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# COAL RESOURCE OCCURRENCE AND COAL DEVELOPMENT POTENTIAL MAPS OF THE WILLOW CROSSING QUADRANGLE, POWDER RIVER AND ROSEBUD COUNTIES, MONTANA

[Report includes 14 plates]

By

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This report has not been edited for conformity with U.S. Geological Survey editorial standards or stratigraphic nomenclature.

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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 Willow Crossing quadrangle, Powder River and Rosebud Counties, Montana, (13 plates; U.S. Geological Survey Open-File Report 79-101). 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 are overlain by 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 are overlain by less than 1,000 feet (305 m) of overburden.

## Location

The Willow Crossing 7 1/2-minute quadrangle is in northwestern Powder River County and southeastern Rosebud County, Montana, about 36 miles (58 km) west-northwest of Broadus, Montana, a small town on east-west U.S. Highway 212. The quadrangle is 48 miles (77 km) south-southeast of Forsyth, a town in the Yellowstone River valley of eastern Montana. U.S. Interstate Highway 94 and the main east-west routes of the Chicago, Milwaukee, St. Paul and Pacific Railroad and the Burlington Northern Railroad follow the Yellowstone River and pass through Forsyth.

## Accessibility

U.S. Highway 212 passes east-west through the central part of the Willow Crossing quadrangle. On this highway the quadrangle is 0.5 mile (0.8 km) east of the small town of Ashland and about 36 miles (58 km) west-northwest of

Broadus, Montana. The nearest railroad is 20 miles (32 km) to the northwest at the Big Sky coal mine located in the Colstrip SE quadrangle. This spur line at the mine comes from the main line of the Burlington Northern Railroad in the Yellowstone River valley near Forsyth about 35 miles (56 km) to the north.

## Physiography

The Willow Crossing quadrangle is within the Missouri Plateau division of the Great Plains physiographic province. The land is maturely dissected, mostly by Otter Creek and its tributaries. Otter Creek flows northwestward across the southwestern part of the quadrangle, and joins the Tongue River near Ashland about 1 mile (1.6 km) west of the quadrangle. Small areas of the quadrangle are drained by minor tributaries of the Tongue River. The Tongue River flows northward and then northeastward about 60 miles (96 km) to the Yellowstone River at Miles City, Montana.

Otter Creek has a flood plain 0.5 to 0.8 mile (0.8 to 1.3 km) in width at an elevation of 2,930 to 3,050 feet (893 to 930 m). The principal tributaries of Otter Creek -- Threemile Creek, Home Creek, and East Fork of Otter Creek -- have narrower flood plains. The sides of the valleys rise steeply 100 to 150 feet (30 to 46 m) from the valley floors to a relatively smooth upland surface at an elevation of 3,150 to 3,300 feet (960 to 1,006 m). This surface is intricately dissected by deep, narrow, steep-sided ephemeral stream valleys. Several buttes near the southwest corner of the quadrangle, buttes along a north-trending spur of King Mountain, rise 300 feet (91 m) above this surface to 3,600 feet (1,097 m).

The highest elevation in the quadrangle, about 3,960 feet (1,207 m) is on a southward-pointing spur of Cook Mountain near the northeast corner of the quadrangle. The lowest elevation, about 2,930 feet (893 m), is on Otter Creek at the west border of the quadrangle. Topographic relief is 1,030 feet (314 m).

### Climate

The climate of Powder River and Rosebud Counties 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 Northern Powder River Basin Known Recoverable Coal Resource Area covers most of the quadrangle except for some areas in, or adjacent to, the valleys of Otter, Threemile, Home, and Cook Creeks, as shown by the Boundary and Coal Data Map (pl. 2). Plate 2 shows the land ownership status of lands in the quadrangle. There were no outstanding Federal coal leases or prospecting permits recorded as of 1977.

## GENERAL GEOLOGY

### Previous work

Bass (]932, pl. 3) mapped all of the Willow Crossing quadrangle, except the southern two tiers of sections, as part of the Ashland coal field, Rosebud, Powder River, and Custer Counties, Montana. Brown and others (1954, fig. 28) mapped a few square miles in the northern part of the quadrangle as the Cook Creek deposit of strippable coal.

Warren (1959, pl. 19) mapped the southern two tiers of sections in the quadrangle as part of the Birney-Broadus coal field. Matson and Blumer (1973, pls. 12, 13A, and 13B) mapped parts of the quadrangle as parts of the Otter Creek and Ashland coal deposits. The Bureau of Land Management's Energy Mineral

Rehabilitation Inventory and Analysis (EMRIA) Report No. 1 (1975) on the Otter Creek study site covers the southeastern part of the quadrangle. McKay (1976) mapped all of the quadrangle.

