COAL RESOURCES OF MONTANA

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ABSTRACT

Coal has been a valuable source of energy and vital part of Montana's history and economy for 200 years, providing energy for heating homes and cooking, fuel for the westward expansion of railroads, raw material for smelting and other industrial applications, and since about the 1960s, a major source of fuel for generating electricity. Montana ranks first among the states in the size of its demonstrated reserve base, with 119 billion short tons of coal, and sixth in production at roughly 40 million short tons per year. The most economically important coal resources occur in the Paleocene Fort Union Formation in the Powder River Basin, Bull Mountain Basin, and Williston Basin in eastern Montana. These account for over 95 percent of Montana's coal resources and all of the State's current coal production. Since the 1970s, research on Montana coal has focused almost exclusively on quantifying resource tonnages and chemical composition of Fort Union Formation coalbeds available for strip mining.

BACKGROUND

Coal has played a vital role in Montana's history and economic development. This brief historical view provides a backdrop to the discussion that follows on Montana's coal fields. More detailed historical reviews are provided by Morgan (1966) and Chadwick (1973).

Coal-bearing formations underlie about 35 percent of Montana (fig. 1). Coal rank generally increases from east to west—from lignite in the east, to subbituminous and bituminous coal further west. The coal-bearing formations range in age from Late Jurassic/Early Cretaceous to Tertiary (Miocene; fig. 2). Although historically, mining has been conducted in all of Montana's coal regions, commercial mining during the past 50 yr has been limited to Tertiary (Fort Union Formation) coalbeds in the Powder River Basin, Bull Mountain Basin, and Williston Basin (fig. 1).

Discovery

On July 28, 1806, Captain William Clark of the Corps of Discovery observed coal in the bluffs along the Yellowstone River of southeastern Montana:

> *"in the evening I passd. Straters of Coal in the banks on either Side. those on the Stard. Bluffs was about 30 feet above the water and in 2 vanes from 4 to 8 feet thick, in a horozontal position. the Coal Contained in the Lard Bluffs is in Several vaines of different hights and thickness. this Coal or Carbonated wood is like that of the Missouri of an inferior quallity." (Moulton, 2001).*

Uses and Demands

Heating

In 1807, Manuel Lisa, a French fur trader, built a trading post at the confluence of the Bighorn and Yellowstone Rivers and utilized lignite coal from nearby outcrops to heat buildings during the winter months (Morgan, 1966). During the homesteading era of the late 1800s and early 1900s, coal was used as fuel for cooking and heating homes by farmers and ranchers, and local coal mines appeared across rural Montana.

Coal for Metals Mining

With the advent of hardrock mining in Montana in the mid-1800s came demand for transportation and smelting fuels. Steam, generated by coal, powered mine equipment (steam hoists and transportation) and provided energy to move ore from mines to smelters. Coking coal (or metallurgical coal) from three of Montana's coal fields was important for use in blast furnaces for copper smelting in the late 1800s and early 1900s (Averitt, 1966). Coking ovens were built and operated near Livingston, Great Falls, and Gardner. The demand for coking coal waned in the early 1900s due to the development of more efficient methods of smelting.

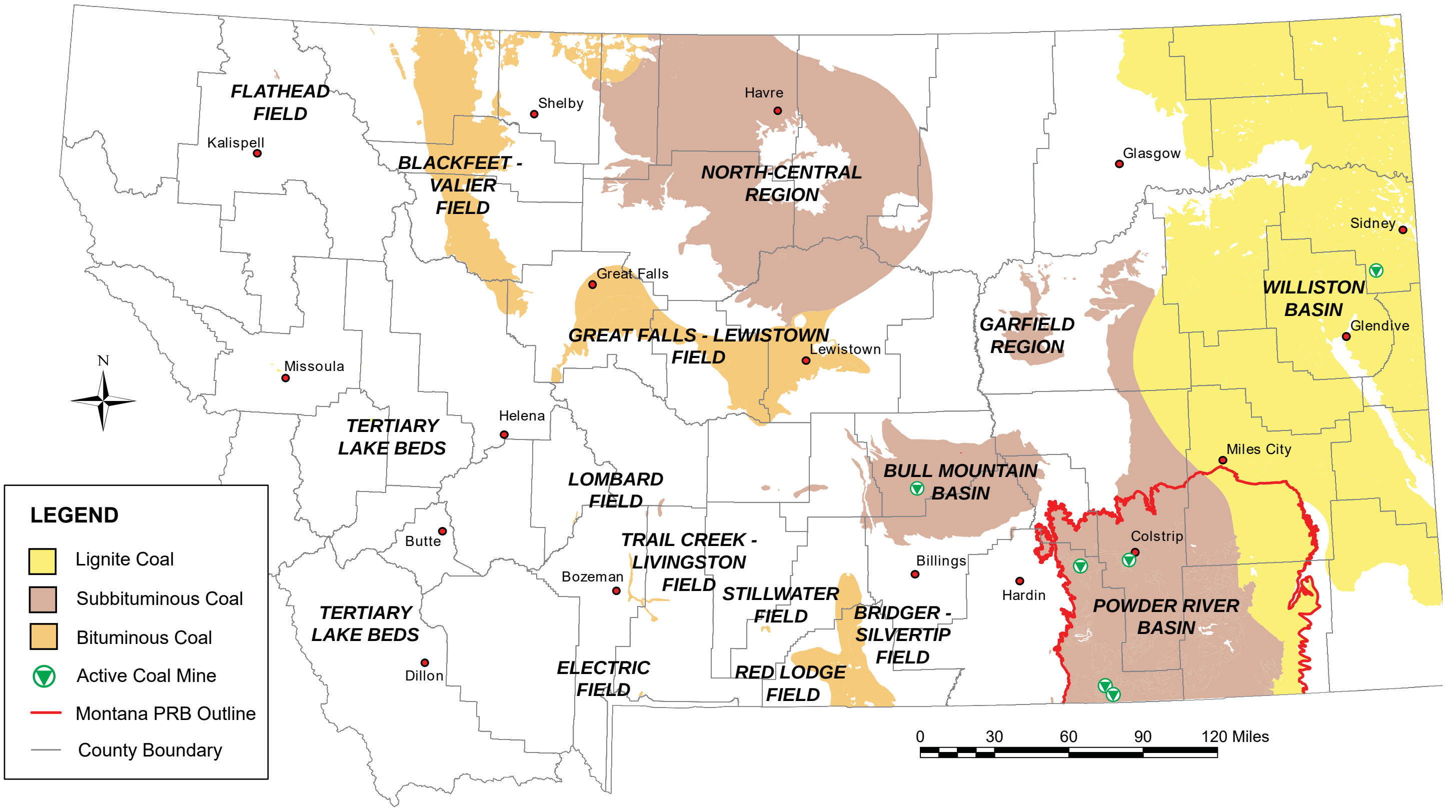


Figure 1. Map of Montana coal regions (modified from Cole and others, 1982).

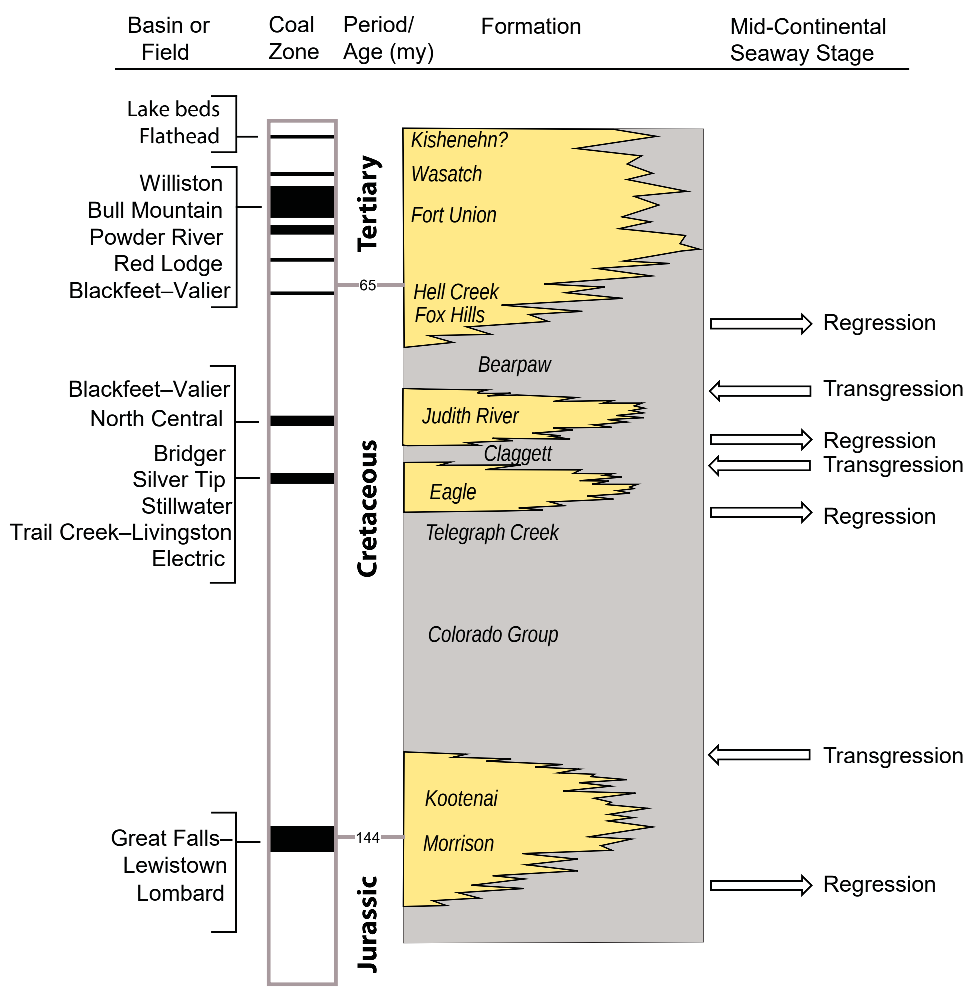


Figure 2. General stratigraphic position and age of coal-bearing formations.

Transcontinental Railroads

The railroads headed west through Montana to connect major Midwestern cities to the Pacific coast during the 1880s. To encourage expansion into the western states, the Federal government enticed railroads to expand service by granting them land and mineral rights in every odd-numbered, 640-acre section within 10 mi on each side of the track (U.S. Government, 1862). Coal was preferred over wood as fuel for steam locomotives because it has higher energy content per unit volume. In response to the demand for coal, many small mining operations opened to supply the railroad. By the 1950s, diesel engine locomotives replaced steam engines and the early era of robust coal mining in Montana came to a close (fig. 3).

Thermal Electric Generation

The coal industry in Montana was rejuvenated in the 1970s when the Clean Air Act of 1970 was enacted, allowing the U.S. Environmental Protection Agency to limit sulfur-dioxide emissions and other air pollutants that threatened public health. Rather than incurring the expense of retrofitting coal-fired power plants with emission controls to accommodate high-sulfur eastern U.S. coal, companies sought western U.S. coal with lower sulfur content. As a consequence, the Powder River Basin (PRB) emerged as one of the primary coal-producing regions in the United States. Demand for low-sulfur eastern Montana coal, along with use of dedicated coal trains, or "unit trains," marked the beginning of the modern coal era in Montana.

