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COAL RESOURCE OCCURRENCE AND COAL DEVELOPMENT POTENTIAL MAPS OF THE SAYLE QUADRANGLE, POWDER RIVER COUNTY, MONTANA

[Report includes 41 plates]

By

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ILLUSTRATIONS

[Plates are in pocket]

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Conversion table

To convert	Multiply by	To obtain
feet	0.3048	meters (m)
miles	1.609	kilometers (km)
acres	0.40469	hectares (ha)
tons (short)	0.9072	metric tons (t)
short tons/acre-ft	7.36	metric tons/hectare-meter (t/ha-m)
Btu/lb	2.326	kilojoules/kilogram (kJ/kg)

INTRODUCTION

Purpose

This text is for use in conjunction with the Coal Resource Occurrence (CRO) and Coal Development Potential (CDP) maps of the Sayle quadrangle, Powder River County, Montana, (41 plates; U.S. Geological Survey Open-File Report 79-789). This set of maps was compiled to support the land-use planning work of the Bureau of Land Management in response to the Federal Coal Leasing Amendments Act of 1976 and to provide a systematic inventory of coal resources on Federal coal lands in Known Recoverable Coal Resource Areas (KRCRAs) in the western United States. The inventory includes only those beds of subbituminous coal that are 5 feet (1.5 m) or more thick and under less than 3,000 feet (914 m) of overburden and those beds of lignite that are 5 feet (1.5 m) or more thick and under less than 1,000 feet (305 m) of overburden.

Location

The Sayle 7 1/2-minute quadrangle is in southwestern Powder River County, Montana, about 30 miles (48 km) southwest of Broadus, a small town in the Powder River valley, and about 52 miles (84 km) northeast of Sheridan, Wyoming. Broadus is on U.S. Highway 212. Sheridan is on U.S. Interstate Highway 90 and on the Burlington Northern Railroad.

Accessibility

The quadrangle is accessible from Broadus by going about 23 miles (37 km) westward on U.S. Highway 212 to Pumpkin Creek, then southward on the Pumpkin Creek Road through the town of Sonnette for a distance of 26 miles (42 km) to the northwest corner of the Sayle quadrangle. The quadrangle is also accessible from Sheridan, Wyoming, by going about 49 miles (79 km) eastward on U.S. Highways 14 and 16 to the Powder River Road, then about 32 miles (51 km) northeastward to the intersection of the Powder River Road and the Spring Creek Road, then about 3 miles (4.8 km) northwestward to the eastern boundary of the quadrangle. The nearest railroad is the Burlington Northern Railroad at Kendrick, Wyoming, about 30 miles (48 km) south-southwest of the Sayle quadrangle.

Physiography

The Sayle quadrangle is within the Missouri Plateau division of the Great Plains physiographic province. The Sayle quadrangle lies along the divide between the Powder River and Otter Creek drainages, which follows a very irregular course with an overall north-south orientation through the center of the quadrangle. The northeastward-flowing Powder River passes within about 1.5 miles (2.4 km) of the southeast corner of the quadrangle. Otter Creek flows northward beginning in the Sayle Hall quadrangle about 6 miles (9.7 km) southwest of the quadrangle. Roughly 40 percent of the quadrangle, along its eastern edge, drains eastward and southeastward into the Powder River; the remaining part of the quadrangle drains westward and northwestward into Otter Creek. From north to south in the quadrangle the major tributaries of the Powder River are Bloom Creek, Plum Creek, Spring Creek, and Flood Creek; the major tributaries of Otter Creek are South Fork Taylor Creek, an unnamed tributary of South Fork Taylor Creek, North Fork Indian Creek, and Indian Creek. All of these tributaries are intermittent streams.

The divide between the Powder River and Otter Creek drainages is comprised of an irregular series of short, narrow, steep ridges and small mesas separated by narrow to broad saddles. Many crests along the divide achieve elevations of between 4,200 and 4,300 feet (1,280 to 1,311 m). To the east the divide falls away rapidly into the thoroughly dissected drainage basins of the incising tributaries of the Powder River. Most of this area is occupied by steep slopes; the valley bottoms are narrow, and only limited, relatively level upland areas remain undissected between the streams. Most of the slopes rise 300 to 500 feet (91 to

152 m) over distances of 0.3 to 0.6 mile (0.5 to 1.0 km). To the west, the terrain falls away much more gradually. Prominent, often flat-topped ridges extend across the western part of the quadrangle. These are only locally dissected, and many of the headwater basins of Otter Creek have broad, gradual slopes. The highest point in the quadrangle is Diamond Butte, at the north edge of the quadrangle, with an elevation of 4,301 feet (1,311 m). The lowest point, with an elevation of about 3,530 feet (1,076 m), is along Spring Creek at the east edge of the quadrangle. Topographic relief in the quadrangle is about 771 feet (235 m).

Climate

The climate of Powder River County is characterized by pronounced variations in seasonal precipitation and temperature. Annual precipitation in the region varies from less than 12 inches (30 cm) to about 16 inches (41 cm). The heaviest precipitation is from April to August. The largest average monthly precipitation is during June. Temperatures in eastern Montana range from as low as -50°F (-46°C) to as high as 110°F (43°C). The highest temperatures occur in July and the lowest in January; the mean annual temperature is about 45°F (7°C) (Matson and Blumer, 1973, p. 6).

Land status

The Boundary and Coal Data Map (pl. 2) shows the land ownership status within the Sayle quadrangle. All of the quadrangle is within the Northern Powder River Known Recoverable Coal Resource Area (KRCRA). The north half of the quadrangle is within the Custer National Forest. The Federal government owns virtually all of the coal rights. There were no outstanding Federal coal leases or prospecting permits recorded as of 1977.