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

## Stratigraphy

A generalized columnar section of the coal-bearing rocks is shown on the Coal Data Sheet (pl. 3) of the CRO maps. The exposed bedrock units belong to the Tongue River Member, the uppermost member, of the Fort Union Formation (Paleocene). This member consists of light-colored sandstone, sandy shale, and important coal beds. The thicker coal beds have burned along the outcrop and have fused the overlying rock into reddish-colored slag or clinker. The upper part of the Tongue River Member has been removed by erosion in the Willow Crossing quadrangle so that only about the lower 1,000 feet (305 m) remains. No coal of economic importance occurs in the lower two members of the Fort Union: the middle Lebo Shale Member or the lowermost Tullock Member.

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 Willow Crossing quadrangle is in the north-central part of the Powder River structural basin. The strata in general dip southward at an angle of less than 1 degree. In places the regional structure is modified by low-relief folds, as shown by the structure contour maps drawn on top of the coal beds, (pls. 4, 7, and 10). Some of the nonuniformity in structure may be due to irregularities in deposition of the coals and other beds as a result of their continental origin.

# COAL GEOLOGY

The known coal beds in the Willow Crossing quadrangle are shown in outcrop on the Coal Data Map (pl. 1A) and in section on the Coal Data Sheet (pl. 3). All the coal beds belong to the Tongue River Member of the Fort Union Formation.

The lowermost known coal beds in the Willow Crossing quadrangle are the Flowers-Goodale coal bed and a thin, local bed 110 feet (33 m) below it which were penetrated by an oil-and-gas test hole in sec. 20, T. 3 S., R. 45 E. The Flowers-Goodale is here about 280 feet (85 m) above the base of the Tongue River Member. The Flowers-Goodale coal bed is overlain in ascending stratigraphic order by the following: a noncoal interval of about 100 to 120 feet (30.5 to 36.6 m) that contains in places local coal beds, the Knobloch coal bed, a noncoal interval of about 180 feet (55 m) that contains in places local coal beds, the Sawyer coal bed, a noncoal interval of about 40 to 60 feet (12.2 to 18.3 m), the C coal bed, a noncoal interval of 20 to 35 feet (6.1 to 10.7 m), the D coal bed, a noncoal interval of 20 to 40 feet (6.1 to 12.2 m), the Cache coal bed (of McKay, the Odell coal bed of Warren), a noncoal bed of about 120 to 150 feet (36.6 to 45.7 m) that contains in places a local bed, the E coal bed (local coal

bed of McKay), a noncoal interval of 130 to 160 feet (39.6 to 48.8 m), the Lower Cook coal bed (Pawnee (?) of McKay).

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).

### Lowermost local bed

A local bed about 6 feet (1.8 m) thick, which lies about 110 feet below the Flowers-Goodale coal bed, was recognized on logs of an oil-and-gas test hole in sec. 20, T. 3 S., R. 45 E. (pl. 1B). This thin bed may correlate with the Terret coal bed which was described by Bass (1932, p. 51) from a small mine on the Terret Ranch about 8 miles (12.9 km) north of the Willow Crossing quadrangle in the Cook Creek Reservoir quadrangle. However, because this bed does not outcrop in the Willow Crossing quadrangle and is not penetrated elsewhere in the quadrangle by test holes, it is considered here as a local coal bed and has not been assigned economic coal resources.

### Flowers-Goodale coal bed

The Flowers-Goodale coal bed was described by Bass (1932, p. 53) from two small mines about 14 miles (22.5 km) north of the Willow Crossing quadrangle in the Brandenberg quadrangle. Bass (1932, pl. 3) mapped this coal bed in the Willow Crossing quadrangle near its western border in the valley of Otter Creek where it is mainly covered by alluvium. The Flowers-Goodale has been penetrated by a few test holes (pl. 1B) in the Willow Crossing quadrangle. The isopach and structure contour map (pl. 10) shows that the Flowers-Goodale coal bed ranges from about 5 to 14 feet (1.5 to 4.3 m) in thickness, and dips generally southward at an angle of less than 1 degree. This dip is modified in the southern part of

the quadrangle by a synclinal fold of low relief. Overburden covering the Flowers-Goodale coal bed (pl. 11) ranges from 0 feet at the outcrops to about 900 feet (0-274 m) in thickness.