The anticipated growth in coal production and use was outlined in a major 1975 study that listed potential for up to 52 new electrical generating plants in the northern Great Plains, with 9 located in Montana (NGPRP, 1975). Of the 9 anticipated sites in Montana, only 4 were constructed and are located at Colstrip, Montana. The same report presented three development scenarios projecting growth in Montana coal production from 7.1 million short tons (MST) per year in 1971 to between 58 and 393 MST per year by 2000. Even the lowest projection was never realized; instead, Montana's coal production has remained level at about 30 to 40 MST per year since the late 1970s (fig. 3).

Coal Mining in Montana

Current Mining

Montana currently produces about 35 to 40 MST per year of coal from five strip mines and one underground mine (table 1, fig. 3). Nearly all coal currently mined is used for electrical generation, with small amounts used for home heating. Roughly 25 percent of the coal produced in Montana is used locally to generate electrical power; the remaining 75 percent is shipped overseas and to coal-fired power plants in the Midwest.

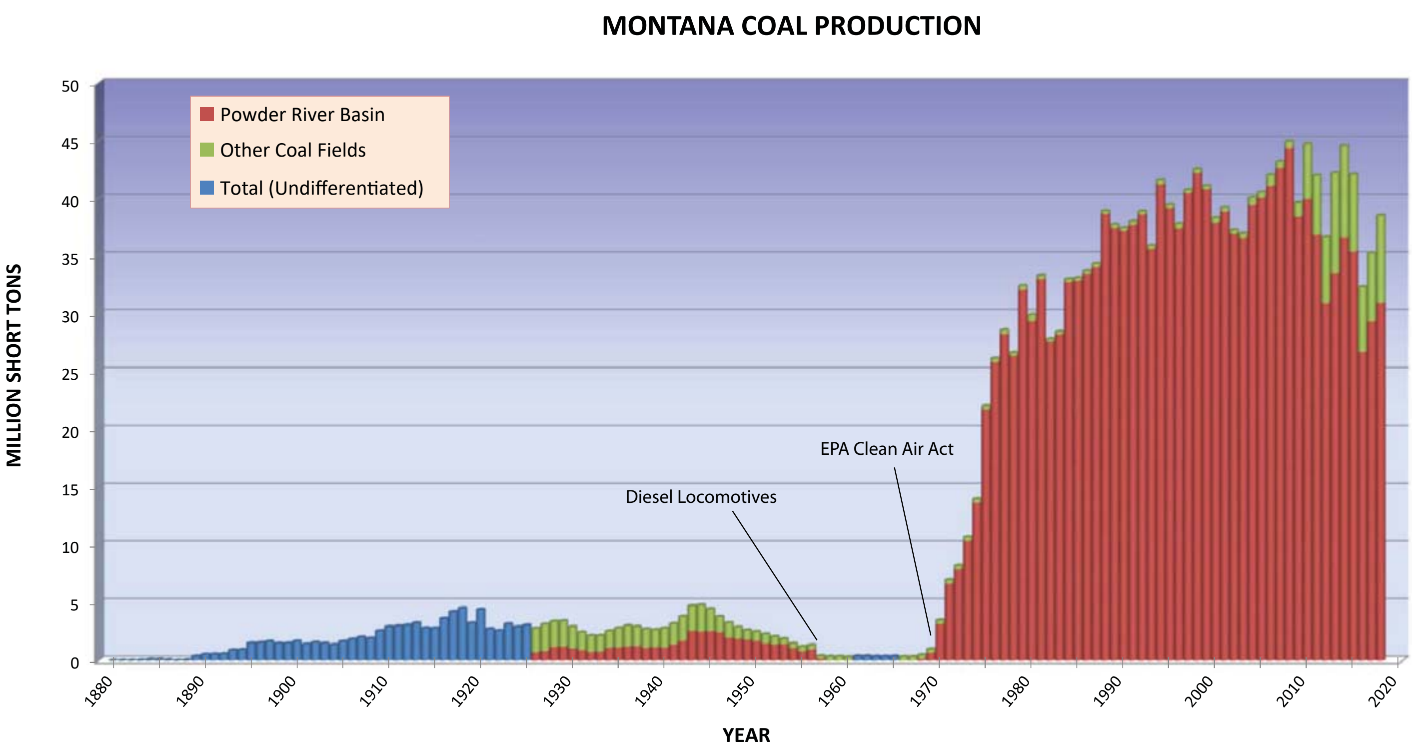


Figure 3. Montana coal production (1880–2018). Data source: Montana Department of Labor and Industry; Milici, 1997.

Table 1. Coal production from modern mines in Montana.

Mine Name Years of Production and Status	Coalbed Name	Coal Production in 2018 (millions of short tons)	Coal Production 5-yr Average (millions of short tons)	Total Cumulative Coal Production (millions of short tons)
Absaloka (1974–2019; active)	Rosebud, McKay	3.8	4.8	214.9
Big Sky (1969–2003; closed)	Rosebud, McKay	—	*2.5	104.2
Decker (1970–2019; active)	Anderson, Dietz 1, Dietz 2	4.7	3.7	390.2
Rosebud (1968–2019; active)	Rosebud	8.4	8.9	509.7
Spring Creek (1979–2019; active)	Anderson, Dietz 1, Dietz 2	13.8	14.2	409.0
Signal Peak (2003–2019; active)	Mammoth/Rehder	7.6	6.7	66.3
Savage (1958–2019; active)	Pust	0.3	0.3	16.3
Total:		**38.6**		**1710.6**

*Average of the most recent 5 years of production (1999–2003).
Note. Data Source: Montana Department of Labor and Industry.

Future Mining

Two conditions are putting downward pressure on current coal markets in the United States. First, a renewed focus on coal's environmental impact (concerns about climate change due to CO_2 emissions; changes in local hydrologic balance; and restoration of the soils and surface usage) has resulted in decreased usage. Aging coal-fired power plants are being shut down rather than retrofitted with additional emissions control equipment. Second, increased natural gas production from unconventional resources is replacing coal for a larger portion of electrical power generation. Although coal will continue to be an important part of the U.S.'s energy portfolio, the U.S. Energy Information Administration (EIA) projects flat coal production and consumption for the next several decades (EIA, 2019). The future of coal may well depend on new technologies for utilization—technologies that are more efficient, cost-effective, and environmentally friendly than those used today.

Environmental Impacts

Coal mining falls under the jurisdiction of State and Federal bonding and reclamation rules (Montana Code Annotated, 2017; SMCRA, 1977). Reclamation rules require mining companies to restore land (hydrology, topography, soils, and vegetation) that has been disturbed by mining activities to original condition and use. Impacts to and recovery of the hydrogeologic system is discussed in detail in Meredith and others (2020). Climate change, soils, air quality, and land use fall outside the purview of the Montana Bureau of Mines and Geology (MBMG), and the reader is referred to the Montana Department of Environmental Quality, Coal and Uranium Program.

OVERVIEW OF COAL IN MONTANA

Coal Formation

Coal is a combustible sedimentary rock composed of organic material [primarily carbon (C), hydrogen (H), and oxygen (O)] derived from the decay of plant matter, plus variable amounts of moisture, volatiles, other elements such as sulfur and nitrogen, and inorganic material (mineral matter). The relative amounts of organic constituents (particularly percent carbon) determine coal rank, an important measure of coal quality that is directly related to heating value or energy content (fig. 3 and table 4 in Averitt, 1975). Coal heating value is generally expressed in British thermal units per pound (Btu/lb). Inorganic material within coalbeds comes from the occasional influx of clastic sediment into the coal-forming swamp or basin. This material—termed "ash"—can be dispersed within coal or occur as thin, definable layers, called partings.

Coal forms in wetlands (e.g., swamps, bogs, mires, floodplains, and lagoons) where the accumulation of decaying plant material, or peat, exceeds the rate of bacterial decay and oxidation of the plant debris. As peat is buried and compacted, heat and pressure drive off volatiles and moisture, to form lignite (low rank) coal. Continued metamorphism transforms low rank coal into higher rank coal (lignite to subbituminous to bituminous to anthracite). It may take as much as 100 ft of plant material to form a 5-ft-thick bed of bituminous coal. Because heat and pressure increase with depth, and since older coalbeds tend to have been buried more deeply than younger coalbeds, there is a general relationship between age and coal rank; older coalbeds tend to be higher rank than younger coalbeds.

Coal Depositional Environments

Coal-forming environments exist in both coastal (marginal marine) and terrestrial (non-marine) settings (fig. 4). Both types of depositional environments were active in Montana's past, a consequence of the Jurassic and Cretaceous seas that periodically flooded and drained the mid-continental region of North America (fig. 2).

After the Jurassic seas withdrew from North America, rivers and lakes formed on the broad low-lying floodplain that remained. These floodplain wetlands became sites for peat accumulations that eventually formed the terrestrial coalbeds of the Late Jurassic/Early Cretaceous Morrison Formation. During the Late Cretaceous, several cycles of marine transgressions and regressions led to frequent flooding of coastal swamps and lagoons lying landward of the shoreline. Thus, Late Cretaceous coalbeds in Montana are primarily marginal marine in origin. Final regression of the sea at the end of the Cretaceous once again left a newly exposed land surface that was drained by a large-scale fluvial system(s) flowing northward into the retreating Cannonball Sea during the Tertiary (Flores, 1992). Interfluvial wetlands such as mires, lakes, and bogs accumulated an immense amount of peat, resulting in Tertiary coal deposits that are the largest in the State.

The type of depositional environment—marginal marine or terrestrial—can lead to very different coalbed distributions, geometries, and composition. Coalbeds that form in coastal wetlands tend to be thin, laterally continuous, elongate parallel to the paleoshoreline, and occur in sequences of mixed marine and non-marine rocks (fig. 4). Terrestrial coal-forming environments are typically fluvial and lacustrine in origin and include interfluvial mires, swamps, and other localized wetlands. Coalbeds formed in fluvial environments are lenticular and discontinuous; they often merge and split over relatively short distances.

Coal quality, or chemistry, is also influenced by depositional environment (Fort Union Coal Assessment Team, 1999). For example, sulfur content tends to be higher in marginal marine coal than terrestrial coal. Ash content from the influx of clastic material is generally higher in low-lying peat mires where fine-grained sediments can accumulate more easily than in raised swamps.

Coal Quality

The term "coal" encompasses a wide range of rocks with a wide range of properties and composition. Some coal constituents are harmful to the environment (e.g., mercury and oxides of sulfur and nitrogen); others may require special equipment and/or equipment maintenance for combustion (e.g., sodium). The primary indicator for the quality of coal as a fuel is rank, or heating value. Thus, determination of coal quality—or coal chemistry—is important because it impacts coal utility and value, emissions, waste products, and equipment design and efficiency (e.g., turbines, boilers). Coal quality can be assessed via chemical and petrographic analyses.

