources and to estimate reserve base tonnage. Reserve calculations depend on current economics and were not included for this study.

Total coal resources for each well were computed by summing the thicknesses of all coalbeds greater than 2.5 ft thick. Partings of up to 2 ft thick within coal seams were allowed provided the coalbeds above and below the parting were each at least 2 ft thick. Parting thicknesses were not included in the final coal resource numbers. Coal resource maps for the Judith River and Eagle Formations were generated by gridding the total coal resource at each well location with PETRA's least squares gridding algorithm (plates 1 and 2).

Selected Definitions for Subbituminous Coal Classification (from Wood and others, 1983)

Resources—coalbeds >2.5 ft thick and <6,000 ft deep.

Reserve Base (also Demonstrated Reserve Base)—coalbeds >5.0 ft thick and <1,000 ft deep and lying within ¾ miles of a point of measurement (e.g., outcrop or wellbore).

Reserves—that portion of the reserve base deemed to be economically producible at the time of classification.

The reserve base thickness at each well location was calculated by summing the thickness of all coalbeds greater than 5.0 ft thick and less than 1,000 ft deep (Wood and others, 1983). Reserve base thicknesses for each well were imported into Esri's ArcGIS, gridded using an inverse distance weighting algorithm, and "clipped" to a ¾-mile radius around each data point (fig. 5). The tonnage of demonstrated reserve base was computed by multiplying the gridded reserve base thickness by the area within the ¾-mile radius around each wellbore and an average density of 1,770 short tons/acre-ft for subbituminous coal (Wood and others, 1983).

RESULTS AND DISCUSSION

Coalbeds in the Judith River Formation are typically only 2–4 ft thick, but range up to 10 ft thick. The mean coalbed thickness is 3 ft. Coalbeds occur in two main coal zones, each about 100–150 ft thick—one just above the base of the formation and another just below the top of the formation (plate 3). In the upper coal zone (UCZ), as many as 8 to 10 individual beds can be present, with a cumulative coalbed thickness up to 30–35 ft. This is similar to what Frank (2006) reported for the upper part of the Belly River Group in Saskatchewan. The lower coal zone (LCZ) contains fewer coalbeds—typically 5 or 6 beds—that are equivalent to coalbeds within the Ribstone Creek Member of the Belly River Group (Frank, 2006). Although individual coalbeds in the Judith River Formation are difficult to correlate from well to well, the two primary coal zones can be traced for tens of miles in the subsurface, particularly in the northern part of the study area furthest from the faulting associated with the Bearpaw uplift (plate 3).

Most of the coal resources identified in the Judith River Formation occur in northern Hill County, northwestern Blaine County, and southern Blaine County along the southeast margin of the Bearpaw Mountains (plate 1).

In northern Hill and Blaine Counties, large coal resources are due to an increase in the number of coalbeds present in the Judith River Formation's upper and lower coal zones (plate 3). In Blaine County, the UCZ contains as much as 35 ft of coal at depths of 400–800 ft. Up-dip to the west in Hill County, erosion has removed the UCZ but there is an increase in the

