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

[Report includes 38 plates]

By

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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 Sonnette quadrangle, Powder River County, Montana, (38 plates; U.S. Geological Survey Open-File Report 79-098). 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 Sonnette 7 1/2-minute quadrangle is near the center of Powder River County, Montana, about 62 miles (100 km) south of Miles City, a town in the Yellowstone River valley of eastern Montana. Miles City is on U.S. Interstate Highway 94 and the main east-west routes of the Burlington Northern Railroad and the Chicago, Milwaukee, St. Paul and Pacific Railroad. The quadrangle is also 17 miles (27 km) west of Broadus, Montana, a small town in the Powder River valley.

Accessibility

The quadrangle is accessible from Broadus by taking paved, east-west U.S. Highway 212 about 22 miles (35 km) west-northwestward to its intersection with the Pumpkin Creek road, then southward on the Pumpkin Creek road 3 miles (4.8 km) to the northern border of the quadrangle. The Pumpkin Creek road continues southward through the quadrangle. The Fifteenmile Creek and Tenmile Creek roads connect with the Pumpkin Creek road in the southern part of the quadrangle near

the hamlet of Sonnette and provide access to the southwestern part of the quadrangle. A number of unimproved roads and trails connect with the main roads and provide access to the remainder of the quadrangle. The point on the railroad to which coal could be most easily trucked would be Miles City, some 75 miles (120 km) to the north by way of the Pumpkin Creek road to Volborg, Montana, and then by U.S. Highway 312 to Miles City.

Physiography

The Sonnette quadrangle is within the Missouri Plateau division of the Great Plains physiographic province. The plateau, formed of nearly horizontal strata, has been deeply and intricately dissected by Pumpkin Creek and its tributaries which has created rough topography. Remnants of the plateau are visible at an elevation of approximately 4,000 feet (1,219 m). Northward-flowing Pumpkin Creek, which rises near the south border of the quadrangle, is the principal stream in the quadrangle. Two Tree Creek and North Fork Two Tree Creek flow northeastward and drain the northeastern part of the quadrangle. The highest elevation, 4,162 feet (1,269 m), is on an unnamed hill in the west-central part of the quadrangle about 1.75 miles (2.8 km) northwest of Sonnette. The lowest point, 3,500 feet (1,067 m), is where Pumpkin Creek flows in the northwest corner of the quadrangle. Topographic relief is 662 feet (202 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 Sonnette quadrangle is entirely within the Northern Powder River Basin Known Recoverable Coal Resource Area (KRCRA). The quadrangle lies outside of the Custer National Forest area. The Boundary and Coal Data Map (pl. 2) shows the land ownership status. There were no outstanding Federal coal leases or prospecting permits recorded as of 1977.

GENERAL GEOLOGY

Previous work

Warren (1959) mapped all of the Sonnette quadrangle as part of the Birney-Broadus coal field. Matson, Dahl, and Blumer (1968) mapped the strippable coal deposits on State land in Powder River County. Matson and Blumer (1973) mapped the quadrangle as part of the Threemile Buttes and Sonnette coal deposits.

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 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 the lower 1,500 feet (457 m) of the member 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 Sonnette quadrangle is in the northeastern part of the Powder River structural basin. Regionally the strata dip westward or southwestward at an angle of less than 1 degree. The regional dip is modified in places by minor local folding (pls. 5, 8, 11, 14, 17, 20, 24, 29, 32, and 35).

COAL GEOLOGY

The coal beds in the Sonnette 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 coal beds are in the Tongue River Member of the Fort Union Formation. The lowermost, important coal is the Broadus coal bed, which occurs about 120 to 180 feet (37 to 55 m) above the base of the Tongue River Member. The Broadus coal bed is overlain successively by a noncoal interval of about 40 feet (12 m), the Nance coal bed, a sandstone and shale interval about 100 feet (30 m) thick which contains a thin local coal bed, the Knobloch coal bed, a noncoal interval of about 200 to 260 feet (61 to 79 m), the lower split of the Sawyer coal bed, a noncoal interval of about 40 to 80 feet (12 to 24 m), the upper split of the Sawyer coal bed, an essentially noncoal interval of about 280 to 340 feet (85 to 104 m)