Chemistry

There are two common analytical tests performed on coal samples to determine coal quality: proximate and ultimate analyses. Proximate analyses are related to burning characteristics and used to determine heating value (Btu/lb), moisture content, volatile matter, fixed carbon, and percent ash. Ultimate analyses provide information about the major organic elemental composition of coal in terms of carbon, hydrogen, sulfur, oxygen, and nitrogen. Guidelines for sample collection and analytical methods are given by Golightly and Simon (1989) and Speight (2005).

Coal-quality data from Montana have been gathered and reported since the early 1900s. Early mappers of the U.S. Geological Survey (USGS) and the U.S. Bureau of Mines (USBM) collected samples at mine locations and reported results in reconnaissance mapping publications. These data were compiled by Fieldner and others (1932) and Gilmour and Dahl (1967).

A large amount of quality data were gathered on coal samples from drillhole cores and from active mines during the joint USGS and MBMG exploratory drilling program of the 1960s, 1970s, and 1980s. Results of proximate and ultimate analyses were published along with drillhole stratigraphic data in several USGS reports: for example, Affolter and Hatch (1980) and Tewalt and others (1989). Other coal-quality data are found in many of the coal publications cited in this review, such as Matson and others (1973).

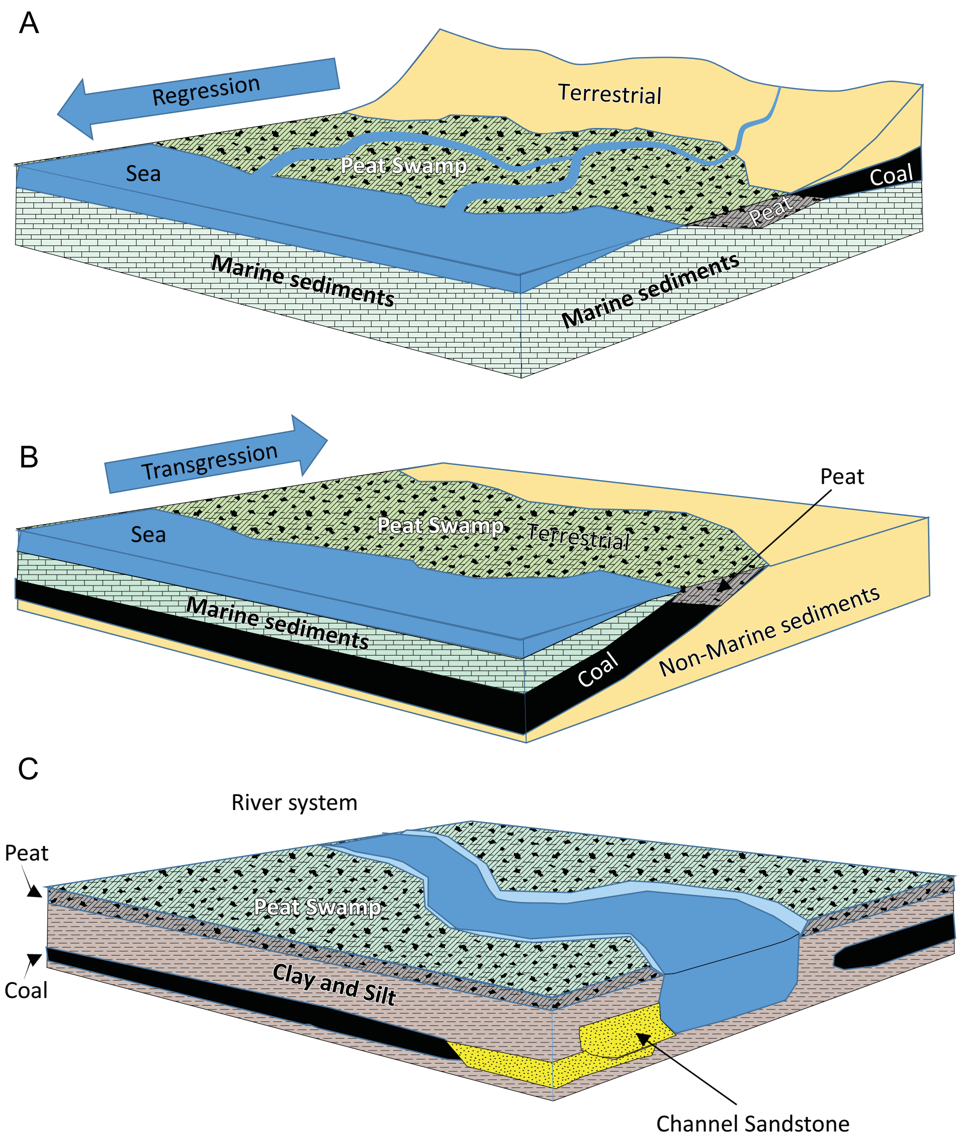


Figure 4. Simplified sketches of coal-forming environments in marginal marine (coastal) and terrestrial (fluvial) settings. (A) Marginal marine setting (regression). (B) Marginal marine setting (transgression). (C) Fluvial setting.

Some data are publicly available from the USGS coal quality (COALQUAL) database (Palmer and others, 2015) and from the National Coal Quality Inventory (NaCQI) database (Hatch and others, 2006).

Petrography

At the microscopic level, coal is made up of organic particles called macerals (e.g., liptinite, vitrinite, inertinite), similar to the way an igneous rock is made up of minerals. The petrographic approach to the study of coal composition employs the idea that coal macerals have distinct physical and chemical properties that control the overall composition and behavior of coal (Stach and others, 1982). Few petrographic studies have been conducted on Montana coalbeds; one example is a study by Sholes and Daniel (1992) on the Knobloch coalbed.

Sulfur Content

The modern mining surge in Montana was the direct result of a national concern with acid rain during the early 1970s. Burning coal releases sulfur in the form of SO_2 that can react with water and oxygen in the atmosphere to form sulfuric acid (H_2SO_4), which can then be incorporated into rain water. The need to mitigate acidic rain led to demand for the low-sulfur (<1 percent sulfur) coal found in the Powder River Basin (PRB) of Montana and Wyoming. Nationally, sulfur content in coal ranges from about 0.5 to 5.0 percent (Chou, 2012). Sulfur content in Tertiary coal of eastern Montana is typically less than 1.0 percent.

In coal, sulfur is present primarily in mineral form such as pyrite (FeS_2) and associated sulfide minerals, secondarily as organic sulfur, and lastly in sulfate or elemental forms. The sulfur originates from two predominant sources: parent plant material and sulfate in seawater that floods coastal peat swamps (Chou, 2012). Most freshwater streams and rivers are low in sulfate concentrations, and contribute little sulfur to coal. Generally, low-sulfur coal such as that in the PRB and Williston Basin was deposited in freshwater, fluvial systems.

Resource Assessments

The quantity of coal in Montana has been estimated several times, and these estimates vary depending on the data available and the economics of foreseeable demands. Estimates are described as resources and reserves, which have different, yet very specific meanings. Coal resources include tonnage estimates of identified and hypothetical resources for coal zones of a minimum thickness and within certain depth limits (commonly 0–2,000 ft deep). Coal reserves, a subset of coal resources, are considered economically producible at the time of classification. A review of these and other terms related to coal tonnage estimates is provided by Wood and others (1983) and Pierce and Dennen (2009). The reader should be aware that many authors (past and present) use criteria similar to Wood and others (1983), but with their own modifications. For coal tonnage estimates cited in this paper, we retain the original authors' use of the terms resource and reserve.

Total identified coal resources in Montana were estimated in 1975 to be 291.6 billion short tons (BST; Averitt, 1975). This includes all bituminous coal more than 14 in thick and all subbituminous coal and lignite beds more than 30 in thick to a depth of 3,000 ft. The EIA (2018) currently estimates the demonstrated reserve base for Montana to be 118.6 BST, with 74.4 BST deemed to be recoverable (38.5 BST surface-minable and 35.9 BST underground-minable).

Early Estimates of Total Resources

Coal tonnage estimates were a critical component of early 1900s mapping and formed the foundation for some of the first statewide coal resource and reserve estimates for Montana. Combo and others (1949) summarized coal in Montana by county, rank, reliability category, and thickness. Their estimate of 222 BST of coal included 2.4 BST of bituminous, 132.1 BST of subbituminous, and 87.5 BST of lignite coal. They specified reliability categories of *measured and indicated, inferred*, and *unclassified as to thickness* based on distance from the drillhole or outcrop, and depths up to 2,000 ft.

Strippable Deposits and Reserves

Beginning in the 1960s, attention shifted to identifying and quantifying coal reserves rather than total resources, with greater emphasis on strippable deposits in eastern Montana (i.e., coalbeds in the Fort Union Formation). Averitt (1965) provided an estimate of what he termed strippable resources of 5.1 BST for several fields with thick coalbeds located near existing infrastructure in eastern Montana. During the next 5 yr, several reports quickly increased strippable reserve estimates to nearly 25 BST based on additional mapping and drillhole information (e.g., Ayler and others, 1969; Matson, 1969).

In a comprehensive report on eastern Montana strippable coal, Matson and others (1973) provided detailed coalbed and overburden thickness maps, lithologic data, and coal-quality data for 32 individual coal deposits in the PRB. Their compilation of coal deposits in the Montana portion of the PRB gave an indicated strippable coal reserve (as they defined the term) of 32 BST based on coal thickness, overburden thickness, and a 2- to 3-mi radius around data points. Matson (1975) later included several more strippable deposits in the Williston Basin, Bull Mountain Basin, and on Indian lands in the PRB to get a total of 42.6 BST of strippable coal reserves (as he defined the term).

In 1975, the USBM published a report summarizing the strippable and underground coal reserve base of the United States by state and county (Hamilton and others, 1975). This report estimated Montana's demonstrated reserve base to be 108.4 BST: 65.8 BST underground and 42.6 BST strippable.

Availability and Recoverability

The proportion of coal resources that are recoverable from undisturbed deposits varies from less than 40 percent in some underground mines to more than 90 percent at some surface mines. The USGS also recognized that better resource and reserve estimates could be obtained by considering and excluding certain land-use and technological restrictions such as cemeteries, roads, other infrastructure, alluvial valleys, etc.—issues that could significantly reduce the amount of coal considered to be recoverable (Fort Union Coal Assessment Team, 1999; Luppens and others, 2009). Thus, new coal tonnage estimates by the USGS and state geological surveys were needed to place more emphasis on "available" and "recoverable" coal.

In 1995, the USGS began the U.S. National Coal Resources Assessment (NCRA) project, in cooperation with state geological surveys, to conduct systematic, geology-based, regional assessments of the Nation's remaining recoverable coal resources for significant coalbeds in major coal provinces and regions (Pierce and Dennen, 2009).

The Powder River Basin was the first of four Northern Rocky Mountains and Great Plains coal regions to be assessed in the NCRA program. Coal availability studies were produced for significant individual coalbeds (Fort Union Assessment Team, 1999), first over specific 7.5-minute quadrangles in the Montana PRB (e.g., Gruber, 1990; Wilde and Sandau, 2004), and then for the entire Montana portion of the PRB (Haacke and others, 2013). These local and regional studies formed the underpinnings for a complete reassessment of coal reserves in the Montana–Wyoming PRB (Luppens and others, 2015). Of the estimated 1,162 BST of original coal resources in the PRB, only 25 BST—or about 2 percent—are deemed to be reserves. These results demonstrate the impact of various technical constraints, land-use restrictions, and mining economics on computing coal reserves.