There is no known, publicly available chemical analysis of the Flowers-Goodale coal bed in the Willow Crossing quadrangle. However, an analysis of this coal from a depth of 153 to 162 feet (46.6 to 49.4 m) in drill hole SH-7076 (sec. 14, T. 1 S., R. 45 E.) about 8 miles (12.9 km) north of the Willow Crossing quadrangle in the Cook Creek Reservoir quadrangle shows ash 8.14 percent, sulfur 0.961 percent, and a heating value of 8,102 Btu per pound (18,845 kJ/kg) on an as-received basis (Matson and Blumer, 1973, p. 121). 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 in the Cook Creek Reservoir quadrangle is subbituminous C in rank. Because the Cook Creek Reservoir and Willow Crossing quadrangles have similar positions in the basin, it is assumed that the Flowers-Goodale coal in the Willow Crossing quadrangle is similar and is also subbituminous C in rank.

### Knobloch coal bed

The Knobloch coal bed was described by Bass (1932). The coal bed was named from the Knobloch Ranch and coal mine about 12 miles (19.3 km) southwest of the Willow Crossing quadrangle in the Birney Day School quadrangle. In the Willow Crossing quadrangle, the Knobloch coal bed is about 100 to 120 feet (30.5 to 36.6 m) above the Flowers-Goodale coal bed. Reddish-colored clinker formed by burning of the Knobloch coal bed covers the sides of the principal valleys in the quadrangle. Because of the extensive burning there are no thickness measurements of the coal at the surface. However, the coal has been penetrated in a number of test holes. The isopach and structure contour map of the Knobloch coal bed (pl. 7) shows that this bed ranges from about 40 to 70 feet (12.2 to 21.3 m) in

thickness and, in general, dips southward at an angle of less than 1 degree. This dip is modified in the northern and southern parts of the quadrangle by simple folds of low relief. Overburden on the Knobloch coal bed (pl. 8) ranges from about 60 to 800 feet (18.3 to 243.8 m) in thickness.

Several chemical analyses of the Knobloch coal from test holes in the Willow Crossing quadrangle are given by Matson and Blumer (1973, p. 68, 69, 72, and 73). These analyses show that the ash content ranges from 2.952 to 6.381 percent, sulfur from 0.104 to 0.388 percent, and heating value from 7,671 to 9,314 Btu per pound (17,843 to 21,664 kJ/kg) on an as-received basis. These heating values convert to about 8,067 to 9,671 Btu per pound (18,764 to 22,495 kJ/kg) on a moist, mineral-matter-free basis, indicating that the Knobloch coal in the Willow Crossing quadrangle ranges in rank from lignite A to subbituminous B in rank. For purposes of calculating resource tonnages, all of the coal in the quadrangle was considered to be subbituminous in rank.

### Sawyer coal bed

The Sawyer coal bed was first described by Dobbin (1930, p. 28) from exposures in the foothills of the Little Wolf Mountains (Rough Draw and Black Spring quadrangles) in the Forsyth coal field about 30 miles (48 km) northwest of the Willow Crossing quadrangle. The Sawyer coal bed in the Willow Crossing quadrangle is about 180 feet (55 m) above the Knobloch coal bed. In the northern part of the quadrangle, the Sawyer coal is a single coal bed which splits into two beds in the central part of the quadrangle (pls. 1 and 4), the Upper and Lower Sawyer coal beds. The isopach and structure contour map of the Sawyer coal bed and its upper split (pl. 4) shows that the Sawyer ranges in thickness from about 8 to 16 feet (2.4 to 4.9 m) in thickness. The bed, in general, dips southward at an angle of less than 1 degree, but this dip is modified by a broad, synclinal fold of low relief in the east-central part of the quadrangle. The Upper and

Lower Sawyer coal beds crop out in the southern part of the quadrangle and are less than 5 feet (1.5 m) thick (pls. 1 and 3); consequently, coal resources have not been calculated for them. Overburden on the Sawyer coal bed and its upper split (pl. 5) ranges from 0 feet at the outcrops to 600 feet (0-183 m) in thickness.

There is no known chemical analysis of the Sawyer coal in the Willow Crossing quadrangle. However, there is an analysis of this coal from a depth of 82 to 92 feet (25 to 28 m) in coal test hole SH-7066, sec. 36, T. 2 S., R. 45 E., about 0.25 mile (0.4 km) east of the quadrangle in the Coleman Draw quadrangle. This analysis (Matson and Blumer, 1973, p. 73) shows ash 4.672 percent, sulfur 0.97 percent, and heating value 8,015 Btu per pound (18,643 kJ/kg) on an as-received basis. This heating value converts to 8,408 Btu per pound (19,557 kJ/kg) on a moist, mineral-matter-free basis, indicating that the coal at that location is subbituminous C in rank. Because that location is so close to the Willow Crossing quadrangle it is assumed that the Sawyer coal in this quadrangle is similar and is also subbituminous C in rank.