containing three thin local coal beds, the Pawnee coal bed, an essentially noncoal interval of about 160 to 260 feet (49 to 79 m) containing a thin local coal bed, the lower split of the Cook coal bed, a noncoal interval of about 20 to 120 feet (6 to 36 m), the upper split of the Cook coal bed, a noncoal interval of about 20 to 100 feet (6 to 30 m), the Ferry coal bed, a noncoal interval of about 20 to 40 feet (6 to 12 m), the lower split of the Canyon coal bed, a noncoal interval of 30 to 60 feet (9 to 18 m), the upper split of the Canyon coal bed, a noncoal interval of about 160 feet (49 m), and the Garfield coal bed which has been removed by erosion over most of the quadrangle.

The coal found along the eastern flank of the Powder River Basin in Montana increases in rank from lignite in the east to subbituminous in the deeper parts of the basin to the west. The rank of coal is controlled by the amount of compaction to which the coal is subjected. The compaction is a result of the original depth of burial of the coal (thickness of overlying overburden) and of the degree of tectonic (mountain-building) activity to which the coal has been subjected. The eastern flank of the Powder River Basin has not been subjected to very much squeezing of sediments produced by tectonic activity so that the rank of coal there is primarily related to the original depth of burial (thickness of overburden) to which the coal has been subjected. Lignite A is a coal that has a heating value of 6,300 to 8,300 Btu per pound (14,654 to 19,306 kJ/kg) on a moist, mineral-matter-free basis. Subbituminous C coal has a heating value of 8,300 to 9,500 Btu per pound (19,306 to 22,097 kJ/kg) on a moist, mineral-matter-free basis.

All available analyses of the Broadus coal bed, the stratigraphically lowermost coal bed of importance in this area, were considered in making our decision to assign a rank of subbituminous C to the Broadus coal within this quadrangle. Overlying coal beds in this quadrangle grade upward into increasingly lower

ranks of coal (coal having lower Btu values per pound of coal on a moist, mineral-matter-free basis) as the coal is less and less compacted because of decreasing amounts of overburden. Several of the overlying coal beds in this quadrangle, which are stratigraphically higher than the Broadus coal bed, have been determined to be lignite in rank. However, early in this mapping project to expedite the calculation of resource tonnage and the evaluation of development potential for surfacing mining of the near-surface coal beds, it was arbitrarily decided by us to assign a rank of subbituminous C to all of the coal beds above the Broadus in this quadrangle. Consequently, we have used the 500-foot (152-m) stripping limit (which the USGS has arbitrarily assigned for multiple beds of subbituminous coal in this area of Montana) in this quadrangle for all of the coal beds above the Broadus even though our subsequent detailed work has indicated that the 200-foot (61-m) stripping limit assigned for lignite beds in this area should have been used for the seven coal beds above the Knobloch coal bed.

It is recommended that the 200-foot (61-m) stripping limit and the lignite weight-conversion factor should be used in any future revisions of the maps and coal tonnage calculations of these seven coal beds in this quadrangle. The use of the 200-foot (61-m) stripping limit will produce a more conservative and realistic picture of the surface-mining potential of the various coal beds in this quadrangle.

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 near the town of Broadus in the Broadus quadrangle about 16 miles (26 km) east of the Sonnette quadrangle. The Broadus coal bed occurs about 120 to 180 feet (37 to 55 m) above the base of the Tongue River Member. The Broadus coal bed does not crop out in the Sonnette quadrangle, but was penetrated by a drill hole in the west-central portion of the quadrangle (pls. 1 and 3). The isopach and structure contour map of the Broadus coal bed (pl. 35) shows that, where present, the Broadus coal ranges from about 5 to 20 feet (1.5 to 6.1 m) in thickness and is essentially flat lying, although the dip is controlled by a minor, anticlinal fold whose axis trends northeast-southwest. Overburden on the Broadus coal bed (pl. 36) ranges from about 600 to 1,200 feet (183 to 366 m) in thickness.