DESCRIPTION OF MONTANA COAL FIELDS

Many studies and reports that describe and inventory coal in Montana have been generated. Territorial geologists, railroad geologists, and USGS workers began mapping coal ahead of the westward expansion of the railroad during the late 1800s and early 1900s. Working solely from surface information, they described and mapped Montana's coal-bearing regions and specific coal fields or deposits. One example of original mapping is by Woolsey and others (1917), who describe the Bull Mountains Coal Field. Another example is work published by Baker (1929), who mapped the northward extension of the Sheridan Coal Field in Wyoming into Montana. These early publications provide reconnaissance geologic maps and township-by-township, or in some cases section-by-section, descriptions of near-surface coal deposits in Montana.

An excellent compilation of these early inventories is provided by Combo and others (1949). They included descriptive field summaries, a list of references for the early 1900s publications, and estimates of total coal reserves (as they defined the term) for Montana. Other statewide summaries are given by Bateman (1966) and Cole and others (1982). Matson (1975) provides a summary of field mapping completed on strippable coal deposits in eastern Montana. A particularly useful publication by Pinchock (1975) gives a location map and references for coal field studies completed prior to the mid-1970s. Rather than cite all of the early studies in this review, we refer the reader to Combo and others (1949) and Pinchock (1975).

We present here a brief summary of Montana's coal regions and individual coal fields (fig. 1), organized by the three major periods of coal formation in Montana: the Late Jurassic/Early Cretaceous, Late Cretaceous, and Tertiary. Table 2 provides basic characteristics of each field or region for comparison. All coal-quality information in table 2 and in the text that follows is reported on an "as-received" basis unless stated otherwise.

Late Jurassic/Early Cretaceous (Morrison Formation)

Following the last of the Jurassic marine regressions (~155 Ma), fine-grained distal sediments of the Morrison Formation were deposited on the emerging surface of marine sediments during Late Jurassic and Early Cretaceous. The coal-bearing upper part of the Morrison Formation, considered to be Early Cretaceous (Engelhardt, 1999; Vuke, 2000), includes mudstones, siltstones, and fine-grained sandstones formed in a mixed fluvial-lacustrine environment (Harris, 1966, 1968; Walker, 1974).

Coalbeds deposited in the Early Cretaceous Morrison Formation occur in the Great Falls–Lewistown field and the Lombard field. Although continental, nearshore, and lacustrine deposition continued in the Early Cretaceous, no other Lower Cretaceous coalbeds have been recorded in Montana.

Great Falls–Lewistown Field

Coalbeds in the Great Falls–Lewistown field occur within the upper part of the 180- to 200-ft-thick Jurassic–Cretaceous Morrison Formation along the north slopes of the Little Belt and Snowy Mountains in central Montana (fig. 1). The primary coal zone varies in thickness from 3 to 18 ft with coalbeds in 2 to 3 benches averaging 4 to 5 ft thick each, separated by 1- to 10-in-thick shale partings.

Coal in the Great Falls–Lewistown field is bituminous with heating values ranging from 8,700 to 12,900 Btu/lb and averaging 10,200 Btu/lb. Sulfur content varies from 1.7 to 4 percent and ash content

Table 2. General coal field characteristics. Heating value, ash, and sulfur reported on an “as received” basis.

Region/Field	Period (Series)	Formation	Rank	Beds	Bed Thickness	Btu/lb	S (%)	Ash (%)
Great Falls–Lewistown	Early Cretaceous	Morrison	Bituminous	1	zone is 3–18', net coal 5–9' in 2–3 benches	8,700–12,900 (10,200)	(1.7) GF (4.0) Lewis	(18.1) GF (8.0) Lewis
Lombard	Early Cretaceous	Morrison	Bituminous	1	≤6' lenses	~10,000	(8.2)	(29.7)
Bridger–Silvertip–Stillwater	Late Cretaceous	Eagle	Bituminous	1–3	2–6' in 2–3 benches	(10,100)	0.3–0.5	13–19
Livingston–Trail Creek	Late Cretaceous	Eagle	Bituminous	3–4	2–5' total, in benches of 1–3' of coal each	9,900–11,500 (10,950)	(0.6)	(8.5)
Electric	Late Cretaceous	Eagle	Bituminous	3	3–5'	(11,410)	(1.3)	(19.5)
North-Central	Late Cretaceous	Eagle Judith River	Subbituminous Subbituminous	1–2 4–10	2–3' 2–8' (2 primary zones)	(9,100) (8,590)		11.5 10
Blackfeet–Valier	Late Cretaceous	Two Medicine	Bituminous	1–2	20" (Two Medicine) ≤3.5' (St. Marys)			
Powder River Basin	Tertiary (Paleocene)	Fort Union*	Subbituminous	25–30	up to 80'	6,770–10,900 (8,140)	0.11–1.63	3.8–10.6
Williston Basin	Tertiary (Paleocene)	Fort Union*	Lignite	10–15	up to 40'	5,800–7,525 (6,670)	0.2–1.1	3.5–10.7
Bull Mountain Basin	Tertiary (Paleocene)	Fort Union	Subbituminous	26	up to 15'	9,270–11,000 (9730)	0.4–1.3	3.3–7.7
Redlodge	Tertiary (Paleocene)	Fort Union	Bituminous	9	3–10'	10,000–12,000 (10,330)	1–1.3	5–13
Tertiary Lake Beds	Tertiary (Eoc-Mio)	?	Various		5–25'	6,000–9,000	1–6	17–30
Flathead	Tertiary (Eoc-Mio)	Kishenehn?	Subbituminous		≤3'	(8,120)	(2.9)	(15.4)

*Also includes some Hell Creek (Maastrichtian) coalbeds.

Note. Parentheses indicate values are reported as "average" or "typical."

ranges from 8 to 30 percent. Generally, there is lower ash content and higher sulfur content in coal from the Lewistown portion of the field. Silverman and Harris (1967) estimated reserves (as they defined the term) to be 822 MST.

Workable coal thicknesses are concentrated in several separate "depositional basins" within the Great Falls and Lewistown fields. Silverman and Harris (1967) provide a stratigraphic, petrographic, and economic review of the individual coal basins. Some underground (room and pillar) mining at Sand Coulee (Great Falls portion of the field) in the early 1900s produced coking coal. The Anaconda Mining Company operated coke ovens at Belt, but the ovens and mines were abandoned in the early 1900s because only a portion of the coal had coking properties and it was too difficult to separate coking from non-coking coal (Averitt, 1966).

Lombard Field

The Lombard field is a small (6 mi^2) area of northern Gallatin and southern Broadwater Counties (fig. 1). The coal-bearing Morrison Formation in this area has been folded and faulted. Coalbeds up to 6 ft thick occur in lenses and have variable rank due to the deformation (Combo and others, 1949). Coal is bituminous, with a typical heating value of about 10,000 Btu/lb, but tectonism may have altered coal to essentially graphite in some places (Stebinger, 1914). Sulfur content is about 8 percent and ash content near 30 percent.

Late Cretaceous (Eagle, Judith River, Two Medicine, Hell Creek, and St. Mary River Formations)

During the Late Cretaceous (~100–65 Ma) in eastern Montana, several cycles of marine transgressions and regressions created conditions favorable for peat deposition in coastal wetlands that rimmed the Western Interior seaway. Major delta systems existed along the shoreline, between which, lagoons, estuaries, and swamps were available for peat accumulation. Swamps of Eagle time were elongate and parallel to the shoreline, evidenced by the fact that coalbeds interfinger with clastic shoreline deposits seaward (eastward) and interfinger with terrestrial deposits landward (westward). Late Cretaceous coalbeds are present in the Eagle, Judith River, and Two Medicine Formations.

Coalbeds in the Eagle Formation lie within a north–south corridor of central Montana that includes the Bridger, Silvertip, Stillwater, Electric, and Livingston–Trail Creek fields and the North-Central coal region. Coalbeds in the Judith River Formation (mixed terrestrial and marine deposits) occur in the North-Central coal region. The coal in the Eagle and Judith River Formations is almost all accessible only via underground mining.

In northwestern Montana, continental deposits of the Two Medicine and overlying St. Mary River Formations contain coalbeds in the Blackfoot–Valier field. The Two Medicine Formation is, at least in part, correlative to the marginal marine and coastal deposits of the Eagle, Claggett, Judith River, and Bearpaw Formations. The St. Mary River Formation is equivalent to the Hell Creek Formation of eastern Montana. Both are primarily terrestrial in origin.

Bridger–Silvertip–Stillwater Fields

These three fields are located along the margins of the northern Bighorn Basin (fig. 1), where strata are tilted, exposing the coal-bearing Eagle Formation. One or two minable coalbeds up to 6 ft thick occur in each of these fields. A typical coal sample has heating values of just over 10,000 Btu/lb, sulfur content from 0.3 to 0.5 percent, and ash content of 13 to 19 percent.

Livingston–Trail Creek Field

In the Livingston–Trail Creek field (fig. 1), coal is present in an abnormally thick section of sandstone in the Eagle Formation. One to four coalbeds are present at any one location, and they vary from 2 to 5 ft thick. The area is structurally complex, with faulting, folding, and steeply dipping coalbeds, most in excess of 30°. Heating values range from 9,900 to 11,500 Btu/lb and average 10,950 Btu/lb. Sulfur content averages 0.6 percent and ash content averages 8.5 percent.

Some of the coal from this field was mined and used to produce coke during the late 1800s and early 1900s, but it is no longer being commercially mined. The best coking coal occurs in the least deformed areas along the flanks of anticlines and synclines. Roberts (1966) estimated remaining coal reserves (as he defined the term) of 301 MST in beds 14 in or more in thickness and within 3,000 ft of the surface. Of these, 70 MST occur in the Cokedale bed, the coalbed with the best coking properties.

Electric Field

Coal of the Electric field (fig. 1) has heating values averaging 11,400 Btu/lb. Beds are up to 5 ft thick, but average about 3 ft thick. Sulfur content averages about

1.3 percent and ash content averages about 19.5 percent.

Coal mined from the No. 1 coalbed in this region was used to produce coke in the late 1800s and early 1900s. Mining was difficult because of complex structure; beds are folded, faulted, and steeply dipping. Most of the coke was shipped to copper smelters in Anaconda and Butte, but high ash content was problematic and smelters abandoned using coking coal from this field (Averitt, 1966).

North-Central Region

Coalbeds in the North-Central region are present in both the Eagle and Judith River Formations (fig. 1). Coalbeds tend to occur as thin, lenticular bodies that generally thicken westward. Most beds are 2 to 3 ft thick, although they can be up to 8 ft thick in the Judith River Formation. Heating values average 9,000 Btu/lb and ash content ranges between 10 and 12 percent.

Only one or two coalbeds occur in the Eagle Formation—typically just above the massive sandstone known as the Virgelle Member. The Judith River Formation can have up to 8 or 10 coalbeds occurring in two distinct zones, one each near the top and base of the formation. Individual beds are not laterally continuous, but the two coal zones are persistent in the area north and northwest of the Bearpaw Mountains (Gunderson, 2018). The Judith River Formation coalbeds extend northward into Saskatchewan, Canada, where equivalent Belly River Formation coalbeds may be viable coalbed methane targets (Frank, 2006).