Warren (1959, pl. 19) mapped the King coal bed in the southern part of the Willow Crossing quadrangle. Warren's King coal bed appears to be equivalent to the Sawyer coal bed as mapped by Bass (1932, pl. 3), and to the Lower Sawyer as mapped by McKay (1976). The King bed of Warren (1959) is equivalent to the Lower Sawyer of this report.

### C and D coal beds

The C and D coal beds were first described by Bass (1932, p. 55) after exposures in the Ashland coal field, possibly in the Cook Creek Reservoir or Beaver Creek School quadrangles, just north and northeast of the Willow Crossing quadrangle, although a type locality was not given. The lower of the two beds, the C coal bed, is about 40 to 60 feet (12.2 to 18.3 m) above the Sawyer coal bed and

20 to 35 feet (6.1 to 10.7 m) below the D coal bed. The beds have been mapped in the southwestern part of the quadrangle (pl. 1). According to Bass (1932, p. 55), the C coal bed is of little economic importance because it contains an abundance of silicified, partly carbonized tree stumps and fragments of logs that destroy the value of the bed. In the Willow Crossing quadrangle both beds are less than 5 feet (1.5 m) thick; consequently, economic coal resources have not been calculated for them.

### Cache coal bed as mapped by McKay in 1976 (or the Odell coal bed as mapped by Warren in 1959)

The Cache coal bed was first described by Warren (1959, p. 572) from exposures near Cache Creek in the Yarger Butte and Lonesome Peak quadrangles about 27 miles (43 km) southeast of the Willow Crossing quadrangle. McKay (1976) mapped the Cache bed in the Willow Crossing quadrangle. The two previous workers, Bass (1932) and Warren (1959), did not map the Cache coal bed in this quadrangle. However, Warren (1959, pl. 19) shows the Odell coal bed in the southwestern part of the quadrangle at about the same stratigraphic position as the Cache bed as mapped by McKay (1976). Thus, the two names may well refer to the same coal bed in this quadrangle, and we have chosen to call it the Cache coal bed in this report. The Odell coal bed was first described by Warren (1959, p. 572), probably from exposures near O'Dell Creek about 6 miles (9.6 km) southwest of the Willow Crossing quadrangle in the Green Creek quadrangle.

The Cache coal bed as mapped by McKay (1976) is shown in the southwestern part of the Willow Crossing quadrangle (pl. 1). It occurs about 20 to 40 feet (6.1 to 12.2 m) above the D coal bed where the latter is mapped. Wherever measured the Cache coal bed is less than 5 feet (1.5 m) thick; consequently, economic coal resources have not been calculated for it.

### E coal bed

The E coal bed, or more properly group of coal beds, was first described by Bass (1932, p. 55) after exposures in the Ashland coal field, possibly from the Cook Creek Reservoir or Beaver Creek School quadrangles just north and northeast of the Willow Crossing quadrangle, although a type locality was not given. The E coal bed was mapped by Bass (1932, pl. 3) in the northeastern part of the Willow Crossing quadrangle (pl. 1) where it occurs about 120 to 150 feet (36.6 to 45.7 m) above the Cache. McKay (1976) shows a local bed at about the same position. Because the E coal bed (local bed of McKay, 1976) is less than 5 feet (1.5 m) thick, economic coal resources have not been calculated for it.

### The Lower Cook coal bed

The name Cook coal bed was first used by Bass (1932, p. 59,60) to describe a coal bed in the Ashland coal field, probably in the Cook Creek Reservoir quadrangle just north of the Willow Crossing quadrangle. In some places there are Upper and Lower Cook coal beds, but in the Willow Crossing quadrangle only the Lower Cook coal bed is present. This coal bed crops out only in one small area near the north border of the quadrangle. Here it is about 160 feet (48.8 m) above the E coal bed. This coal bed was mapped by McKay (1976) as the Pawnee(?) coal bed, but its position here indicates that it correlates with the Lower Cook coal bed in the quadrangle to the north.

### Local coal beds

The local coal beds which occur at various places in the Willow Crossing quadrangle are of limited areal extent and less than 5 feet (1.5 m) thick. Consequently, economic coal resources have not been calculated for them.

## 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.

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.