There is no known, publicly available chemical analysis of the Broadus coal in the Sonnette quadrangle. However, a chemical analysis of the Broadus coal from the Peerless mine, sec. 23, T. 4 S., R. 50 E., about 10.5 miles (16.9 km) east of the Sonnette quadrangle in the Epsie NE 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 at that locality is lignite A in rank. However, because the Sonnette quadrangle lies deeper in the Powder River structural basin, it is assumed that the coals are more compacted and that the Broadus coal in this quadrangle is subbituminous C in rank.

Nance coal bed

The Nance coal bed was named for its occurrence at a depth of 242 feet (73.8 m) in the Nance and Hayes M11-2 drill hole located in the SE¼ SE¼ sec. 25, T.

5 S., R. 42 E., about 30 miles (48 km) southwest of the Sonnette quadrangle in the Browns Mountain quadrangle (Mapel and Martin, 1978, p. 21). The Nance coal bed is believed to occur about 40 feet (12 m) above the Broadus coal bed although it does not crop out in the Sonnette quadrangle, nor was it penetrated by deep drill holes. However, it was projected into the southwest corner of the quadrangle from the adjacent quadrangles to the south and west. The isopach and structure contour map of the Nance coal bed (pl. 32) shows that the coal is 10 to 11 feet (3.1 to 3.3 m) thick and dips slightly to the west. Overburden on the Nance coal bed (pl. 33) is almost 900 to 1,100 feet (274 to 335 m) thick.

There is no known, publicly available chemical analysis of the Nance coal in the Sonnette quadrangle. Because of the stratigraphic relationship of the Nance coal to the Knobloch coal bed, it is assumed that the coals are similar. Therefore, a rank of subbituminous C has been assigned to the Nance coal in the Sonnette quadrangle.

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 28 miles (45 km) west of the Sonnette quadrangle. The Knobloch coal bed occurs about 100 feet (30 m) above the Nance coal bed. The Knobloch coal bed does not crop out in the Sonnette quadrangle, but was penetrated by a drill hole (pls. 1 and 3) in the northwest quarter of the quadrangle. The isopach and structure contour map of the Knobloch coal bed (pl. 29) shows that the Knobloch coal bed ranges from 10 to 26 feet (3 to 8 m) in thickness and dips to the west at an angle of less than 1 degree. The bed appears to split in the western part of the quadrangle, and the lower split may correlate with the Nance coal bed which occurs in this area (pl. 3). The shallow dip is modified in places by

minor, low-relief folds. Overburden on the Knobloch coal bed (pl. 30) ranges from about 500 to 1,100 feet (152 to 335 m) in thickness.

A chemical analysis of the Knobloch coal at a depth of 177 to 185 feet (54 to 56 m) from drill hole SH-7049, sec. 2, T. 5 S., R. 46 E. in the Yager Butte quadrangle, about 8 miles (12.9 km) west of the Sonnette quadrangle, shows ash 5.22 percent, sulfur 0.22 percent, and heating value 8,261 Btu per pound (19,215 kJ/kg) on an as-received basis (Matson and Blumer, 1973, p. 68, pl. 12). This heating value converts to about 8,716 Btu per pound (20,273 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 of that location to the Sonnette quadrangle, it is assumed that the coals are similar and that the Knobloch coal in this quadrangle is also subbituminous C in rank.

Upper and lower splits of the Sawyer coal bed

The Sawyer coal bed was first described by Dobbin (1930, p. 28) from exposures in the Forsyth coal field, possibly in the Rough Draw or Black Spring quadrangles where the Sawyer is well exposed in the foothills of the Little Wolf Mountains. These quadrangles are about 46 miles (74 km) west-northwest of the Sonnette quadrangle.