Blackfeet–Valier Field

Coalbeds of the Cretaceous Two Medicine and St. Mary River Formations in the Blackfeet–Valier field (fig. 1) are described as bituminous, but no detailed quality information is available. Beds are generally only 20 to 36 in thick.

Late Cretaceous–Tertiary (Hell Creek, Fort Union, Wasatch Formations)

Stratigraphic units of the Late Cretaceous (Fox Hills and Hell Creek Formations) and Early Tertiary (Fort Union and Wasatch Formations) form a regressive sequence that records the final retreat of the Cretaceous seaway from the mid-continent region of North America. The Fox Hill Formation is a shoreface sandstone with no appreciable coal; the overlying Hell Creek Formation is composed of fluvial-deltaic deposits with thin coalbeds, probably from short-lived coastal swamps. The delta-plain sands and shales of the Hell Creek Formation grade upward into fluvial-dominated sediments of the Fort Union Formation that include interbedded shale, siltstone, sandstone, and abundant deposits of coal. The overlying continental sediments of the Eocene Wasatch Formation contain thick coalbeds in Wyoming, but are almost completely eroded from Montana other than a small area of southern Montana where a few minor coalbeds remain.

The Fort Union Formation covers much of eastern Montana (fig. 1) and is the most prolific coal-bearing formation in the State. Thousands of feet of clastic sediments and associated thick coalbeds are preserved in several structural depressions, namely the Bighorn, Powder River, Bull Mountain, and Williston Basins. The Powder River Basin is particularly important because it contains some of the thickest and most extensive deposits of low-sulfur, subbituminous coal in the world (Molnia and Pierce, 1992).

Studies of the Fort Union Formation Coal

Because of their economic importance, the Fort Union coalbeds have been studied in considerable detail over the past 50 yr, with an overall goal to inventory coal resources available for use in power generation. Over time, these studies included detailed field mapping, exploration drilling, subsurface coalbed correlation, sedimentary facies descriptions to understand the depositional processes that control coalbed distribution, and the use of computers and geographical information systems (GIS) to improve resource and reserve estimates. Many facies studies and depositional models have been presented in attempts to understand the depositional settings that influence coalbed geometries and coal quality. Results of these studies allow construction of sedimentologic models that provide a basis for the prediction of coal resources in areas where data are sparse. The models also help explain coal quality and thickness variations, and aid in exploration and development of the resource.

A joint USGS–MBMG–Bureau of Land Management (BLM) program to drill exploratory coal holes in eastern Montana was active from 1969 to 1982. Roughly 1,700 coal exploration holes were drilled and logged with lithologic sample descriptions and various geophysical logs. Annual drilling reports were jointly published; a few examples are USGS and MBMG (1977, 1980) and Kirschbaum and others (1982). A complete list of drilling reports can be found in Fine (1981) and Heald (1983). Coal stratigraphic data are archived in USGS and MBMG databases, both available to the public (USGS COALSTRAT; http://www.mbmg.mtech.edu/datacenter/datacenter.asp). Raw records and original field notes from the drilling program are stored at the MBMG in Billings.

The program also produced a series of over 20 reports for Montana and other western states, referred to as the Energy Mineral Rehabilitation Inventory and Analysis (EMRIA) reports. One example is BLM (1977). Archived copies of EMRIA reports are available at the Billings office of the MBMG.

Another USGS program begun in 1977 to compile information on unleased Federal coal resources in the PRB of Wyoming and Montana was the Coal Resource Occurrence/Coal Development Potential (CRO/CDP) program. This, and others, were initiated and maintained to update national data and information with the most current coal resource knowledge. The USGS published coal stratigraphic data, coal outcrop maps, and coal resource estimates for 108 7.5-minute quadrangles in Montana. Trent (1985, 1986) provides a summary of the CRO/CDP program and a list of the open-file reports that were published as a result. The open-file reports are available online from the USGS Publications Warehouse (http://pubs.er.usgs.gov/). Digital coal outcrop patterns (shape files) for Montana PRB coalbeds from these reports are available from the MBMG (Gunderson, 2015).

Many others of the MBMG, BLM, USBM, and USGS were involved in mapping and reporting on individual strippable coal deposits in the Fort Union Formation of eastern Montana. In 1973, the MBMG published a significant work that included field maps of minable areas for 32 strippable coal deposits, mostly within the Powder River Basin in Montana (Matson and others, 1973). Other studies are cited in the Resource Assessments section of this report. Published estimates of strippable coal reserves in eastern Montana based on work in the 1970s are presented in table 3. Coal field locations are shown in figure 5.

Stratigraphic Framework and Correlation

Coalbeds formed in fluvial environments are lens or disk shaped—thick in the middle, tapered in all directions. They generally form elongated bodies, roughly parallel to channel flow direction; they merge, thin, and split over short distances when traced perpendicular to depositional dip. Because there is an overall lack of continuity of coalbeds formed in fluvial environments, correlating individual coalbeds and coal zones across the PRB has been difficult (Culbertson and Saperstone, 1987a,b; Fort Union Coal Assessment Team, 1999; Flores and others, 2010). In some cases, the same name has been applied to different coalbeds in different coal fields. In others (e.g., CRO/CDP mapping), a single coalbed has been assigned different names in adjacent quadrangles.

Coal correlations, basin stratigraphy, and various names for individual coalbeds and coal zones have been published for the PRB for the past 30 yr. A report by Kent and others (1980) describes the northern part of the Gillette coal field in Wyoming and established a coalbed nomenclature system that formed the foundation for much of the PRB in Wyoming and Montana. Molnia and Pierce (1992) also described coalbed stratigraphy in the central PRB in Wyoming and Montana; their nomenclature follows the usage of Culbertson and others (1979), Law and others (1979), Flores (1979), Derkey (1986), Culbertson and Saperstone (1987a,b), Culbertson (1987), McLellan and Biewick (1988), and McLellan and others (1990). A west-to-east cross section from Decker 80 mi eastward to Bear Skull Mountain further connects the framework and illustrates the basin structure and sedimentation (McLellan, 1991). The stratigraphic framework extends southward into the PRB of Wyoming. The resulting interlocking network reveals not only the extent of the coalbeds, but also furnishes information on the depositional history of the Tullock, Lebo, and Tongue River Members of the Fort Union Formation in the Powder River Basin. Recent work has refined these interpretations, but made few structural changes (Flores and others, 2010).

In the Williston Basin region of eastern Montana, geologic mapping, coal correlations, and stratigraphic studies were conducted in the Sidney, Glendive, Baker, and Wibaux 30´ x 60´ quadrangles of eastern Montana by the MBMG under cooperative agreements with the USGS (Sholes, 1988; Sholes and others, 1989; Mathews and Wilde, 1989a,b,c,d). Additional research (Belt and others, 1984; Flores, 1992; Hardie and Arndt, 1990) has helped to clarify the stratigraphy, structure, and sedimentology in some areas, but correlation of specific bed names and zones across the region has not been completed. Coal nomenclature and coal correlations in the Williston basin continue to evolve.

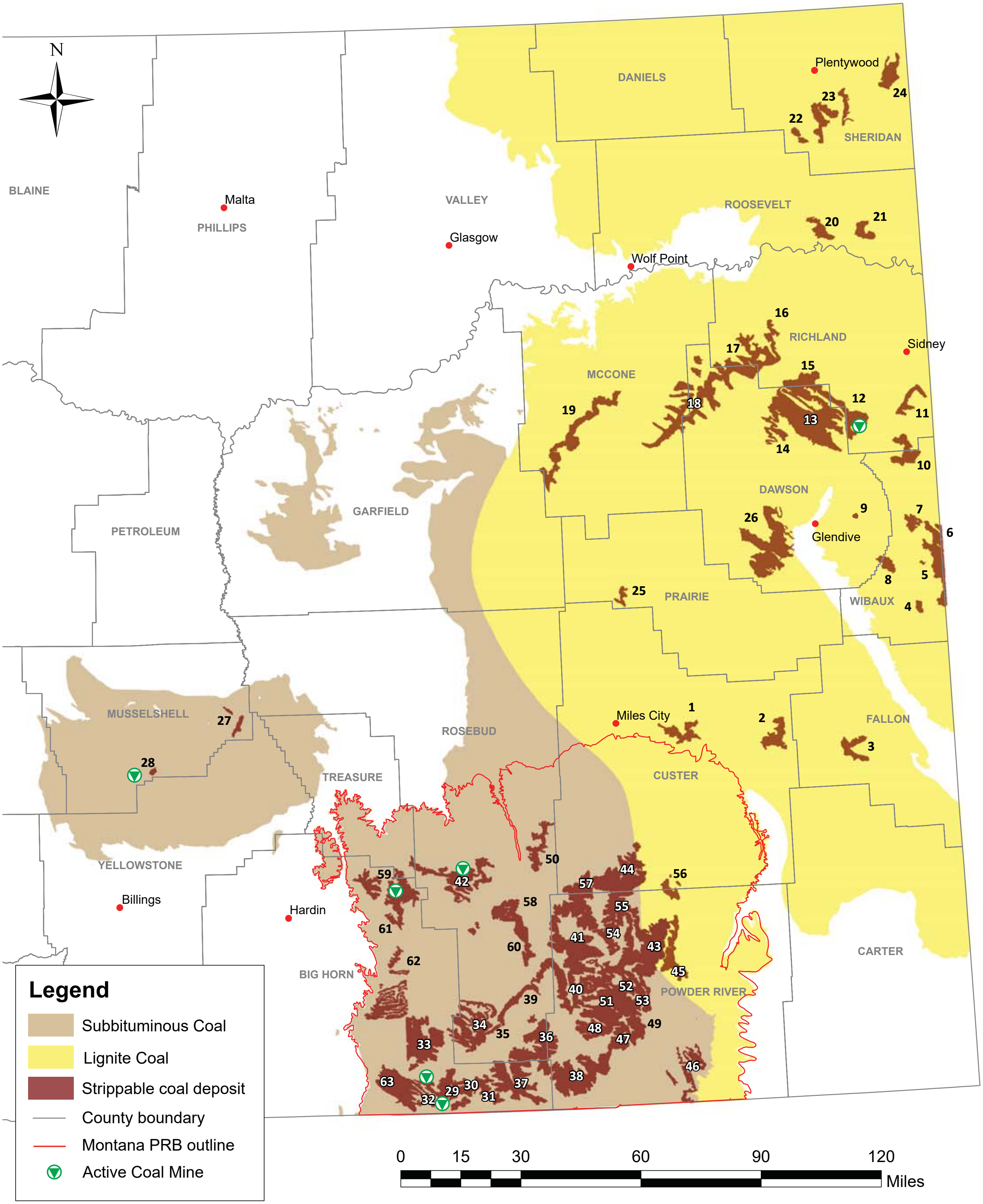


Figure 5. Map of strippable coal deposits in the Fort Union Formation of Montana (modified from Cole and others, 1982). Numbers correspond to table 3.