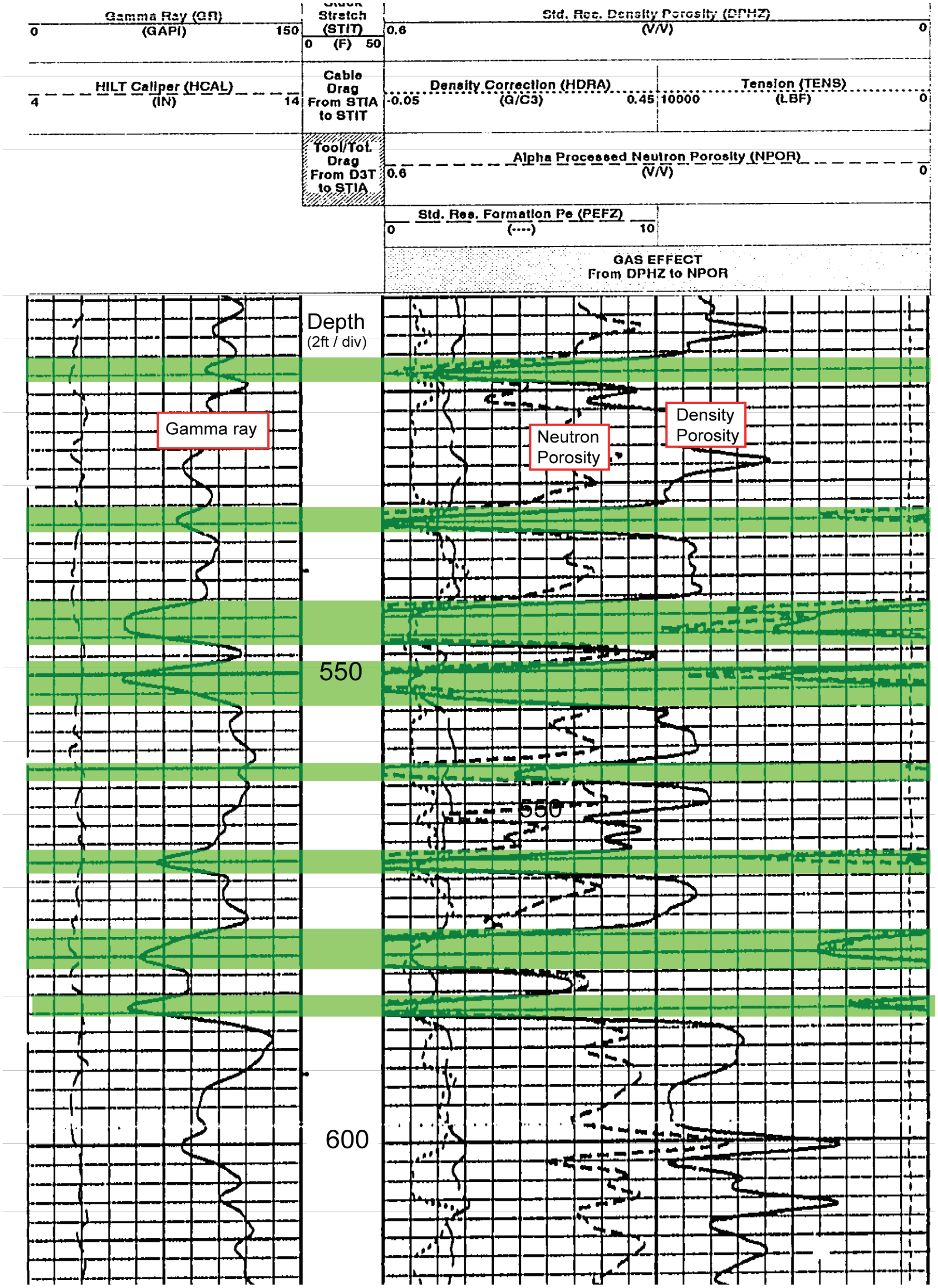

Figure 4. Example of coalbed picks in the Judith River Formation from the Northwestern Corp. Battle 7-26 well (API = 25005228830000). Gamma ray (solid line) in left-hand track; density (solid line) and neutron (short dashed line) logs in the right-hand track. Green shaded blocks are interpreted as coalbeds.