In the Sonnette quadrangle, the lower split of the Sawyer coal bed is about 200 to 260 feet (61 to 79 m) above the Knobloch coal bed. It does not crop out in the Sonnette quadrangle, but it is penetrated by a drill hole (pls. 1 and 3). The isopach map of the upper and lower splits of the Sawyer coal bed (pl. 23) shows that the upper coal ranges from about 5 to 24 feet (1.5 to 7.3 m) in thickness. The lower split ranges from 5 to 16 feet (1.5 to 4.9 m) in thickness. The structure contour map (pl. 24) indicates that the bed dips westward at an angle of less than 1 degree. Overburden on the lower split of the Sawyer coal bed (pl. 27) ranges from 400 to 800 feet (122 to 244 m) in thickness. Overburden on

the upper split (pl. 25) is 200 to 800 feet (61 to 244 m) in thickness. The separation between the lower and upper splits of the Sawyer coal bed ranges from about 40 to 80 feet (12 to 24 m).

There is no known, publicly available chemical analysis of coal from either the upper or lower splits of the Sawyer bed in the Sonnette quadrangle. However, chemical analyses from drill hole PC-15 in sec. 32, T. 3 S., R. 49 E., Leslie Creek quadrangle, from depths of 52 to 64 feet (16 to 19.5 m) and from 112 to 124 feet (34 to 38 m) for the coal of the upper and lower splits, respectively, show ash 6.54 percent, sulfur 0.31 percent, and heating value 7,510 Btu per pound (17,468 kJ/kg) for the upper split, and ash 9.99 percent, sulfur 0.35 percent, and heating value 7,140 Btu per pound (16,607 kJ/kg) for the lower split on an as-received basis (Matson and Blumer, 1973, p. 83). These heating values convert to 8,035 and 7,932 Btu per pound (18,689 and 18,450 kJ/kg), respectively, on a moist, mineral-matter-free basis, indicating that coal from both splits of the Sawyer bed at that locality are lignite A in rank. This drill hole is located in sec. 32, T. 3 S., R. 49 E., about 3 miles (4.8 km) northeast of the Sonnette quadrangle in the Leslie Creek quadrangle. Because of the proximity of that location to the Sonnette quadrangle, it is assumed that the coals are similar and that coal of the upper and lower splits of the Sawyer bed in this quadrangle is also lignite A in rank.

Pawnee 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 Sonnette quadrangle. In the nearby Threemile Buttes, Yager Butte, Goodspeed Butte, and Reanus Cone quadrangles to the west and southwest, 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 coal bed crops out in the northern and central parts of the Sonnette quadrangle, where it is marked in places by an extensive clinker bed, formed by the burning of the coal. The Pawnee coal bed occurs about 280 to 340 feet (85 to 104 m) above the Sawyer coal bed. The isopach and structure contour map (pl. 20) shows that the Pawnee coal bed ranges from about 8 to 24 feet (2.4 to 7.3 m) in thickness and dips westward at an angle of less than 1 degree, although this dip is modified in places by minor folding. Overburden on the Pawnee coal bed (pl. 21) ranges from 0 feet at the outcrops to about 600 feet (0-183 m) in thickness.

A chemical analysis of the Pawnee coal from a depth of 40 to 56 feet (12 to 17 m) in drill hole SH-7115, sec. 34, T. 4 S., R. 48 E., in the Sonnette quadrangle, shows ash 3.877 percent, sulfur 0.191 percent, and heating value 7,228 Btu per pound (16,812 kJ/kg) on an as-received basis (Matson and Blumer, 1973, p. 110). This heating value converts to 7,520 Btu per pound (17,492 kJ/kg) on a moist, mineral-matter-free basis, indicating that the Pawnee coal at this location is lignite A in rank.

Upper and lower splits of the Cook coal bed

The Cook coal bed was named by Bass (1932, p. 59) for outcrops on Cook Mountain in the Cook Creek Reservoir quadrangle in the Ashland coal field which lies about 17 miles (27 km) northwest of the Sonnette quadrangle. Warren (1959, p. 573) recognized an upper bench of the Cook coal bed in the Birney-Broadus coal field which includes the Sonnette quadrangle. Matson and Blumer (1972, p. 107 and pl. 25B) recognized two benches of the Cook coal bed in the Sonnette coal deposit which includes the Sonnette quadrangle.