Table 3. Strippable coal deposits of eastern Montana (locations shown in fig. 4). Heating value, ash, and sulfur reported on an "as received" basis.

Map No.	Coal Basin**	Field Name	Bed Name	Strippable Reserves* (MST)	% Ash	% Sulfur	BTU/lb
1	WB	Pine Hills	Dominy	193.9	7.2	0.53	7,293
2	WB	Knowlton	Dominy M&L	747.5	7.1	0.41	6,710
	WB		Dominy U	120.3	5.6	0.38	6,645
3	WB	Lame Jones	Dominy	150.0			6,020
4	WB	Lamesteer	Harmon(?)	35.0			6,332
5	WB	Wibaux	C	643.0	7.9	0.90	6,050
6	WB	Little Beaver	C	134.0			
7	WB	Four Buttes	C	91.0			6,140
8	WB	Hodges		10.0			
9	WB	Griffith Creek		10.0			
10	WB	Smith-Dry Creek	G	150.0			
11	WB	O'Brian–Alkalie Creek		150.0			
12	WB	Breezy Flat	Pust	200.0	6.7	0.50	6,660
13	WB	Burns Creek	Pust	200.0			
14	WB	North Fork 13 Mile Creek	Pust	225.0			6,880
15	WB	Fox Lake	Pust	46.0	6.0	0.50	6,880
16	WB	Lane	Lane	561.0			7,150
17	WB	Carroll	Carroll	345.0	5.5	0.30	7,400
18	WB	Redwater River	S	642.0	6.1	0.40	7,400
19	WB	Weldon–Timber Creek	S	724.0			7,660
20	WB	Fort Kipp	Ft. Kipp–Ft. Peck	331.0	4.6	0.20	6,110
21	WB	Lanark	Lanark	100.0	6.3	0.40	6,853
22	WB	Medicine Lake		58.0	7.2	1.00	6,870
23	WB	Reserve		246.0	7.6	0.40	6,599
24	WB	Coal Ridge	Coal Ridge	150.0	7.5	0.40	5,830
25	WB	Little Sheep Mtn.	A&C	200.0			
26	WB	West Glendive	Peuse, Newton Ranch	458.0	10.4	0.34	6,615
27	BM	Carpenter Creek	Carpenter	50.0	6.5	0.40	9,270
28	BM	Charter	Mammoth	60.0	6.0	0.90	10,190
29	PRB	Decker	Anderson–Dietz 1&2	2240.0	4.0	0.40	9,652
30	PRB	Deer Creek	Anderson–Dietz 1&2	495.7	4.0	0.50	9,282
31	PRB	Roland	Roland	218.0	9.2	0.74	8,164
32	PRB	Squirrel	Roland	133.4	5.5	0.29	7,723
33	PRB	Kirby	Anderson	216.5	4.2	0.32	8,328
	PRB		Wall	473.7			
	PRB		Dietz	834.4	5.8	0.59	8,509
	PRB		Canyon	158.5	5.8	0.24	8,789
34	PRB	Canyon	Wall	1884.3	4.6	0.30	9,088
	PRB		Brewster–Arnold	65.9	7.5	0.40	8,444
35	PRB	Birney	Brewster–Arnold	180.6	5.1	0.41	9,055
36	PRB	Poker Jim Lookout	Anderson–Dietz	872.7	5.2	0.37	7,925

Table 3—*Continued.*

37	PRB	Hanging Woman Creek	Anderson	1583.3	4.9	0.29	8,496
	PRB		Dietz	1121.0	5.5	0.33	8,078
38	PRB	West Moorehead	Anderson	883.7	5.3	0.36	8,296
	PRB		Dietz	397.5	4.1	0.41	7,990
	PRB		Canyon	690.2	5.6	0.45	8,055
39	PRB	Poker Jim O'Dell	Knobloch	373.3	5.1	0.22	8,846
	PRB		Knobloch	564.8			
40	PRB	Otter Creek	Knobloch	2075.6	4.7	0.36	8,468
41	PRB	Ashland	Knobloch	2696.2	4.8	0.15	8,421
	PRB		Sawyer A & C	357.5	4.9	0.49	7,883
42	PRB	Colstrip	Rosebud	1439.3	9.0	0.12	8,836
43	PRB	Pumpkin Creek	Sawyer	2426.5	7.5	0.34	7,438
44	PRB	Foster Creek	Knobloch	708.1	7.8	0.76	7,573
	PRB		Terret	460.9	5.8	0.21	7,770
	PRB		Flowers–Goodale	258.9	7.8	0.51	7,553
45	PRB	Broadus	Broadus	739.8	7.2	0.27	7,437
46	PRB	East Moorhead	T	525.2	6.2	0.57	7,120
47	PRB	Diamond Butte	Canyon	418.0	4.8	0.43	7,330
48	PRB	Goodspeed Butte	Cook	629.0	10.6	1.63	6,771
49	PRB	Fire Gulch	Pawnee & Cook	336.7	3.8	0.33	7,739
50	PRB	Sweeney–Snyder	Terret	326.3	9.1	0.11	8,175
51	PRB	Yager Butte	Elk & Dunning	1175.9	4.8	0.33	7,646
	PRB		Cook	312.0	6.7	0.63	7,254
52	PRB	Threemile Buttes	Canyon & Ferry	225.4	5.5	0.94	6,867
53	PRB	Sonnette	Pawnee	320.3	9.8	0.88	6,964
	PRB		Cook	363.0	8.1	1.23	6,891
54	PRB	Home Creek Butte	Canyon & Ferry	217.2			
55	PRB	Little Pumpkin Creek	Sawyer A & C, D,X, & E	215.8			
56	PRB	Sand Creek	Knobloch	267.3	6.6	0.30	7,340
57	PRB	Beaver–Liscom	Flowers–Goodale & Terret	135.9	8.1	0.96	8,102
	PRB		Knobloch	491.6	7.7	0.50	8,027
58	PRB	Greenleaf–Miller Creek	Rosebud, Knobloch, Sawyer	453.7	7.5	0.71	8,422
59	PRB	Sarpy Creek	Rosebud–McKay	1500.0	6.5	0.50	8,600
60	PRB	Cheyenne Meadows	Knobloch	1200.0	4.1	0.40	8,400
61	PRB	Little Wolf	Rosebud–McKay	314.0			
62	PRB	Jeans Fork		90.0			
63	PRB	Wolf Mountains		1922.0			
			TOTAL	43019.9			

*As defined by the original authors.
**WB, Williston Basin; BM, Bull Mountain Basin; PRB, Powder River Basin.
Note. Data sources: Matson and others, 1973; Matson, 1975; Banet, 1979.

Depositional Models for the Fort Union Formation

Multiple depositional models for Fort Union sediments have been proposed over the decades of research that has occurred in the Tertiary coal fields of eastern Montana. Ayers (1986) suggested the coarse sediments of the Tongue River Member represented deltas formed of material from the Black Hills, building westward into Lake Lebo, thought to occupy the basin axis. Additional sediments came from the southwest and northwest. The coalbeds in this model were considered to be formed in low-lying swamps along the lake margins between deltas. McLellan (1992) proposed that uplift surrounding the Powder River Basin by the Cedar Creek Anticline, Black Hills, and Bighorn Mountains, along with associated subsidence of the basin, created stable swamps stretching hundreds of miles.

The model of raised swamps was first proposed by Jackson (1979, cited in Seeland, 1993). These raised swamps were postulated to be fed either by groundwater or by a combination of groundwater and surface water. The topographic position of raised swamps would naturally restrict clastic input and lead to a low-ash coal, as is the case with most Fort Union coalbeds.

Flores (1981) considered the basin to be drained by a large, northward-flowing river system with peat accumulating in the raised swamps between the tributaries. The lenticular coalbeds of the Wyodak–Anderson coal zone (Smith, Anderson, Dietz 2, Dietz 3, Canyon, Lower Canyon, Ferry, and Werner/Cook) are laterally split by, and pinch out into, strata that were deposited in the adjacent fluvial channels (Ellis and others, 1999). In outcrop, sandstone channel geometries and paleo-current indicators reflect the dominant paleo-drainage to the east–northeast toward the Paleocene Cannonball Sea (Flores, 1992; McLellan, 1992; Seeland, 1993).

These models continued to be refined and were most recently presented in detail after the interpretation of thousands of coalbed-methane well logs (Flores and others, 2010). Based on their model, Fort Union deposition was controlled by tectonic factors (uplift and subsidence) and internal factors including channel geometry, migration, and abandonment. Channel migration leads to coalbed geometries that split and merge; the raised swamps explained the low ash, and the freshwater fluvial system would create a low-sulfur coal.

Coal Fields

Powder River Basin

The PRB is an elongate, north–northwest-trending sedimentary basin that covers about 22,000 mi^2 of northeastern Wyoming and southeastern Montana (fig. 1). It forms a broad asymmetric syncline, bounded by structural uplifts: the Bighorn Mountains to the west and the Black Hills Uplift to the east. The synclinal axis lies near the basin's western margin and trends generally north–northeasterly in the Montana portion of the basin. The basin shallows to the north against the southern flank of the Miles City Arch. Thickness of the Fort Union Formation in the Montana portion of the PRB ranges from a few hundred feet in the northern PRB to approximately 4,000 ft at the Montana–Wyoming border.

The Fort Union Formation is divided into three members: from oldest to youngest, they are the Tullock Member, Lebo Member (informally referred to as the Lebo Shale), and Tongue River Member. Together, they form a thick sequence of interbedded and laterally discontinuous sandstones, pebble conglomerates, siltstones, shales, and coalbeds. Coalbeds are present in all three members of the Fort Union Formation and in the overlying Eocene Wasatch Formation, but the important coalbeds in the Montana PRB are confined to the Tongue River Member of the Fort Union Formation (fig. 6). As many as 26 persistent coalbeds occur within this unit and some attain thicknesses of up to 80 ft. The basin has been subdivided into many coal fields where individual strippable deposits have been delineated and inventoried by Matson and others (1973; fig. 5, table 3).

Coalbeds within the Tongue River Member in the PRB are classified as lignite to subbituminous based on heat of combustion values. There is a general decrease in coal rank from west to east, but the transition is gradual from subbituminous to lignite coal (fig. 5). Heating values for the subbituminous coal ranges from 6,770 to 10,900 Btu/lb and average 8,140 Btu/lb. Sulfur content ranges from 0.11 percent to 1.63 percent, and ash content from 3.8 percent to 10.6 percent.