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). Therefore, 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, are shown on the Areal Distribution and Tonnage maps (see list of illustrations) for each coal bed.

As shown by table 1, the total tonnage of federally owned, surface-minable Reserve Base coal in this quadrangle is estimated to be 1,203.80 million short tons (1,092.09 million t). The total tonnage of federally owned, surface-minable Hypothetical coal is estimated to be 18.39 million short tons (16.68 million t). As shown by table 2, the total federally owned, underground-minable Reserve Base coal is estimated to be 46.61 million short tons (42.28 million t). The total federally owned, underground-minable Hypothetical coal is estimated to be 4.83 million short tons (4.38 million t). The total tonnage of surface- and underground-minable Reserve Base coal is 1,250.41 million short tons (1,134.37 million t), and the total of surface- and underground-minable Hypothetical coal is 23.22 million short tons (21.06 million t).

About 20 percent of the surface-minable Reserve Base tonnage is classed as Measured, 35 percent as Indicated, and 45 percent as Inferred. All of the underground-minable Reserve Base tonnage 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, or where lignite beds of the same thickness are overlain by 200 feet (61 m) or less of overburden. 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 subbituminous 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

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 to 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 low development potential abutting against areas of high development potential.

The coal-development potential for surface-mining methods on Federal coal lands is shown on the Coal Development Potential map (pl. 13). Most of the Federal coal lands in the Willow Crossing quadrangle have a high development potential for surface mining. The coal beds that have a development potential for surface mining, in ascending order, are the Flowers-Goodale, Knobloch, and Sawyer coal beds.

The Flowers-Goodale coal bed (pl. 11) has a considerable area of high development potential (mining-ratio values less than 10) and also of moderate development (mining-ratio values 10-15) in the larger stream valleys. However, these areas are mainly on non-Federal coal lands. Most of the Federal coal lands in this quadrangle are in the wide area of low development potential (mining-ratio values greater than 15) extending beneath the upper slopes and relatively smooth uplands up to the 500-foot (152-m) overburden isopach, the arbitrarily assigned stripping limit.

Practically all of the Knobloch coal bed (pl. 8) has a high development potential for surface mining between the boundary of the coal to the arbitrarily assigned stripping limit at the 500-foot (152-m) overburden isopach. There is only one very small area near the northern border of the quadrangle where the values of the mining ratios are greater than 10.

In the northeastern part of the quadrangle, the Sawyer coal bed and its upper split (pl. 5) have wide areas of high development potential on the upper slopes of valleys and on stream divides where relief is low. There are narrow areas of moderate development potential along the steeper slopes and on some of the higher stream divides. There are broad areas of low development potential beneath the highest ridges, extending up to the arbitrarily assigned stripping limit at the 500-foot (152-m) overburden isopach.

About 87 percent of the Federal coal lands in the quadrangle have a high development potential for surface mining, 6 percent have a moderate development potential, and 7 percent have 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 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 Willow Crossing quadrangle, Powder River and Rosebud Counties, 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 | | | | |
| Sawyer and Upper Sawyer | 47,660,000 | 11,680,000 | 20,240,000 | 79,580,000 |
| Knobloch | 904,090,000 | 18,790,000 | 810,000 | 923,690,000 |
| Flowers-Goodale | 7,550,000 | 12,180,000 | 180,800,000 | 200,530,000 |
| Total | 959,300,000 | 42,650,000 | 201,850,000 | 1,203,800,000 |
| Hypothetical Resource tonnage | | | | |
| Flowers-Goodale | 0 | 0 | 18,390,000 | 18,390,000 |
| Total | 0 | 0 | 18,390,000 | 18,390,000 |
| Grand Total | 959,300,000 | 42,650,000 | 220,240,000 | 1,222,190,000 |

Table 2.--Underground-minable coal resource tonnage (in short tons) by development-potential category for Federal lands in the Willow Crossing quadrangle, Powder River and Rosebud Counties, 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 | | | | |
| Sawyer and Upper Sawyer | 0 | 0 | 220,000 | 220,000 |
| Knobloch | 0 | 0 | 38,590,000 | 38,590,000 |
| Flowers-Goodale | 0 | 0 | 7,800,000 | 7,800,000 |
| Total | 0 | 0 | 46,610,000 | 46,610,000 |
| Hypothetical Resource tonnage | | | | |
| Flowers-Goodale | 0 | 0 | 4,830,000 | 4,830,000 |
| Total | 0 | 0 | 4,830,000 | 4,830,000 |
| Grand Total | 0 | 0 | 51,440,000 | 51,440,000 |

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