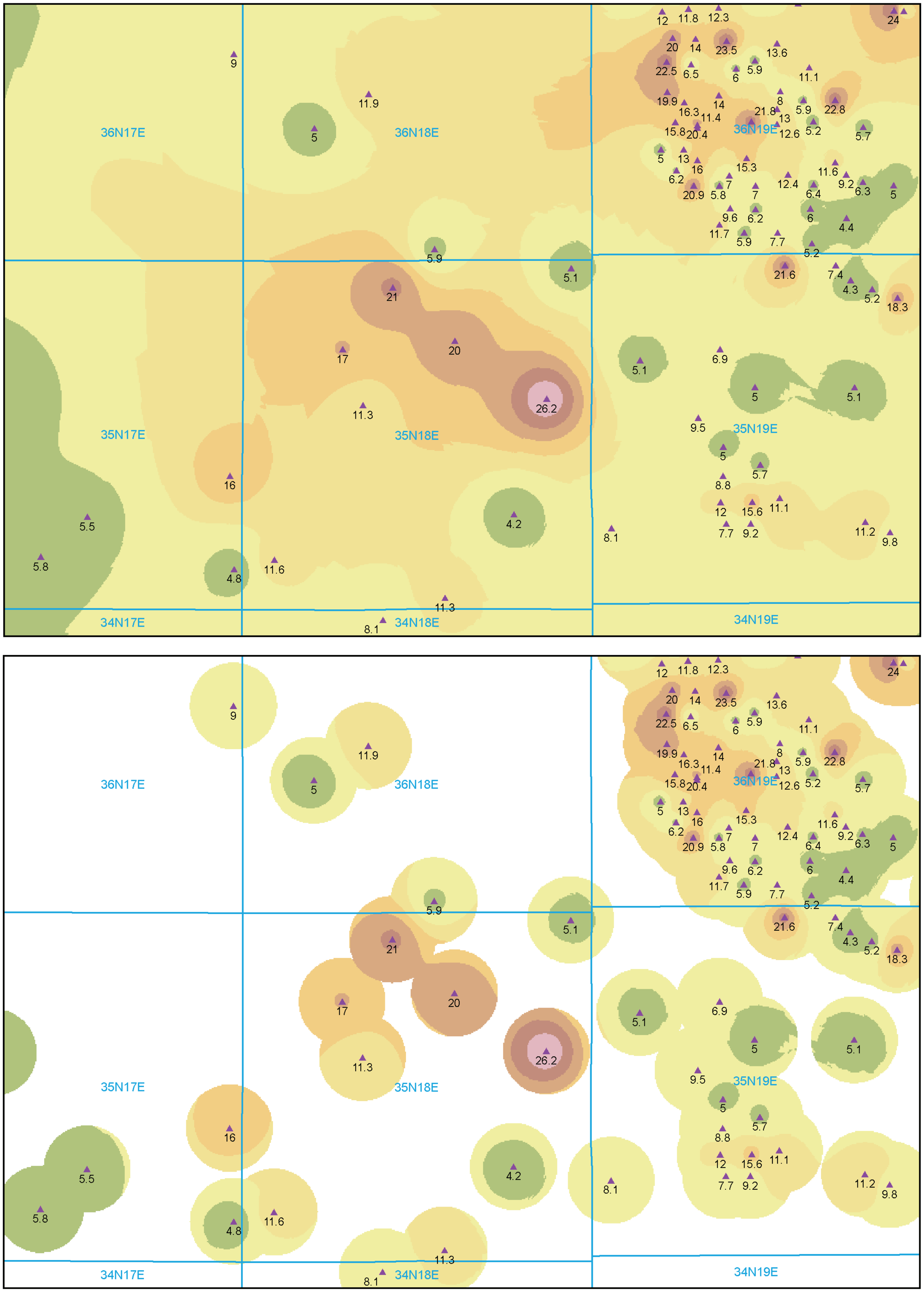

Figure 5. The steps to derive demonstrated reserve base included (1) summing all coalbeds greater than 5 ft thick for each well (total coal thickness shown at well locations); (2) gridding the total coal thicknesses using inverse distance weighting in ESRI ArcGIS (represented by colors in the upper display); (3) clipping the grid to a ¾-mile radius around each well (lower display); and (4) summing volumes around each wellbore (area x grid value) to get the total coal volume in acre-ft. The example is from northeastern Blaine County.

number of coalbeds in the LCZ. Interestingly, some of the most accessible coal resources probably lie between these two areas where the resource map indicates very little coal (plate 1). Here the UCZ lies close to the surface (0–200 ft depth), but coalbeds were not identified because well surface casings extend to depths of 200–300 ft and prevent log data acquisition. So, although shallow coalbeds in eastern Hill County (T. 34–37 N., R. 12–17 E.) would likely add several billion short tons to the reserve base, they cannot be included because they have not been measured.