GENERAL GEOLOGY

Previous work

Bryson and Bass (1973) mapped the Sayle quadrangle as part of the Moorhead coal field. Matson (1971, pls. 1, 2, and 3), and Matson and Blumer (1973, pls. 10A, 10B, and 10C) mapped the strippable reserves of the Canyon, Dietz, and Anderson coal beds in the Sayle quadrangle.

Traces of coal bed outcrops shown by previous workers on planimetric maps which lack topographic control have been modified to fit the modern topographic map of the quadrangle.

Stratigraphy

The exposed bedrock units in the quadrangle belong to the Tongue River Member, the uppermost member of the Fort Union Formation (Paleocene).

The Tongue River Member is made up mainly of yellow to gray sandstone, sandy shale, carbonaceous shale, and coal. Much of the coal has burned, baking the overlying sandstone and shale and forming thick, reddish-colored clinker beds. The upper part of the Tongue River Member has been removed by erosion, leaving about 2,000 feet (610 m) of the member remaining in the quadrangle.

Coal and other rocks comprising the Tongue River Member were deposited in a continental environment at elevations of perhaps a few tens of feet (a few meters) above sea level in a vast area of shifting rivers, flood plains, sloughs, swamps, and lakes that occupied the area of the Northern Great Plains in Paleocene (early Tertiary) time.

Representative samples of the sedimentary rocks overlying and interbedded with minable coal beds in the eastern and northern Powder River Basin have been analyzed for their content of trace elements by the U.S. Geological Survey, and the results have been summarized by the U.S. Department of Agriculture and others (1974) and by Swanson (in Mapel and others, 1977, pt. A, p. 42-44). The rocks contain no greater amounts of trace elements of environmental concern than do similar rocks found throughout other parts of the western United States.

Structure

The Sayle quadrangle is in the central-northeast part of the Powder River structural basin. Regionally the strata dip southwestward at an angle of less than 1 degree. In places, the regional dip is modified by local folding and faulting (pls. 4, 7, 11, 16, 22, 25, 28, 32, 35, and 38). Some irregularities in dip may be caused by depositional variations as well as differential compaction, common in continental strata.

COAL GEOLOGY

The coal beds in the Sayle quadrangle are shown in outcrop on the Coal Data Map (pl. 1) and in section on the Coal Data Sheet (pl. 3). All of the mapped coal beds occur in the Tongue River Member of the Fort Union Formation (Paleocene). No commercial coals are known to exist below the Tongue River Member.

The lowermost recognized coal bed is the Broadus coal bed which occurs about 300 feet (91 m) above the base of the Tongue River Member. The Broadus coal bed is successively overlain by a mostly noncoal interval of about 200 feet (61 m) containing a local coal bed, the Flowers-Goodale coal bed, a noncoal interval of about 80 to 180 feet (24.4 to 54.9 m), the Knobloch coal bed, a mostly noncoal interval of about 280 to 320 feet (85 to 98 m), the Cache coal bed, a noncoal interval of about 120 to 160 feet (37 to 49 m), the Pawnee (Dunning) coal bed, a noncoal interval of about 5 to 50 feet (1.5 to 15 m), the Number 5 coal bed, a noncoal interval of about 160 to 200 feet (49 to 61 m), the lower split of the Cook coal bed, a noncoal interval of about 25 to 100 feet (7.6 to 30.5 m), the upper split of the Cook coal bed, a noncoal interval of about 80 to 180 feet (24 to 55 m), the Canyon coal bed, a noncoal interval of about 80 to 160 feet (24 to 49 m), the lower split of the Dietz coal bed, a noncoal interval of about 0 to 15 feet (4.6 m), the upper split of the Dietz coal bed, a noncoal interval of about 25 to 50 feet (7.6 to 15 m), the lower split of the Anderson coal bed, a noncoal interval of about 5 to 15 feet (1.5 to 4.6 m), the middle split of the Anderson coal bed, a noncoal interval of about 5 to 45 feet (1.5 to 14 m), the upper split of the Anderson coal bed, a noncoal interval of about 200 feet (61 m), a local coal bed, a noncoal interval of about 55 feet (16.8 m), another local coal bed.

The trace-element content of coals in this quadrangle has not been determined; however, coals in the Northern Great Plains, including those in the Fort Union Formation in Montana, have been found to contain, in general, appreciably lesser amounts of most elements of environmental concern than coals in other areas of the United States (Hatch and Swanson, 1977, p. 147).

Broadus coal bed

The Broadus coal bed, first described by Warren (1959, p. 570), derives its name from exposures of coal near the town of Broadus in the Epsie NE quadrangle, about 26 miles (42 km) northeast of the Sayle quadrangle. The Broadus coal bed is not exposed in the Sayle quadrangle but occurs about 300 feet (91 m) above the base of the Tongue River Member. The isopach and structure contour map (pl. 38) is based on data from one drill hole in the southwestern part of the quadrangle and information projected from adjacent quadrangles. This map shows that the Broadus coal bed ranges from about 5 to 15 feet (1.5 to 4.6 m) in thickness and has a general southeastward dip of less than half a degree. Overburden on the Broadus coal bed (pl. 39) ranges from about 1,100 to 1,700 feet (355 to 518 m) in thickness.

There is no known, chemical analysis of the Broadus coal in the Sayle quadrangle. However, a chemical analysis of Broadus coal from the Peerless mine, sec. 23, T. 4 S., R. 50 E. in the Epsie NE quadrangle, located about 23 miles (37 km) northeast of the Sayle quadrangle, shows ash 6.4 percent, sulfur 0.2

percent, and heating value 7,240 Btu per pound (16,840 kJ/kg) on an as-received basis (Gilmour and Dahl, 1967, p. 16). This heating value converts to about 7,735 Btu per pound (17,992 kJ/kg) on a moist, mineral-matter-free basis, indicating that the Broadus coal in that location is lignite A in rank. However, because the Sayle quadrangle lies deeper in the Powder River structural basin, it is assumed that the coals are more compacted and that the Broadus coal in the Sayle quadrangle is subbituminous C in rank.