In the Sonnette quadrangle, the lower split of the Cook coal bed occurs about 160 to 260 feet (49 to 79 m) above the Pawnee coal bed. The lower split of

the Cook coal bed (pl. 2) crops out throughout the quadrangle and is marked, locally, by a clinker bed formed by the burning of the coal. The isopach and structure contour map (pl. 17) shows that the lower split of the Cook coal bed ranges from about 2.9 to 12 feet (0.9 to 3.7 m) in thickness and dips southwestward at an angle of less than 1 degree. Overburden on the lower split of the Cook coal bed (pl. 18) ranges from 0 feet at the outcrops to about 300 feet (0-91 m) in thickness.

The separation between the lower and upper splits of the Cook coal ranges from 20 to 120 feet (6 to 36 m). The upper split of the Cook coal bed crops out through the quadrangle (pl. 1) and is marked, locally, by an extensive clinker bed. The isopach and structure contour map of the upper split of the Cook coal bed (pl. 14) shows that the coal ranges from about 2 to 16 feet (0.6 to 4.9 m) in thickness and generally dips to the southwest, although this dip is modified in places by local folding. Overburden on the upper split of the Cook coal bed (pl. 15) ranges from 0 feet at the outcrops to about 300 feet (0-91 m) in thickness.

Chemical analyses from drill hole SH-7117 from depths of 72 to 82 feet (22 to 25 m) and from 114 to 119 feet (35 to 36 m) for coal of the upper and lower splits of the Cook bed, respectively, show ash 6.500 percent, sulfur 0.736 percent, and heating value 7,186 Btu per pound (16,715 kJ/kg) for the upper split, and ash 8.967 percent, sulfur 1.655 percent, and heating value 7,000 Btu per pound (16,282 kJ/kg) for the lower split, on an as-received basis (Matson and Blumer, 1973, p. 110). These heating values convert to 7,686 and 7,690 Btu per pound (17,878 and 17,887 kJ/kg), respectively, on a moist, mineral-matter-free basis, indicating that coal of the upper and lower splits of the Cook bed at this location is lignite A in rank. This drill hole is located in sec. 7, T. 5 S., R. 48 E., in the Sonnette quadrangle.

Ferry coal bed

The Ferry coal bed was first described by Warren (1959, p. 573) from exposures in the central and southwestern parts of the Birney-Broadus coal field, probably in the Threemile Buttes and Sonnette quadrangles where its thickest sections of 11 to 12.5 feet (3.4 to 3.8 m) were measured. Matson and Blumer (1972, p. 114 and pl. 24) mapped the Ferry coal bed as part of the Sonnette coal field.

In the Sonnette quadrangle, the Ferry coal bed occurs about 20 to 100 feet (6 to 30 m) above the Upper Cook coal bed. The Ferry coal bed crops out in both the northern and southern parts of the quadrangle. The isopach and structure contour map (pl. 11) shows that the Ferry coal bed ranges from about 3.6 to 10 feet (1.1 to 3 m) in thickness and dips gently to the south and west. The dip is modified locally by low-relief folding which is expressed in the Sonnette quadrangle in the form of a north-south trending anticline. Overburden on the Ferry coal bed (pl. 12) ranges from about 0 feet at the outcrops to over 200 feet (0-60 m) in thickness.

There is no known, publicly available chemical analysis of the Ferry coal in or near the Sonnette quadrangle. Because of the stratigraphic relationship of the Ferry coal bed to the Cook coal bed, it is assumed that the coals are similar and, therefore, a rank of lignite A is assigned to the Ferry coal in this quadrangle.

Canyon coal bed

The Canyon coal bed was first described by Baker (1929, p. 36-37) from exposures in the northward extension of the Sheridan coal field. Although a type locality was not given, it may be along Canyon Creek in the northern part of the Spring Gulch quadrangle, about 40 miles (64 km) west-southwest of the Sonnette quadrangle. In the Sonnette quadrangle, the Canyon was mapped by Warren (1959, pl. 19) and by Matson and Blumer (1973, pl. 24).