Coal distribution around the Bearpaw Mountains is not as simple. Igneous intrusions and faulting have disrupted the stratigraphy and lateral continuity of coalbeds, making subsurface mapping of coalbeds difficult. Many wells have either repeat or missing stratigraphic sections due to faulting, and it is common for wells with considerable coal resources to be adjacent to wells with little or no coal. As a result, areas of high coal accumulation near the Bearpaw Mountains tend to be discontinuous and fault-controlled. Wells with repeat or missing section occur up to 20 mi north of the Bearpaw Mountains, suggesting that gravity-slide thrust faults may extend just as far north of the mountains as they do to the south. Fewer faults have been mapped north of the Bearpaw Mountains because they are covered by glacial till and difficult to detect by surface mapping (fig. 2).

The Eagle Formation typically contains just 1–3 coalbeds in the upper 100–150 ft of the formation, about 20–30 ft above the Virgelle Member sandstone (plate 3). Coalbeds average 2–3 ft thick but range up to 6 ft thick. Most of the coal in the Eagle Formation lies along a southeast–northwest trend from northern Fergus County along the western side of the Bearpaw Mountains to northern Liberty County (plate 2). Total coal resources per well are generally only 6 to 7 ft, but can range up to 15 ft in the northern part of the study area. In the heavily faulted area west of the Bearpaw Mountains, wellbores commonly penetrate two or even three repeat sections of Eagle Formation that each include coalbeds, leading to larger coal resources in that area.

Total coal resources for north-central Montana derived from plates 1 and 2 are estimated to be 70,600 million short tons (mst). The demonstrated reserve base from this study is 9,137 mst (table 1). Figures 6 and 7 show the distribution of data used to compute demonstrated reserve base for the Judith River and the Eagle Formations.

Table 1. Demonstrated reserve base in million short tons (mst) by county and formation.

	DEMONSTRATED RESERVE BASE (mst)		
COUNTY	Judith River	Eagle	Total
Blaine	6,331.8	0.0	6331.8
Chouteau	292.1	31.6	323.7
Fergus	135.0	0.0	135.0
Hill	1,530.4	442.8	1973.2
Liberty	79.2	280.6	359.8
Phillips	14.0	0.0	14.0
Total	**8,382.5**	**755.0**	**9,137.5**

SUMMARY

The 9,137 mst of demonstrated reserve base identified during this study have not been previously reported. They are added to Montana's existing reserve base of 118,629 mst (EIA, 2016) to get a new demonstrated reserve base for Montana of 127,766 mst.

To summarize the coal characteristics and coal distribution in Montana's north-central coal region:

- Coalbeds occur in the Judith River and Eagle Formations. They are generally thin—typically only 2–3 ft thick, but can range up to 10 ft thick. They are primarily subbituminous rank.
- There is more coal in the Judith River Formation than the Eagle Formation. The Judith River Formation has two primary coal zones; the best zone is in the upper 100–150 ft of the formation and contains as many as 8–10 individual coalbeds.
- Coal zones in the Judith River Formation are more continuous in the northern portion of the study area, away from faults and igneous intrusions associated with the Bearpaw Mountains.
- The largest concentrations of coal resources identified in this study occur in northern Blaine County, northern Hill County, and around the Bearpaw Mountains. However, the data are biased because (1) the highest well density and best quality log data come from recent gas well drilling, so areas of high coal resources tend to coincide with major gas fields, and (2) coalbeds from 0 to 250 ft deep could not be identified because of surface