Flowers-Goodale coal bed

The Flowers-Goodale coal bed was named by Bass (1932, p. 53-54) for exposures in two mines in the Brandenberg quadrangle in the Ashland coal field, about 41 miles (66 km) north-northwest of the Sayle quadrangle. In the Sayle quadrangle, the Flowers-Goodale coal bed occurs about 200 feet (61 m) above the Broadus coal bed. This coal bed does not crop out in the Sayle quadrangle but was penetrated by an oil-and-gas test hole in the southwestern part of the quadrangle (pls. 1 and 3). Based on this measurement and measurements in adjacent quadrangles, the isopach and structure contour map (pl. 35) shows that the Flowers-Goodale coal ranges from about 5 to 11 feet (1.5 to 3.3 m) in thickness, and has a general southwestward dip of less than half a degree.

There is no known, publicly available chemical analysis of the Flowers-Goodale coal in the Sayle quadrangle. However, Matson and Blumer (1973, p. 121) report that a chemical analysis of the Flowers-Goodale coal from a depth of 53 to 62 feet (16 to 19 m) in coal test hole SH-7076, sec. 14, T. 1 S., R. 45 E. in the Cook Creek Reservoir quadrangle about 35 miles (56 km) north-northwest of the Sayle quadrangle, shows ash 8.144 percent, sulfur 0.961 percent, and heating value 8,102 Btu per pound (18,845 kJ/kg). This heating value converts to about 8,820 Btu per pound (20,515 kJ/kg) on a moist, mineral-matter-free basis, indicating that the Flowers-Goodale coal at that location is subbituminous C. Due to the similar structural position in the Northern Powder River Basin of that location and the Sayle quadrangle, it is assumed that the Flowers-Goodale coal in this quadrangle is similar and is also subbituminous C in rank.

Knobloch coal bed

The Knobloch coal bed was named by Bass (1924) from a small mine on the Knobloch Ranch in the Tongue River valley in the Birney Day School quadrangle about 24 miles (38.6 km) west-northwest of the Sayle quadrangle. The Knobloch occurs about 80 to 180 feet (24.4 to 54.9 m) above the Flowers-Goodale coal bed in the Sayle quadrangle. The Knobloch coal bed does not crop out in the Sayle quadrangle. Information for the isopach and structure contour map (pl. 32) was projected from adjacent quadrangles. This map shows that the Knobloch coal ranges from about 5 to 16 feet (1.5 to 4.9 m) in thickness and has a general southward dip of less than half a degree. Overburden on the Knobloch coal bed ranges from about 800 to 1,000 feet (244 to 305 m) in thickness.

There is no known, publicly available chemical analysis of the Knobloch coal in the Sayle quadrangle. However, Matson and Blumer (1973, p. 72) report that a chemical analysis of the Knobloch coal from a depth of 101 to 111 feet (31 to 34 m) in drill hole SH-7067, sec. 12, T. 3 S., R. 45 E., in the Coleman Draw quadrangle about 25 miles (40 km) north-northwest of the Sayle quadrangle shows ash 4.069 percent, sulfur 0.119 percent, and heating value 8,395 Btu per pound (19,527 kJ/kg) on an as-received basis. This heating value converts to about 8,751 Btu per pound (20,355 kJ/kg) on a moist, mineral-matter-free basis, indicating that the Knobloch coal at that location is subbituminous C in rank. Because of the proximity and similar structural position of the Sayle quadrangle to that location, it is assumed that the Knobloch in this quadrangle is similar and is also subbituminous C in rank.

Cache coal bed

The Cache coal bed was first described by Warren (1959, p. 572) from exposures of coal along Cache Creek in the Lonesome Peak and Yarger Butte quadrangles about 16 miles (26 km) northeast of the Sayle quadrangle. The Cache coal bed occurs about 280 to 320 feet (85 to 98 m) above the Knobloch coal bed in the Sayle quadrangle. The Cache coal bed does not crop out in the Sayle quadrangle but was penetrated by an oil-and-gas test hole in the southwestern part of the quadrangle. The isopach and structure contour maps (pls. 28 and 29) were constructed using data from this drill hole and information projected from the Reanus Cone and Bradshaw Creek quadrangles to the west and south. The isopach and structure contour maps (pls. 28 and 29) show that the Cache coal bed ranges from about 4 to 8 feet (1.2 to 2.4 m) in thickness and has a general southwestward dip of less than half a degree. Overburden on the Cache coal bed ranges from about 400 to 700 feet (122 to 213 m) in thickness.

There is no known, publicly available chemical analysis of Cache coal from the Sayle quadrangle. However, Matson and Blumer (1973, p. 93) report that a chemical analysis of the Cache coal from a depth of 50 to 60 feet (15 to 18 m) in drill hole SH-716, sec. 36, T. 8 S., R. 50 E. in the Bay Horse quadrangle about 18 miles (29 km) east-southeast of the Sayle quadrangle showed ash 5.213 percent, sulfur 0.360 percent, and heating value 7,592 Btu per pound (17,659 kJ/kg) on an as-received basis. This heating value converts to about 8,009 Btu per pound (18,630 kJ/kg) on a moist, mineral-matter-free basis, indicating that the Cache coal at that location is lignite A in rank. However, this heating value is very close to subbituminous C in rank. The Cache coal in the Sayle quadrangle, which is closer to the center of the basin, is likely to have a higher heating value and is probably subbituminous C in rank.

Pawnee (Dunning) coal bed

The Pawnee coal bed was first described by Warren (1959, p. 572) from exposures in the Birney-Broadus coal field, Montana, which includes the Phillips Butte quadrangle, which is just north of the Sayle quadrangle. In the nearby Threemile Buttes, Yager Butte, Goodspeed Butte, and Reanus Cone quadrangles to the north, northwest, and west, we have mapped this same coal bed. However, in those quadrangles the coal is called the Dunning coal bed after usage in early day geological reports on those areas by previous authors. Based upon our present-day coal isopachs and structure contours, the Pawnee and Dunning appear to be the same coal bed.