In the Sonnette quadrangle, the Canyon coal bed splits into two beds in the southern part of the quadrangle. The lower split of the Canyon coal bed occurs about 20 to 40 feet (6 to 12 m) above the Ferry coal bed. It outcrops in the southern part of the quadrangle. The isopach and structure contour map (pl. 8) shows that the coal in the lower split of the Canyon bed ranges from about 3.5 to 12 feet (1.1 to 3.7 m) thick and that it dips slightly to the south and west, although the dip is modified locally by gentle folding. Overburden on the lower split of the Canyon coal bed (pl. 9) ranges from 0 feet at the outcrops to about 200 feet (0-60 m) in thickness.

The separation between the upper and lower Canyon coal beds, where they are split, ranges from 30 to 60 feet (9 to 18 m). The Canyon coal bed and its upper split crop out on the higher buttes along the southern and western edges of the Sonnette quadrangle (pl. 1). The coal isopach map (pl. 4) shows that the Canyon coal bed ranges from 8 to 10 feet (2.4 to 3.1 m) in thickness. The upper split of the Canyon coal bed ranges from about 2.1 to 12 feet (0.6 to 3.7 m) in thickness. The structure contour map (pl. 5) indicates that the beds dip slightly to the south and west. Overburden (pl. 6) ranges from 0 feet at the outcrops to more than 100 feet (0-30 m) in thickness.

There is no known, publicly available chemical analysis for the Canyon coal in the Sonnette quadrangle. However, an analysis was reported in the Threemile Buttes quadrangle about 1.5 miles (2.4 km) west of the Sonnette quadrangle (Matson and Blumer, 1973, p. 112) from a depth of 42 to 50 feet (12.8 to 15.2 m) in coal test hole SH-7142, sec. 23, T. 4 S., R. 47 E. The analysis shows ash 3.856 percent, sulfur 0.389 percent, and heating value 6,904 Btu per pound (16,059 kJ/kg) on an as-received basis. This heating value converts to about 7,180 Btu per pound (16,701 kJ/kg) on a moist, mineral-matter-free basis, indicating that the Canyon coal in that location is lignite A in rank. Because of the proximity of

that location to the Sonnette quadrangle, it is assumed that the Canyon coal in this quadrangle is similar and is lignite A in rank.

Garfield coal bed

The Garfield coal bed was mapped by Warren (1959, p. 24) in the southwest corner of the Sonnette quadrangle. Because of its limited extent and thinness, it was not included in the economic resource base for this quadrangle.

Local coal beds

The local coal beds shown on plates 1 and 3 are thin and of very limited extent, and consequently 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 or lignite that is under less than 200 feet (61 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, or lignite that is under more than 200 feet (61 m), but less than 1,000 feet (305 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) or a conversion factor of 1,750 short tons of lignite per acre-foot (12,870 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 1,393.51 million short tons (1,263.91 million t). The total tonnage of federally owned, surface-minable Hypothetical coal is estimated to be 24.33 million short tons (22.07 million t). As shown by table 2, the total federally owned, underground-minable Reserve

Base coal is estimated to be 704.14 million short tons (638.80 million t). The total federally owned, underground-minable Hypothetical coal is estimated to be 495.55 million short tons (449.56 million t). The total tonnage of surface- and underground-minable Reserve Base coal is 2,097.65 million short tons (1,902.99 million t), and the total of surface- and underground-minable Hypothetical coal is 519.88 million short tons (471.64 million t).

About 4 percent of the surface-minable Reserve Base tonnage is classed as Measured, 23 percent as Indicated, and 73 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). The 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 ratios (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. 38). Most of the Federal coal lands have a high development potential for surface mining.

The Broadus and Nance coal beds, in the Sonnette quadrangle, have no surface-mining potential because the overburden thickness is greater than 500 feet (152 m).

The Knobloch coal bed (pl. 30) has two small areas of low development potential in the north and northeast portions of the Sonnette quarangle. It has no

development potential elsewhere because the overburden is greater than 500 feet (152 m) thick.

The lower split of the Sawyer coal bed (pl. 27) has an area of low development potential in the northeast and northwest portions of the Sonnette quadrangle where the overburden is less than 500 feet (15 m) thick. The upper split of the Sawyer coal bed (pl. 25) has a much larger area of low development potential between the 15 mining-ratio line and the 500-foot (152-m) overburden isopach, two smaller areas of moderate development potential, between the 10 and 15 mining-ratio lines, in the northern corners of the quadrangle, and a very small area of high development potential along Pumpkin Creek at the north edge of the quadrangle.