There are four active strip mines in the PRB of Montana; they are located in Big Horn and Rosebud Counties (fig. 5). Mined beds range from 25 to 80 ft thick. Beds currently being mined are the Anderson, Dietz 1 and 2, Rosebud, and McKay (table 1, fig. 6). Although not currently mined, the Knobloch bed along Otter Creek southeast of Ashland, Montana has been

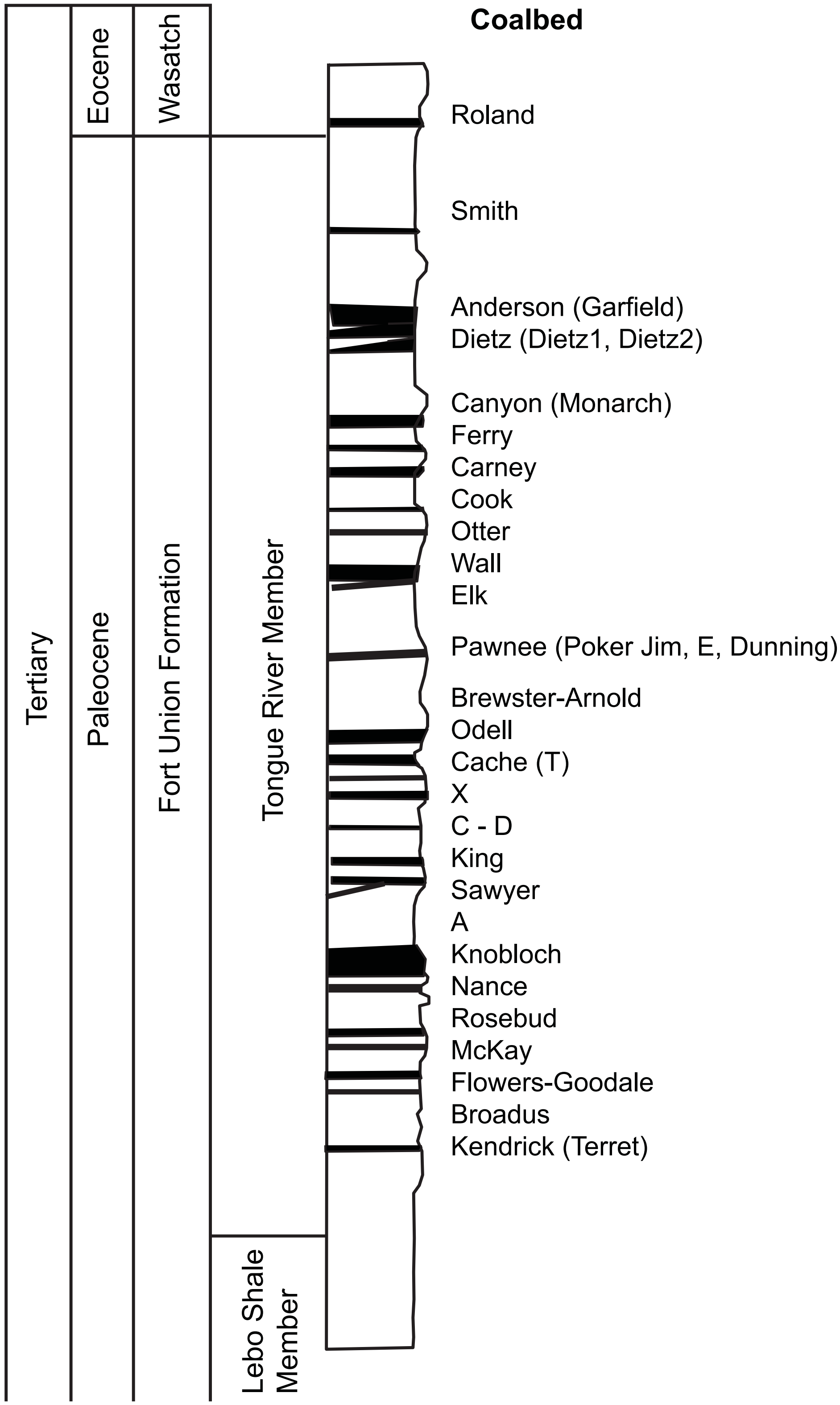


Figure 6. Commonly used nomenclature for coalbeds in the Powder River Basin, Montana (modified from Wheaton and Donato, 2004; Meredith and others, 2012). Not all coalbeds exist at any single location. This chart shows a hypothetical sequence based on studies in multiple coal fields.

the focus of recent mine permit application.

In many parts of southeastern Montana, exposed coalbeds have burned from natural causes such as lightning, wildfires, and spontaneous combustion. Heat from burning coalbeds melts, bakes, fuses, and otherwise alters adjacent sedimentary rocks, creating various brightly colored yellow, orange, and red rocks known as clinker. Clinker covers approximately 1,000 mi^2 of the surface area in the Montana portion of the PRB (Heffern and others, 1993). Clinker beds are a direct indicator that coal is—or was—present, and clinker thickness is generally two to three times the original thickness of the coal that has burned (Matson and others, 1973).

Williston Basin

The Paleocene Fort Union Formation in the Williston Basin region (including the small area in western Garfield County) blankets much of eastern Montana and western North Dakota (fig. 1). Although the coalbeds are laterally discontinuous, major coalbeds appear to be confined to specific stratigraphic horizons within the mapped Fort Union Formation members and can be correlated as coal zones (Sholes, 1988; Sholes and others, 1989; Flores, 1992). Lower Fort Union coalbeds are mostly lenticular, while upper Fort Union coalbeds tend to be thicker and more continuous. Coalbeds generally thin and become less continuous to the north.

Lignite beds locally reach thicknesses of more than 40 ft, but are generally less than 15 ft thick. Heating values range from 5,800 to 7,525 Btu/lb, and average approximately 6,670 Btu/lb. The average sulfur content varies from 0.2 to 1.1 percent, and ash content varies from 3.5 to 10.7 percent.

Major coalbeds that have, at one time or another, been considered minable in the central to southern portion of the region are the Pust bed in Richland County, the Harmon bed (C bed?) in Wibaux and Dawson Counties, the S bed in McCone County, and the Dominy bed in Fallon and Custer Counties (fig. 7). The only lignite mine in the State produces coal from the 15- to 25-ft-thick Pust bed near Savage, Montana.

Bull Mountain Basin

The Bull Mountain Basin is an oval-shaped synclinal basin in southern Musselshell County and northern Yellowstone County (fig. 5). Here, the Fort Union Formation is approximately 2,000 ft thick, with as many as 26 persistent coalbeds. Some of the highest ranking coal commercially mined in Montana is produced from the Bull Mountain Basin. Coal in the region has heating values ranging from 9,270 to 11,000 Btu/lb and averaging 9,730 Btu/lb. Coal sulfur content ranges from 0.4 to 1.3 percent, and ash content ranges from 3.3 to 7.7 percent.

Minable coalbeds in the Bull Mountain region include the Roundup (4 to 6 ft thick), McCleary (up to 9 ft thick), Rehder (5 to 12 ft thick), and Mammoth (5 to 15 ft thick) beds (fig. 8). The Mammoth and Rehder beds have been mined periodically, by both underground and some surface strip mining. Connor (1988, 1989) published structure, outcrop, and isopach maps of the Mammoth coalbed. Other beds that may have minable potential include the Dougherty and the Carpenter. The Carpenter bed has been mined in the northeast portion of the basin.

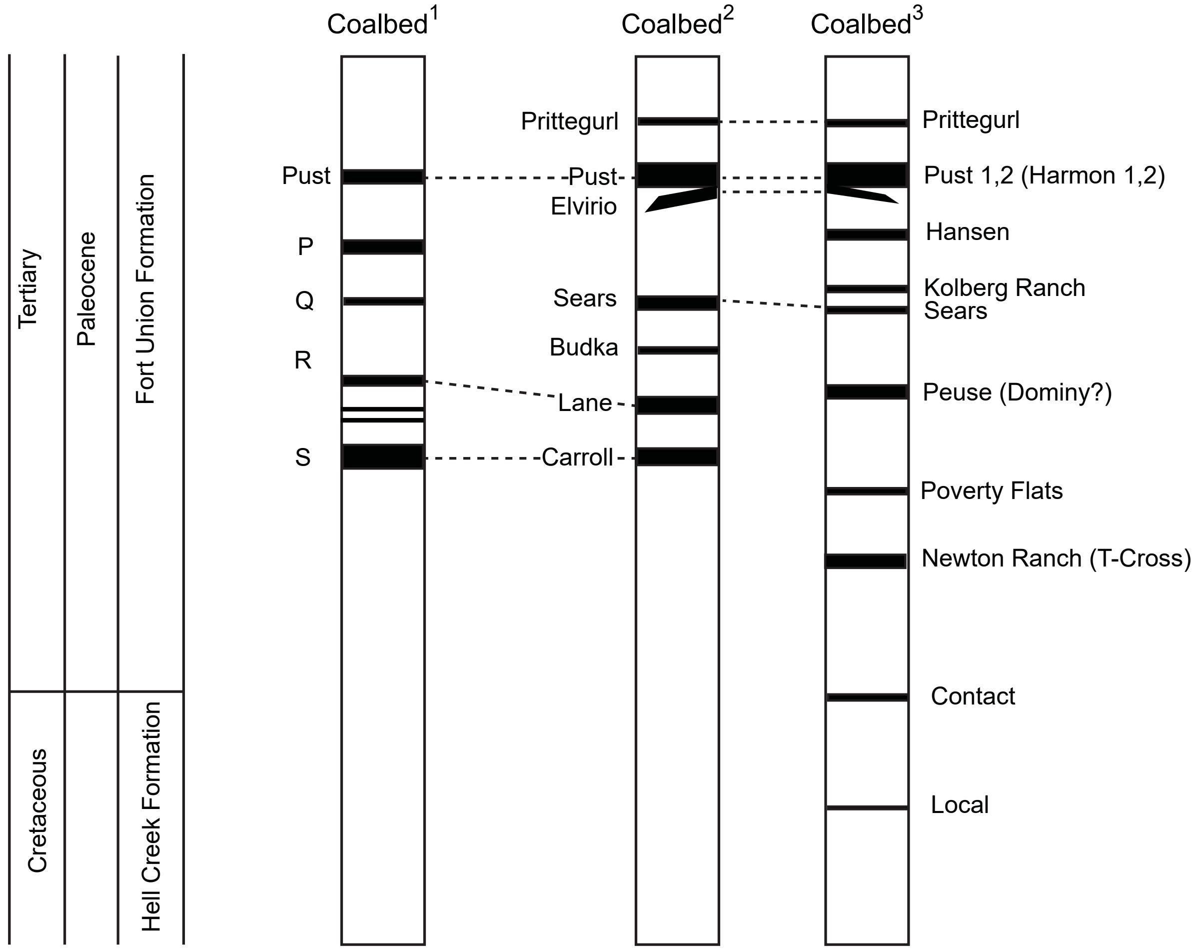
Near the town of Roundup, and mainly south of the Mussellshell River, the Roundup bed was mined from commercial-scale underground mines from 1907 to the 1960s. The coal was primarily used as fuel for the railroads. A typical heating value for the Roundup bed was about 11,000 Btu/lb. Based on volumes of the mine voids estimated from mine maps, about 20 MST of coal was extracted during the life of these mines (Wheaton, 1992).

Montana's only active underground coal mine is located in the Bull Mountain Basin. Coal from the Mammoth bed was intermittently produced at this mine during the 1990s, and the mine has been continuously active since it was reopened in 2009. Key developmental milestones include installation of longwall mining equipment and construction of a rail link connection to regional railroad lines.