The Pawnee (Dunning) coal bed occurs about 120 to 160 feet (37 to 49 m) above the Cache coal bed in the Sayle quadrangle. The Pawnee (Dunning) coal bed does not crop out in the quadrangle but was penetrated by an oil-and-gas test hole in the southwestern part of the quadrangle. Data from this drill hole and information from adjacent quadrangles was used to construct the isopach and structure contour map (pl. 25). This map shows that the Pawnee (Dunning) coal bed ranges from about 8 to 14 feet (2.4 to 4.3 m) in thickness and is almost flat lying. Overburden on the Pawnee (Dunning) coal bed (pl. 26) ranges from about 200 to 600 feet (61 to 183 m) in thickness.

There is no known, publicly available chemical analysis of the Pawnee (Dunning) coal from the Sayle quadrangle. However, Matson and Blumer (1973, p. 110) report that a chemical analysis of the Pawnee (Dunning) coal from a depth of 30 to 37 feet (9 to 11 m) in coal test hole SH-7116, sec. 29, T. 4 S., R. 48 E., in the Sonnette quadrangle, about 14 miles (22.5 km) north-northeast of the Sayle quadrangle, shows ash 6.925 percent, sulfur 1.400 percent, and heating value 7,902 Btu per pound (18,380 kJ/kg) on an as-received basis. This heating value converts to about 8,490 Btu per pound (19,748 kJ/kg) on a moist, mineral-matter-free basis, indicating that the Pawnee (Dunning) coal at that location is subbituminous C in rank. Because of the proximity of that location to the Sayle quadrangle, it is assumed that the coals are similar and that the Pawnee (Dunning) coal in this quadrangle is also subbituminous C in rank.

Number 5 coal bed

The Number 5 coal bed was first described by Bryson and Bass (1973, p. 91) from exposures of coal in the Baldy Peak quadrangle about 15 miles (24 km) east of the Sayle quadrangle. The Number 5 coal bed occurs about 5 to 50 feet (1.5 to 15 m) above the Pawnee (Dunning) coal bed in the Sayle quadrangle. Because this coal bed is less than 5 feet (1.5 m) in thickness, economic resources have not been assigned to it.

Upper and lower splits of the Cook coal bed

The Cook coal bed was named by Bass (1932, p. 59) for exposures on Cook Mountain in the Cook Creek Reservoir quadrangle which is about 29 miles (46.7 km) north-northwest of the Sayle quadrangle. Warren (1959, p. 573) recognized the upper split of the Cook coal bed in the Birney-Broadus coal field about 1 mile (1.6 km) north of this quadrangle. Bryson and Bass (1973, pl. 1) mapped the Cook (Number 4) coal bed in the Moorhead coal field which includes the Sayle quadrangle. A preliminary regional isopach map of the Cook coal bed shows that the Cook (Number 4) coal bed of Bryson and Bass (1973) is the upper split of the Cook coal bed.

In the Sayle quadrangle, the lower split of the Cook coal bed occurs about 160 to 200 feet (49 to 61 m) above the Pawnee (Dunning) coal bed. The lower split of the Cook crops out in the southeastern part of the quadrangle and was penetrated by an oil-and-gas test hole in the southwestern part of the quadrangle. The isopach and structure contour map (pl. 22) which is based on limited data shows that the lower split of the Cook coal bed ranges from about 2.5 to 5 feet (0.8 to 1.5 m) in thickness and is almost flat lying. Overburden on the lower split of the Cook coal bed (pl. 23) ranges from about 300 to 500 feet (91 to 152 m) in thickness.

The upper split of the Cook coal bed crops out in the northeastern and southwestern parts of the quadrangle. In the Sayle quadrangle, the upper split of the Cook coal bed occurs about 25 to 100 feet (7.6 to 30.5 m) above the lower split of the Cook coal bed. The isopach and structure contour map (pl. 19) shows that the upper split of the Cook coal bed ranges from about 6 to 18 feet (1.8 to 5.5 m) in thickness and has a general southward dip of less than 1 degree. In places the general dip is modified by low-relief folding. Overburden on the upper split of the Cook coal bed (pl. 20) ranges from 0 feet at the outcrops to about 500 feet (0-152 m) in thickness.

There is no known, publicly available chemical analysis of the upper and lower splits of the Cook coal in the Sayle quadrangle. However, Matson and Blumer (1973, p. 99) report that a chemical analysis of the Cook coal bed at a depth of 125 to 133 feet (38 to 40 m) in drill hole SH-7135, sec. 29, T. 6 S., R. 48 E., in the Hodsdon Flats quadrangle about 2.5 miles (4 km) north-northeast of the Sayle quadrangle shows ash 3.458 percent, sulfur 0.384 percent, and heating value 8,198 Btu per pound (19,048 kJ/kg) on an as-received basis. This heating value converts to about 8,482 Btu per pound (19,730 kJ/kg) on a moist, mineral-matter-free basis, indicating that the Cook coal at that location is subbituminous C in rank. Because of the proximity of that location to the Sayle quadrangle and the close stratigraphic relationship of the upper and lower splits of the Cook coal bed, it is assumed that they are similar and are also subbituminous C in rank.

Canyon coal bed

The Canyon coal bed was first described by Baker (1929, p. 36) from exposures in the northward extension of the Sheridan coal field, probably along

Canyon Creek in the northern part of the Spring Gulch quadrangle about 35 miles (56 km) west of the Sayle quadrangle. The Canyon coal bed occurs about 80 to 180 feet (24 to 55 m) above the upper split of the Cook coal bed in the Sayle quadrangle. The Canyon coal bed crops out over most of the quadrangle. The isopach and structure contour map (pl. 16) shows that the Canyon coal bed ranges from about 10 to 20 feet (3 to 6 m) in thickness and has a general southwestward dip of less than half a degree. In places, the general dip is modified by low-relief folding. Overburden on the Canyon coal bed (pl. 17) ranges from 0 feet at the outcrops to about 300 feet (0-91 m) in thickness.