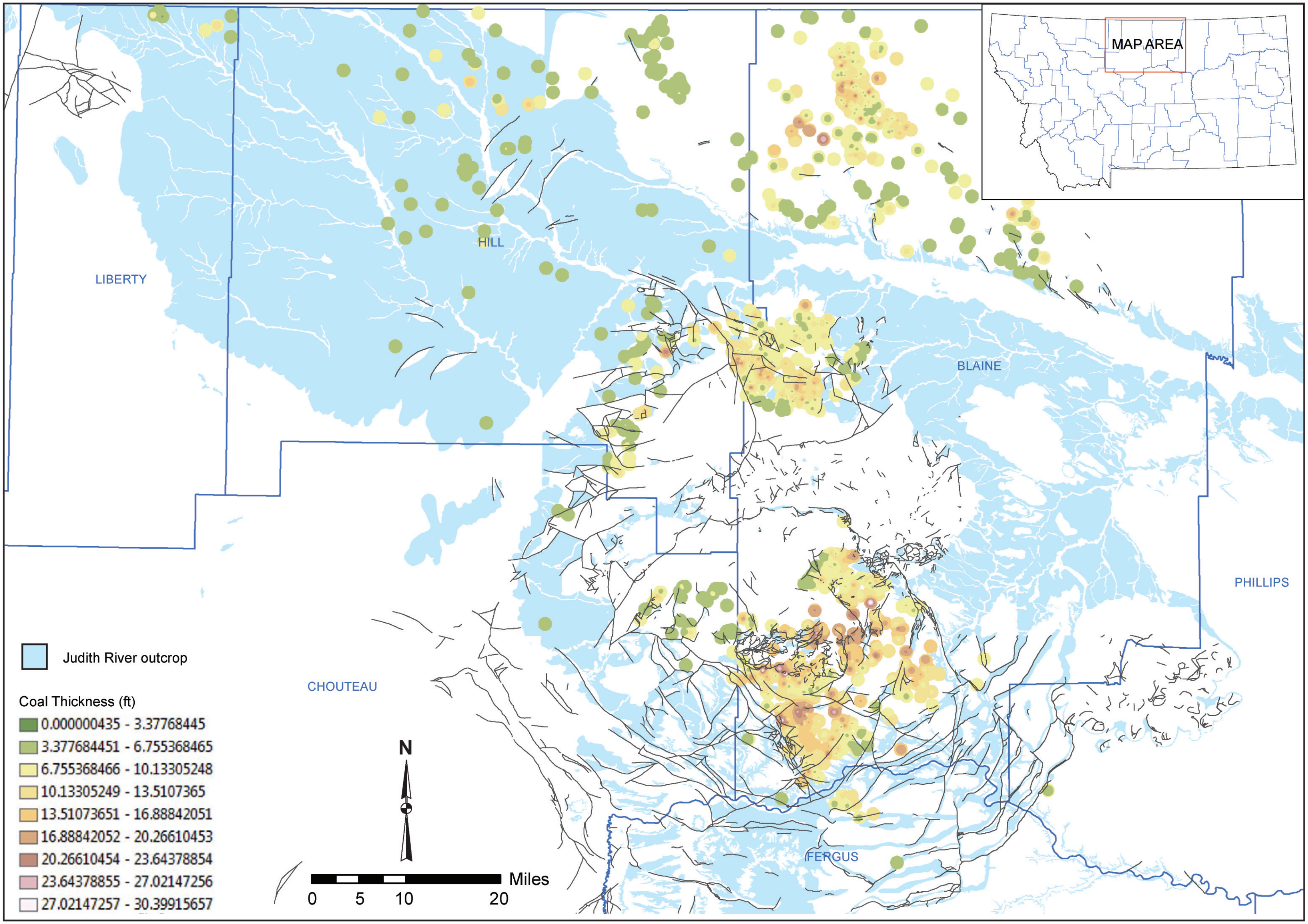

Figure 6. Distribution of data points included in demonstrated reserve base for the Judith River Formation.