The Pawnee coal bed (pl. 21) has a large area of high development potential along the Pumpkin Creek valley. A narrow band of moderate development potential parallels and separates the high development potential from a much larger area of low development potential. Most of the Pawnee coal bed in the southern third of the quadrangle is of low development potential.

The lower split of the Cook coal bed (pl. 18) occurs over much of the Sonnette quadrangle. It has been removed by erosion along Pumpkin Creek, and it is greater than 5 feet (1.5 m) thick only in the southern and western portions of the quadrangle. The lower split of the Cook coal bed has a large area of high development potential along the sides of the Pumpkin Creek valley between the outcrop and the 10 mining-ratio line. The area of moderate development is a narrow band separating the 10 mining-ratio and 15 mining-ratio lines. The bulk of the lower split of the Cook coal bed lies in the southwestern corner of the quadrangle. Development potential is low because of the thick overburden.

The upper split of the Cook coal bed (pl. 15) occurs in much the same fashion as the lower split. Most of the coal has a high development potential

because the depth of overburden is generally not great. A series of narrow bands of moderate development potential surround the topographically higher areas, and areas of low development potential occur beneath the higher buttes.

The Ferry coal bed (pl. 12) occupies a large area in the southwest corner of the Sonnette quadrangle and a few small buttes in the north-central part of the quadrangle. Most of the coal has a high development potential, but the areas of high terrain result in limited areas of low development potential because of overburden depth. Again, the areas of high and low development potential are separated by narrow bands of moderate development potential.

The lower split of the Canyon coal bed (pl. 9) occurs only around the southern periphery of the Sonnette quadrangle. Most of the coal has a high development potential. Small areas of low development potential occur under the higher buttes and narrow bands of moderate development potential separate these areas from the high development potential.

The upper split of the Canyon coal bed (pl. 6) occurs only in small areas along the southern and western boundaries of the Sonnette quadrangle. The bulk of the coal has a high development potential.

About 91 percent of the Federal coal lands has a high development potential for surface mining, about 3 percent has a moderate development potential, and about 6 percent has a low development potential.

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 Sonnette 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				
Upper Canyon	7,120,000	2,070,000	590,000	9,780,000
Lower Canyon	47,500,000	17,040,000	8,790,000	73,330,000
Ferry	41,780,000	13,960,000	24,130,000	79,870,000
Upper Cook	90,580,000	46,720,000	58,320,000	195,620,000
Lower Cook	48,870,000	23,890,000	83,510,000	156,270,000
Pawnee	196,330,000	153,600,000	335,830,000	685,760,000
Upper Sawyer	0	25,390,000	143,540,000	168,930,000
Lower Sawyer	0	0	22,570,000	22,570,000
Knobloch	0	0	1,380,000	1,380,000
Total	432,180,000	282,670,000	678,660,000	1,393,510,000
Hypothetical Resource tonnage				
Upper Sawyer	0	0	24,330,000	24,330,000
Total	0	0	24,330,000	24,330,000
Grand Total	432,180,000	282,670,000	702,990,000	1,417,840,000

Table 2.--Underground-minable coal resource tonnage (in short tons) by development-potential category for Federal lands in the Sonnette 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				
Pawnee	0	0	72,420,000	72,420,000
Upper Sawyer	0	0	140,200,000	140,200,000
Lower Sawyer	0	0	36,570,000	36,570,000
Knobloch	0	0	256,810,000	256,810,000
Nance	0	0	8,880,000	8,880,000
Broadus	0	0	189,260,000	189,260,000
Total	0	0	704,140,000	704,140,000
Hypothetical Resource tonnage				
Upper Sawyer	0	0	17,180,000	17,180,000
Knobloch	0	0	177,580,000	177,580,000
Nance	0	0	44,800,000	44,800,000
Broadus	0	0	255,990,000	255,990,000
Total	0	0	495,550,000	495,550,000
Grand Total	0	0	1,199,690,000	1,199,690,000

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