There is no known, publicly available chemical analysis of the Canyon coal in the Sayle quadrangle. However, Matson and Blumer (1973, p. 96) report that a chemical analysis of the Canyon coal at a depth of 56 to 63 feet (17 to 19 m) in drill hole SH-7124, sec. 30, T. 6 S., R. 47 E., in the Goodspeed Butte quadrangle about 3 miles (4.8 km) northwest of the Sayle quadrangle, shows ash 3.296 percent, sulfur 0.262 percent, and heating value 7,897 Btu per pound (18,368 kJ/kg) on an as-received basis. This heating value converts to about 8,166 Btu per pound (18,994 kJ/kg) on a moist, mineral-matter-free basis, indicating that the Canyon coal at that location is high lignite A in rank. Because of the proximity of that location to the Sayle quadrangle, it is assumed that the coals are similar and that the Canyon coal in this quadrangle is also high lignite A in rank.

Upper and lower splits of the Dietz coal bed

The Dietz 1, 2, and 3 coal beds were first described by Taff (1909, p. 139-140) from exposures near the old mining town of Dietz in the Sheridan coal field, Wyoming, about 51 miles (82 km) southwest of the Sayle quadrangle. Matson and Blumer (1973, p. 67) recognized the Dietz (No. 2) coal bed and an upper split of the Dietz in the Sayle quadrangle.

The lower split of the Dietz coal bed occurs about 80 to 160 feet (24 to 49 m) above the Canyon coal bed in the Sayle quadrangle. The isopach and structure contour maps of the Dietz coal bed and its splits (pls. 10 and 11) show that within the area enclosed by the split line in the northern part of the quadrangle the Dietz coal bed can be separated into an upper and a lower split. In the area outside of the split line, the Dietz is considered to be a single coal bed. The map shows that the lower split of the Dietz coal bed (pl. 10) ranges from about 2 to 6 feet (0.6 to 1.8 m) in thickness and has a general southward dip of less than 1 degree (pl. 11). In places the general dip is modified by low-relief folding and faulting. Overburden on the lower split of the Dietz coal bed (pl. 14) ranges from 0 feet at the outcrops to less than 100 feet (0-30 m) in thickness.

The upper split of the Dietz coal bed occurs from 0 to about 15 feet (0-4.6 m) above the lower split of the Dietz coal bed. The isopach and structure contour maps of the Dietz coal bed and its splits (pls. 10 and 11) show that the upper split of the Dietz coal bed ranges from about 2 to 12 feet (0.6 to 3.7 m) in thickness and has a general southward dip of less than 1 degree. In places, the general dip is modified by low relief folding and faulting. Overburden on the upper split of the Dietz coal bed ranges from 0 feet at the outcrops to about 100 feet (0-30 m) in thickness.

There is no known, publicly available chemical analysis of the upper and lower splits of the Dietz coal in the Sayle quadrangle. However, Matson and Blumer (1973, p. 59) report that a chemical analysis of the Dietz coal at a depth of 59 to 68 feet (18 to 21 m) in drill hole SH-7041, sec. 28, T. 8 S., R. 45 E., in the Bear Creek School quadrangle about 11 miles (18 km) southwest of the Sayle quadrangle shows ash 4.069 percent, sulfur 0.315 percent, and heating value 7,907 Btu per pound (18,392 kJ/kg) on an as-received basis. This heating value converts to about 8,242 Btu per pound (19,172 kJ/kg) on a moist, mineral-matter-free basis, indicating that the Dietz coal at that location is very high lignite A in rank. Because of the proximity of that location to the Sayle quadrangle and the close stratigraphic relationship of the upper and lower splits of the Dietz coal beds, it is assumed that these coals are similar and that the upper and lower splits of the Dietz coal in the Sayle quadrangle are also very high lignite A in rank.

Upper, middle, and lower Anderson coal beds

The Anderson (Dietz 1) coal bed was first described by Baker (1929, p. 35) from exposures in the northward extension of the Sheridan coal field, probably from exposures along Anderson Creek in the southern part of the Spring Gulch quadrangle about 35 miles (56 km) west of the Sayle quadrangle. Bryson and Bass (1973, p. 67) recognized three splits or beds of the Anderson coal bed in the northeastern part of the Sayle quadrangle.

The lower split of the Anderson coal bed occurs about 25 to 50 feet (7.6 to 15 m) above the upper split of the Dietz coal bed in the Sayle quadrangle. The isopach and structure contour map (pl. 7) shows that the lower split of the Anderson coal bed ranges from about 4 to 7 feet (1.2 to 2.1 m) in thickness. The map shows a closed anticline in the northern part of the quadrangle. The bed dips at an angle of less than 1 degree. Overburden on the lower split of the Anderson coal bed (pl. 8) ranges from 0 feet at the outcrops to about 100 feet (0-30 m) in thickness.

The middle split of the Anderson coal bed occurs about 5 to 15 feet (1.5 to 4.6 m) above the lower split of the Anderson coal bed. The middle split of the Anderson coal bed attains a thickness of 5 feet (1.2 m) in a small area of less than 40 acres (16.2 ha); therefore, economic resources have not been assigned to this coal bed.