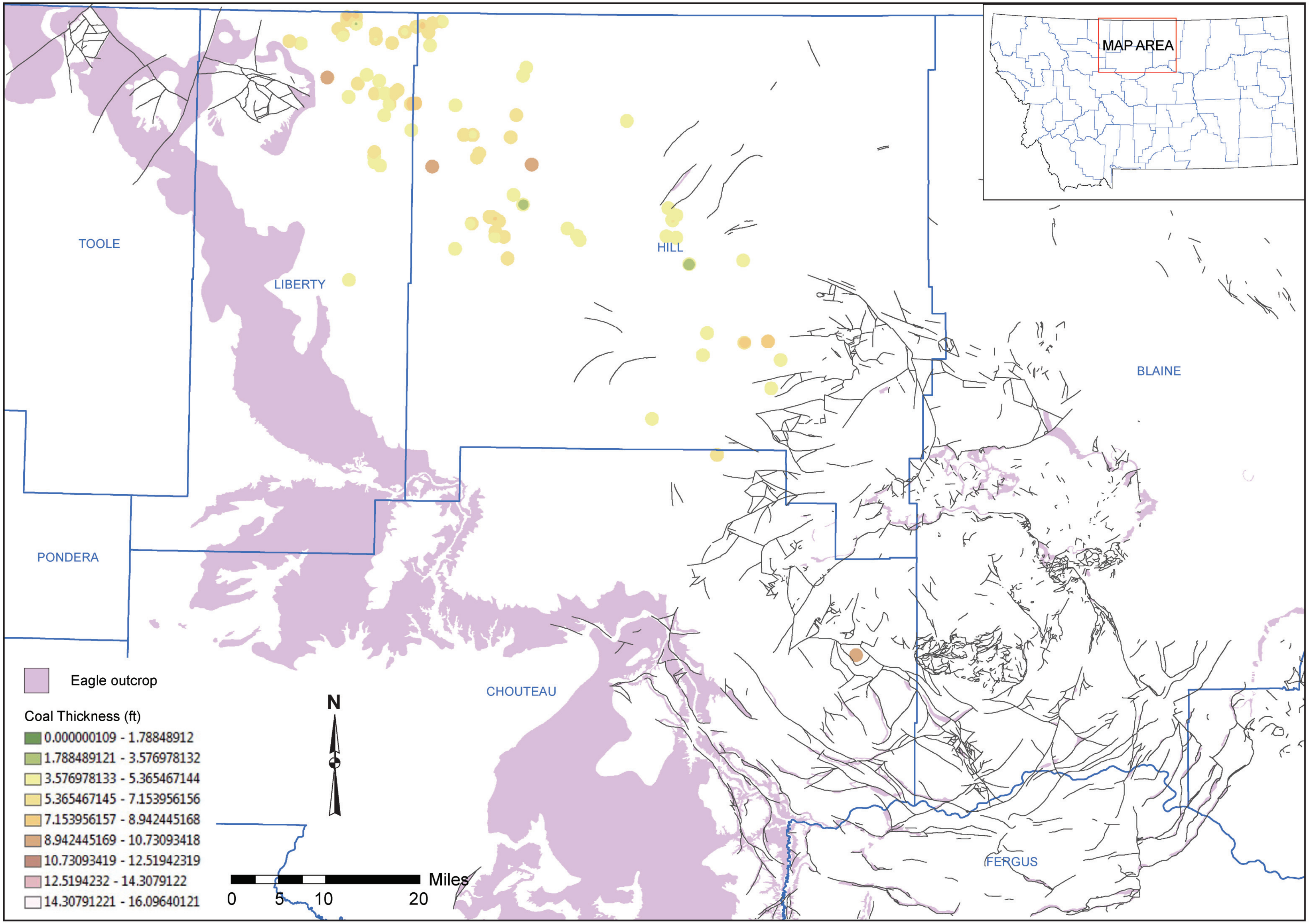

Figure 7. Distribution of data points included in demonstrated reserve base for the Eagle Formation.

casing and the lack of shallow log data. As a result, only the areas with deep coalbeds (300–1,200 ft) were recognized; areas with shallow coalbeds were not.

The coalbeds in Montana's north-central region are too thin to compete economically with the thick, low-sulfur coal available for surface mining in the Powder River Basin. However, their energy content could be extracted using some alternative technology, either existing or yet to be developed. For example, they may be viable coalbed methane targets like the Belly River coalbeds in Saskatchewan (Frank, 2006). They could also be suitable targets for in situ coal gasification, where fault-bounded coalbeds can be advantageous for maintaining control of underground burn cavities and containing product gases.

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