Red Lodge field

In the Red Lodge field, the Fort Union Formation is up to 8,500 ft thick along the western edge of the Bighorn Basin and along the Beartooth Mountain Front (fig. 1). Stratigraphically from top down, the Fort Union Formation is composed of 2,000 ft of barren clastic sediments, an 800-ft interval containing up to nine coalbeds, and a lower 5,000 ft of non-coal-bearing rock.

Coalbeds are 3.5 to 11 ft thick and designated simply by numbers 1 through 9. Heating values are 10,000 to 12,000 Btu/lb and average 10,330 Btu/lb. Sulfur content is 1 to 1.3 percent, and ash content varies from 5 to 13 percent.



[1]Nomenclature used in McCone County (Collier and Knechtel, 1939); correlations from Wicenentsen (1979).

[2]Nomenclature used in northern Dawson and Richland Counties (Mathews and Wilde, 1989a)

[3]Nomenclature used in southern Dawson and Wibaux Counties (Sholes, 1988; Sholes and others, 1989)

Figure 7. Commonly used nomenclature for coalbeds in the Williston Basin, Montana. Not all coalbeds exist at any single location. This chart shows a hypothetical sequence based on studies in multiple coal fields. Coalbeds have not been correlated across fields except where indicated by a dotted line.

Between the late 1800s and mid-1960s, the Red Lodge field (including the Bear Creek area to the east) supported at least eight separate underground mines. The Smith Mine at Bear Creek was the site of the worst coal mine disaster in Montana. Seventy-four miners died as a result of a gas and coal dust explosion on February 27, 1943.

Tertiary (Other than Fort Union Formation)

Tertiary Lake Beds

Several coalbeds are associated with Tertiary (Eocene–Miocene) lake beds that formed in the intermontane basins of western Montana, primarily between Helena, Butte, and Missoula (fig. 1). These coalbeds are 5 to 25 ft thick and tend to occur in small lenticular bodies. Quality varies, but most beds are lignite with an average of about 6,700 Btu/lb, 20 percent ash content, and 1.0 percent sulfur content.

Tertiary coalbeds in southwestern Montana are up to 7 ft thick and vary in rank from lignite to bituminous, with heating values ranging from 6,000 to 9,700 Btu/lb and averaging 8,000 Btu/lb (Dyni and Schell, 1982). Sulfur content ranges from 1 to 6 percent, and ash content ranges from 21 to 30 percent.

Flathead Field

In northwestern Montana, Tertiary coal in the Flathead field (fig. 1) ranks subbituminous with a typical heating value of 8,120 Btu/lb. Beds are only up to 3 ft thick and sometimes occur in multiple benches. Sulfur content of a typical sample is about 3 percent with 15 percent ash.

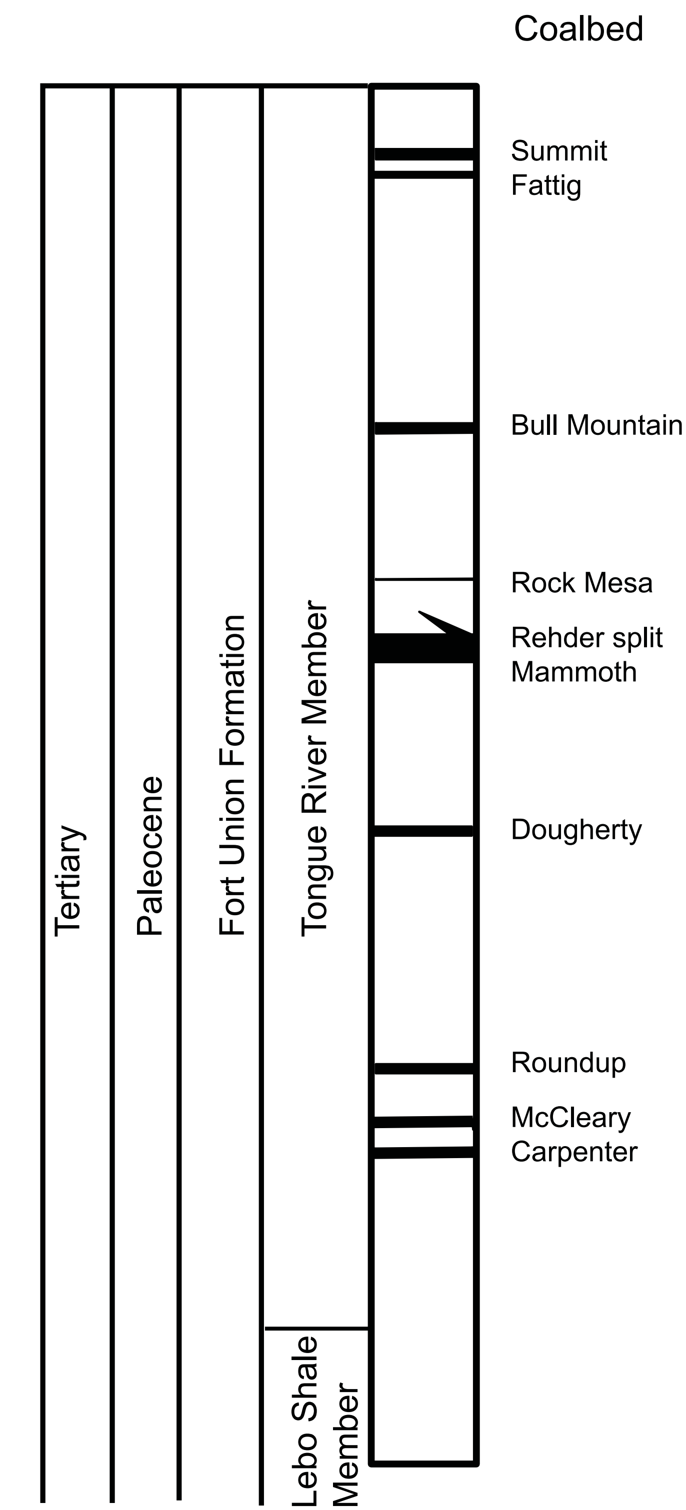


Figure 8. Commonly used nomenclature for coalbeds in the Bull Mountain Basin, Montana (modified from Woolsey and others, 1917; Connor, 1989).

OTHER COAL-RELATED TOPICS

Coalbed Methane

Hydrocarbon gases are generated during all phases of coal maturation through a variety of chemical and biological actions. Anaerobic microbes produce methane from organic compounds through a multistep process of anaerobic respiration (methanogenesis). Under certain chemical and physical settings, large volumes of these gases (mainly methane) can remain in coalbeds or migrate and become trapped in adjacent strata. Gases that remain in the coalbed are adsorbed on coal cleat (fractures) and micro-pore surfaces and held in place by weak Van der Waals bonds and hydrostatic pressure. Gas is released when the production of water reduces hydrostatic pressure, allowing the adsorbed gases (primarily methane) to migrate to the well bores. In some cases, wells must produce water for years before gas production volumes surpass water volumes and the wells become commercially viable. Produced water is an environmental consideration and must be managed at the surface (Meredith and others, 2012). The production life of typical coalbed-methane (CBM) wells is estimated to be about 10 to 12 yr, although production from multiple coalbeds may extend the life of CBM wells.

Coalbed-methane production in Montana began in 1999 and field development proceeded at a much slower pace than in neighboring Wyoming. Just over 1,100 CBM wells have been drilled in the southern part of the Montana PRB near the Montana–Wyoming state line, while over 30,000 CBM wells have been drilled in the Wyoming portion of the PRB.

Coalbeds in the Montana PRB are not as well suited to CBM development as those in Wyoming because they are not as deep or as thick. In the Montana portion of the PRB, coalbeds become shallower and eventually crop out to the north in response to structural and topographic control. While this may be advantageous for surface mining, it is not beneficial for CBM development. Coalbeds at shallow depths or near outcrops are likely to have lower hydrostatic pressures (the pressures necessary to hold the adsorbed methane in place). Under reduced pressures, methane gas in coalbeds can migrate toward the outcrop and eventually escape to the atmosphere. Van Voast and Thale (2001) show, qualitatively, areas of low, moderate, and high CBM potential for the Knobloch and Anderson–Dietz coalbeds based on coal thickness and depth, proximity to outcrop, and groundwater chemistry.

Coalbed-methane drilling and production activity was short-lived in Montana. The number of producing wells active at one time peaked at 670 in 2008. By 2017, only 37 wells were producing methane in Montana. One CBM well was drilled in 2018, the most recent drilling at the time of this writing. The emergence of gas produced from shales has displaced CBM gas production.

Groundwater Aquifers

As much as 70 percent of all water usage in the PRB comes from groundwater aquifers (Van Voast and Reiten, 1988). Coalbeds are more laterally continuous and generally have higher hydraulic conductivity than channel sandstones in the same area. For these reasons, fractured coalbeds are aquifers and furnish much of the local livestock and domestic water supply in many areas of eastern Montana.

The resources in coalbeds can involve as many as three separate mineral estates (oil and gas, coal, and water as part of the surface rights). Conflicts can occur between mineral owners, so sound water management requires third-party science. The MBMG has, therefore, been publishing research results on coal hydrogeology in the PRB since the early 1970s. Issues being considered include: the effect of mining coalbeds on water quality; the degree and extent of hydrostatic-pressure declines as coalbed aquifers are mined or depressurized as a result of coalbed-methane development; the effect of mine spoils as groundwater barriers; and management and disposal of coalbed methane production water (Meredith and others, 2020; Wheaton and Brown, 2005; Brinck and others, 2005).

Uraniferous Lignites

Interest in nuclear source material led to several studies of uranium occurrence in coalbeds in the 1950s and 1960s. Denson and Gill (1965) summarize several reconnaissance evaluations of uraniferous lignites of the Fort Union Formation in the western Dakotas and southeastern Montana.

In the Ekalaka Hills of eastern Montana, uranium concentrations in lignite beds range from 0.001 to 0.034 percent and average about 0.005 percent (Gill, 1959). The highest concentrations of uranium are found in beds lying within 150 to 200 ft of the base of the overlying Miocene Arikaree Formation. The uranium is probably being leached from tuffaceous sandstones of the Arikaree Formation (or other volcanic or tuffaceous rocks), mobilized by groundwater, and precipitated in carbon-rich rocks such as coalbeds, carbonaceous shales, and carbonaceous sandstones.

Hail and Gill (1953) examined beds of coal and carbonaceous shale at 22 areas throughout western Montana. Other than one 0.5-ft-thick bed of carbonaceous shale in Lewis and Clark County, none of the samples collected and analyzed contained uranium concentrations greater than 0.01 percent.

Rare Earth Elements

Trace elemental analyses indicate that some coalbeds, lignites in particular, attract unusual elements including rare earth elements (lanthanide series plus scandium and yttrium). In 2015, the U.S. Department of Energy created the Rare Earth Elements from Coal and Coal By-Products Research and Development Program. Lin and others (2018) analyzed data from the USGS COALQUAL database and found about 9 to 13 percent of the coal samples would be classified as "promising" for rare earth elements. North Dakota recently tested lignite beds in western North Dakota and found rare earth elemental concentrations higher than the 300 parts per million threshold for economic development (Murphy, 2019). Elevated concentrations of rare earth elements may also exist in eastern Montana lignite beds and a similar study should be conducted in Montana.

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