The Anderson coal bed and the upper split of the Anderson coal bed (pl. 4) can be recognized north of the split line in the northern part of the quadrangle. South of the split line, the beds merge into one bed, the Anderson coal bed. In the Sayle quadrangle, the Anderson coal bed has been burned forming an extensive clinker bed. The Anderson coal bed occurs about 50 to 70 feet (15 to 21 m) above the upper split of the Dietz coal bed. The interval between the middle split of the Anderson coal bed and the upper split of the Anderson coal bed ranges from about 5 to 45 feet (1.5 to 14 m) in thickness. The isopach and structure contour map (pl. 4) shows that the upper split of the Anderson coal bed is less than 4 feet (1.2 m) in thickness and that the Anderson coal bed ranges from about 5 to 30 feet (1.5 to 9.1 m) in thickness. The Anderson coal beds have a general southeastward dip of less than half a degree. In places the general dip is modified by low-relief faulting and folding. Overburden on the Anderson coal bed and the upper split of the Anderson coal bed (pl. 5) ranges from 0 feet at the outcrops to about 200 feet (0-61 m) in thickness.

There is no known, publicly available chemical analysis of the Anderson coal and its splits in the Sayle quadrangle. However, Matson and Blumer (1973, p. 60) report that a chemical analysis of the Anderson coal at a depth of 86 to 115 feet (26 to 35 m) in drill hole SM-4, sec. 27, T. 8 S., R. 47 E., in the Bradshaw Creek quadrangle about 1 mile (1.6 km) south of the Sayle quadrangle shows ash 5.1 percent, sulfur 0.4 percent, and heating value 8,150 Btu per pound (18,957 kJ/kg) on an as-received basis. This heating value converts to about 8,588 Btu per pound (19,976 kJ/kg) on a moist, mineral-matter-free basis, indicating that the Anderson coal at that location is subbituminous C in rank. Because of the proximity of that location to the Sayle quadrangle and the close stratigraphic relationship of the Anderson coal and its splits, it is assumed that these coals are similar and that the Anderson coal and its splits are similar and are also subbituminous C in rank.

Local coal beds

Local coal beds occur at several places in the Sayle quadrangle (pls. 1 and 3). Because these local beds are thin and are of limited areal extent, they have not been assigned economic coal resources.

COAL RESOURCES

Data from all publicly available drill holes and from surface mapping by others (see list of references) were used to construct outcrop, isopach, and structure contour maps of the coal beds in this quadrangle.

A coal resource classification system has been established by the U.S. Bureau of Mines and the U.S. Geological Survey and published in U.S. Geological Survey Bulletin 1450-B (1976). Coal resource is the estimated gross quantity of coal in the ground that is now economically extractable or that may become so. Resources are classified as either Identified or Undiscovered. Identified Resources are specific bodies of coal whose location, rank, quality, and quantity are known from geologic evidence supported by specific measurements. Undiscovered Resources are bodies of coal which are surmised to exist on the basis of broad geologic knowledge and theory.

Identified Resources are further subdivided into three categories of reliability of occurrence: namely Measured, Indicated, and Inferred, according to their distance from a known point of coal-bed measurement. Measured coal is coal located within 0.25 mile (0.4 km) of a measurement point, Indicated coal extends 0.5 mile (0.8 km) beyond Measured coal to a distance of 0.75 mile (1.2 km) from the measurement point, and Inferred coal extends 2.25 miles (3.6 km) beyond Indicated coal to a distance of 3 miles (4.8 km) from the measurement point.

Undiscovered Resources are classified as either Hypothetical or Speculative. Hypothetical Resources are those undiscovered coal resources in beds that may reasonably be expected to exist in known coal fields under known geologic conditions. In general, Hypothetical Resources are located in broad areas of coal fields where the coal bed has not been observed and the evidence of coal's existence is from distant outcrops, drill holes, or wells that are more than 3 miles (4.8 km) away. Hypothetical Resources are located beyond the outer boundary of the Inferred part of Identified Resources in areas where the assumption of continuity of the coal bed is supported only by extrapolation of geologic evidence. Speculative Resources are undiscovered resources that may occur in favorable areas where no discoveries have been made. Speculative Resources have not been estimated in this report.

For purposes of this report, Hypothetical Resources of subbituminous coal are in coal beds which are 5 feet (1.5 m) or more thick, under less than 3,000 feet (914 m) of overburden, but occur 3 miles (4.8 km) or more from a coal-bed measurement. Hypothetical Resources of lignite are in lignite beds which are 5 feet (1.5 m) or more thick, under less than 1,000 feet (305 m) of overburden, but occur 3 miles (4.8 km) or more from a coal-bed measurement.

Reserve Base coal is that economically minable part of Identified Resources from which Reserves are calculated. In this report, Reserve Base coal is the gross amount of Identified Resources that occurs in beds 5 feet (1.5 m) or more thick and under less than 3,000 feet (914 m) of overburden for subbituminous coal or under less than 1,000 feet (305 m) of overburden for lignite.

Reserve Base coal may be either surface-minable coal or underground-minable coal. In this report, surface-minable Reserve Base coal is subbituminous coal that is under less than 500 feet (152 m) of overburden. In this report, underground-minable Reserve Base coal is subbituminous coal that is under more than 500 feet (152 m), but less than 3,000 feet (914 m) of overburden.

Reserves are the recoverable part of Reserve Base coal. In this area, 85 percent of the surface-minable Reserve Base coal is considered to be recoverable (a recovery factor of 85 percent). Thus, these Reserves amount to 85 percent of the surface-minable Reserve Base coal. For economic reasons coal is not presently being mined by underground methods in the Northern Powder River Basin. Therefore, the underground-mining recovery factor is unknown and Reserves have not been calculated for the underground-minable Reserve Base coal.

Tonnages of coal resources were estimated using coal-bed thicknesses obtained from the coal isopach map for each coal bed (see list of illustrations). The coal resources, in short tons, for each isopached coal bed are the product of the acreage of coal (measured by planimeter), the average thickness in feet of the coal bed, and a conversion factor of 1,770 short tons of subbituminous coal per acre-foot (13,018 metric tons per hectare-meter). Tonnages of coal in Reserve Base, Reserves, and Hypothetical categories, rounded to the nearest one-hundredth of a million short tons, for each coal bed are shown on the Areal Distribution and Tonnage maps (see list of illustrations).

As shown by table 1, the total tonnage of federally owned, surface-minable Reserve Base coal in this quadrangle is estimated to be 1,915.14 million short tons (1,737,42 million t). The total tonnage of federally owned, surface-minable Hypothetical coal is estimated to be 390.31 million short tons (354.09 million t). As shown by table 2, the total federally owned, underground-minable Reserve Base coal is estimated to be 567.08 million short tons (514.45 million t). The total federally owned, underground-minable Hypothetical coal is estimated to be 662.73 million short tons (601.23 million t). The total tonnage of surface- and underground-minable Reserve Base coal is 2,482.22 million short tons (2,251,87 million t), and the total of surface- and underground-minable Hypothetical coal is 1,053.04 million short tons (955.32 million t).

About 3 percent of the surface-minable Reserve Base tonnage is classed as Measured, 16 percent as Indicated, and 81 percent as Inferred. About 1 percent of the underground-minable Reserve Base tonnage is Measured, 6 percent is Indicated, and 93 percent is Inferred.

The total tonnages per section for both Reserve Base and Hypothetical coal, including both surface- and underground-minable coal, are shown in the northwest corner of the Federal coal lands in each section on plate 2. All numbers on plate 2 are rounded to the nearest one-hundredth of a million short tons.

COAL DEVELOPMENT POTENTIAL

There is a potential for surface-mining in the Northern Powder River Basin in areas where subbituminous coal beds 5 feet (1.5 m) or more thick are overlain by less than 500 feet (152 m) of overburden (the stripping limit), or where lignite beds of the same thickness are overlain by 200 feet (61 m) or less of overburden (the stripping limit). This first thickness of overburden is the assigned stripping limit for surface mining of multiple beds of subbituminous coal in this area. Areas having a potential for surface mining were assigned a high, moderate, or low development potential based on their mining-ratio values (cubic yards of overburden per short ton of recoverable coal).

The formula used to calculate mining-ratio values for coal is:

$$MR = \frac{t_o\ (cf)}{t_c\ (rf)}$$

where MR = mining ratio

t_o = thickness of overburden, in feet

t_c = thickness of coal, in feet

rf = recovery factor = 0.85 in this area

cf = conversion factor = 0.911 cu. yds./short ton for subbituminous coal or 0.922 cu. yds./short ton for lignite

The mining-ratio values are used to rate the degree of potential that areas within the stripping limit have for surface-mining development. Areas having mining-ratio values of 0 to 10, 10 to 15, and greater than 15 are considered to have high, moderate, and low development potential, respectively. This grouping of mining-ratio values was provided by the U.S. Geological Survey and is based on economic and technological criteria. Mining-ratio contours and the stripping-limit overburden isopach, which serve as boundaries for the development-potential areas, are shown on the overburden isopach and mining-ratio contour plates. Estimated tonnages of surface-minable Reserve Base and Hypothetical coal resources in each development-potential category (high, moderate, and low) are shown in table 1.

Estimated tonnages of underground-minable coal resources are shown in table 2. Because coal is not presently being mined by underground mining in the Northern Powder River Basin for economic reasons, for purposes of this report all of the underground-minable coal resources are considered to have low development potential.

Development potential for surface-mining methods

The Coal Development Potential (CDP) map included in this series of maps pertains only to surface mining. It depicts the highest coal development-potential category which occurs within each smallest legal subdivision of land (normally about 40 acres or 16.2 ha). For example, if such a 40-acre (16.2-ha) tract of land contains areas of high, moderate, and low development potential, the entire tract is assigned to the high development-potential category for CDP mapping purposes. Alternatively, if such a 40-acre (16.2-ha) tract of land contains areas of moderate, low, and no development potential, the entire tract is assigned to the moderate development-potential category for CDP mapping purposes. For practical reasons, the development-potential categories of areas of coal smaller than 1 acre (0.4 ha) have been disregarded in assigning a development potential to the entire 40-acre (16.2-ha) tract.

In areas of moderate or high topographic relief, the area of moderate development potential for surface mining of a coal bed (area having mining-ratio values of 10 to 15) is often restricted to a narrow band between the high and low development-potential areas. In fact, because of the 40-acre (16.2-ha) minimum size of coal development-potential tracts, the narrow band of moderate development-potential area often does not appear on the CDP map because it falls within the 40-acre (16.2-ha) tracts that also include areas of high development potential. The Coal Development Potential (CDP) map then shows areas of high development potential abutting against areas of low development potential.

The coal development potential for surface-mining methods on Federal coal lands is shown on the Coal Development Potential map (pl. 41). Most of the coal lands in the quadrangle have a high development potential for surface mining.

The Broadus, Flowers-Goodale, and Knobloch coal beds have no development potential for surface mining because overburden on all of these coal beds is greater than 500 feet (152 m), the arbitrarily assigned stripping limit.

The Cache coal bed (pl. 30) has an insignificant area of low development potential for surface mining extending from the approximate 400-foot (123-m) overburden isopach up the slopes to the 500-foot (152-m) overburden isopach. The remainder of the coal has no development potential for surface mining because it is beyond the stripping limit.

The Pawnee (Dunning) coal bed (pl. 26) has development potential for surface mining in areas scattered throughout the quadrangle. Relatively large areas of low development potential extend from the borders of the quadrangle up the stream valleys to the 500-foot (152-m) stripping limit. Extremely large areas of no development potential extend from the 500-foot (152-m) overburden isopach under the crests of the hills.

The Number 5 coal bed has no development potential for surface mining because the coal is less than 5 feet (1.5 m) in thickness.

The lower split of the Cook coal bed (pl. 23) has a small area of low development potential for surface mining in the southwestern part of the quadrangle.

The upper split of the Cook coal bed (pl. 20) has development potential for surface mining over the entire quadrangle. Relatively large areas of high development potential extend from the outcrops up the stream valleys to the 10 mining-ratio contour. Large areas of moderate development potential occur as narrow to wide bands between the 10 and 15 mining-ratio contours. Extremely large areas of low development potential extend from the 15 mining-ratio contour under the crests of the highest hills.

The Canyon coal bed (pl. 17) has development potential for surface mining over the entire quadrangle. Very large areas of high development potential extend from the outcrops up the stream valleys to the 10 mining-ratio contour. Extremely large areas of moderate development potential occur as narrow to wide bands between the 10 and 15 mining-ratio contours. Small areas of low development potential extend from the 15 mining-ratio contour under the crests of the ridges.

The lower split of the Dietz coal bed (pl. 15) has development potential for surface mining in two small areas in the northeastern part of the quadrangle. These areas have high and moderate development potential.

The upper split of the Dietz coal (pl. 12) bed has development potential for surface mining in several, small to large, areas scattered throughout the quadrangle. Large areas of high development potential extend from the outcrops up the slopes to the 10 mining-ratio contour. Small areas of moderate development occur as bands between the 10 and 15 mining-ratio contours. Large areas of low development potential extend from the 15 mining-ratio contour and the coal boundaries under the crests of the hills.

The lower split of the Anderson coal bed (pl. 8) has development potential for surface mining in one rather small isolated area in the northwestern part of the quadrangle. This area has high and moderate development potential.

The middle split of the Anderson coal bed attains a 5-foot (1.5 m) thickness in only one very small area in the northwestern part of the quadrangle. Because this area is less than 40 acres (16.2 ha) development potential maps have not been constructed for this coal bed.

The Anderson coal bed and the upper split of the Anderson coal bed (pl. 5) have development potential for surface mining over about one-half of the quadrangle. The upper split has some very small areas of high and moderate development near the northern boundary of the quadrangle. The Anderson coal bed has extremely large areas of high development potential extending from the outcrops up the slopes to the 10 mining-ratio contour. Very small areas of moderate development potential occur as bands between the 10 and 15 mining-ratio contours.

As shown by the coal development potential map (pl. 41), essentially all of the Federal coal lands in the Sayle quadrangle have a high development potential for surface mining.

Development potential for underground mining and in-situ gasification

Subbituminous coal beds 5 feet (1.5 m) or more in thickness lying more than 500 feet (152 m) but less than 3,000 feet (914 m) below the surface and lignite beds of the same thickness lying more than 200 feet (61 m) but less than 1,000 feet (305 m) below the surface are considered to have development potential for underground mining. Estimates of the tonnage of underground-minable coal are listed in table 2 by development-potential category for each coal bed. Coal is not currently being mined by underground methods in the Northern Powder River Basin because of poor economics. Therefore, the coal development potential for underground mining of these resources for purposes of this report is rated as low, and a Coal Development Potential map for underground mining was not made.

In-situ gasification of coal on a commercial scale has not been done in the United States. Therefore, the development potential for in-situ gasification of coal found below the surface-mining limit in this area is rated as low, and a Coal Development Potential map for in-situ gasification of coal was not made.

Table 1.--Surface-minable coal resource tonnage (in short tons) by development-potential category for Federal coal lands in the Sayle quadrangle, Powder River County, Montana

[Development potentials are based on mining ratios (cubic yards of overburden/short ton of recoverable coal). To convert short tons to metric tons, multiply by 0.9072]

Coal bed	High development potential (0-10 mining ratio)	Moderate development potential (10-15 mining ratio)	Low development potential (>15 mining ratio)	Total
Reserve Base tonnage				
Anderson and Upper Anderson	246,800,000	5,270,000	270,000	252,340,000
Lower Anderson	5,200,000	1,210,000	370,000	6,780,000
Upper Dietz	39,860,000	15,610,000	30,540,000	86,010,000
Lower Dietz	1,470,000	280,000	50,000	1,800,000
Canyon	705,360,000	225,670,000	45,400,000	976,430,000
Upper Cook	44,330,000	97,850,000	317,560,000	459,740,000
Lower Cook	0	0	7,350,000	7,350,000
Pawnee (Dunning)	0	1,020,000	122,220,000	123,240,000
Cache	0	0	1,450,000	1,450,000
Total	1,043,020,000	346,910,000	525,210,000	1,915,140,000
Hypothetical Resource tonnage				
Upper Cook	28,880,000	31,380,000	224,360,000	284,620,000
Pawnee (Dunning)	0	0	105,690,000	105,690,000
Total	28,880,000	31,380,000	330,050,000	390,310,000
Grand Total	1,071,900,000	378,290,000	855,260,000	2,305,450,000

Table 2.--Underground-minable coal resource tonnage (in short tons) by development-potential category for Federal lands in the Sayle quadrangle, Powder River County, Montana

[To convert short tons to metric tons, multiply by 0.9072]

Coal bed	High Development potential	Moderate development potential	Low development potential	Total
Reserve Base tonnage				
Upper Cook	0	0	3,350,000	3,350,000
Pawnee (Dunning)	0	0	183,740,000	183,740,000
Cache	0	0	39,540,000	39,540,000
Knobloch	0	0	97,850,000	97,850,000
Flowers-Goodale	0	0	184,140,000	184,140,000
Broadus	0	0	58,460,000	58,460,000
Total	0	0	567,080,000	567,080,000
Hypothetical Resource tonnge				
Upper Cook	0	0	2,600,000	2,600,000
Pawnee (Dunning)	0	0	398,150,000	398,150,000
Knobloch	0	0	92,410,000	92,410,000
Flowers-Goodale	0	0	109,760,000	109,760,000
Broadus	0	0	59,810,000	59,810,000
Total	0	0	662,730,000	662,730,000
Grand Total	0	0	1,229,810,000	1,229,810,000

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