UNITED STATES DEPARTMENT OF THE INTERIOR

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# COAL RESOURCE OCCURRENCE AND COAL DEVELOPMENT POTENTIAL MAPS OF THE GOODSPEED BUTTE QUADRANGLE, POWDER RIVER COUNTY, MONTANA

[Report includes 37 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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[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 Goodspeed Butte quadrangle, Powder River County, Montana, (37 plates; U.S. Geological Survey Open-File Report 79-088). 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 Goodspeed Butte 7 1/2-minute quadrangle is in western Powder River County, Montana, about 29 miles (47 km) west-southwest of Broadus, Montana, 17 miles (27 km) south-southeast of Ashland, Montana, and 50 miles (80 km) northeast of Sheridan, Wyoming. Broadus is on U.S. Highway 212 near its interchange with U.S. Highway 312. Ashland is 44 miles (71 km) west of Broadus on U.S. Highway 212. Sheridan is on U.S. Interstate Highway 90 and a main line of the Burlington Northern Railroad.

## Accessibility

The Goodspeed Butte quadrangle is accessible from Ashland, Montana, by traveling eastward from Ashland about 4 miles (6.4 km) on U.S. Highway 212 to the improved, graveled Otter Creek Road, then traveling southward on this road about 20 miles (32 km) to the intersection with the Taylor Creek Road. Turn eastward on the Taylor Creek Road about 2 miles (3.2 km) to the southwestern border of the quadrangle. The quadrangle is also accessible from Decker, Montana, by traveling northeastward over improved, graveled roads about 48 miles (77 km) to the southwestern part of the quadrangle. Unimproved local roads and trails provide access to most parts of the quadrangle.

## Physiography

The Goodspeed Butte quadrangle is in the Missouri Plateau division of the Great Plains Physiographic province. The quadrangle is on the eastern side of the Otter Creek drainage basin. Otter Creek, a major tributary of the Tongue River, flows northward about 1 mile (1.6 km) west of the quadrangle. The quadrangle is drained by several westward-flowing intermittent tributaries of Otter Creek, including Taylor, Dry, Lyon, Ash, and Elk Creeks. These creeks have narrow flood plains as much as 0.25 mile (0.4 km) in width. The sides of the valleys rise steeply 300 to 500 feet (91 to 152 m) to rather flat-topped interstream uplands which are 1 to 3 miles (1.6 to 4.8 km) in width. The tops of the uplands are grass covered, but their steep, gullied sides are forested. All of the quadrangle is within the Custer National Forest. The highest elevation in the quadrangle, 4,106 feet (1,252 m), is at the Taylor triangulation station near the eastern border of the quadrangle and north of the North Fork of Taylor Creek. The lowest elevation, about 3,190 feet (972 m), is on Elk Creek near the northwest corner of the quadrangle. Topographic relief in the quadrangle is about 916 feet (279 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 Goodspeed Butte quadrangle. All of the quadrangle is within the Northern Powder River Basin Known Recoverable Coal Resource Area (KRCRA). All of the quadrangle is within the Custer National Forest. The Federal government owns most of the coal rights. In 1977 there were no Federal coal leases or prospecting permits.

## GENERAL GEOLOGY

### Previous work

Warren (1959, pl. 19) mapped all except the southern part of the Goodspeed Butte quadrangle as part of the Birney-Broadus coal field. Bryson and Bass (1973, pl. 1) mapped the southernmost part of the quadrangle as part of the Moorhead coal field. Matson and Blumer (1973, pls. 19, 20, 23A, and 23B) mapped the Canyon, Cook, Elk, and Dunning (Pawnee) coal beds within the quadrangle as parts of the Diamond Butte, Goodspeed Butte, and Yager Butte 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

A generalized columnar section of the coal-bearing rocks of the Goodspeed Butte quadrangle 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.

The Tongue River Member consists of interbedded, lenticular beds of gray, fine- to very fine-grained sandstone, light- to dark-gray siltstone, gray shale and claystone, brown carbonaceous shale, and coal beds. The thicker coal beds have been burned along the outcrops, baking the overlying sandstone and shale and forming thick, reddish-colored clinker beds. The upper part of the Tongue River Member has been removed from the quadrangle by erosion, but about 1,600 feet (488 m) of strata remains.

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 Goodspeed Butte quadrangle is in the north-central part of the Powder River structural basin. The strata dip regionally southwestward at an angle of less than 1 degree, but in the Goodspeed Butte quadrangle this dip is considerably modified by low-relief folding. Some of the nonuniformity in structure may be caused by differential compaction and to irregularities in deposition of the coals and other lenticular beds as a result of their continental origin.

# COAL GEOLOGY

The coal beds in the Goodspeed Butte 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 Contact coal bed which occurs about 40 feet (12.2 m) above the base of the Tongue River Member. The Contact coal bed is overlain successively by a noncoal interval of about 165 feet (50.3 m), the Broadus coal bed, a mainly noncoal interval of about 227 feet (69 m) containing a local coal bed, the Flowers-Goodale coal bed, a noncoal interval of about 120 feet (36.6 m), the Nance coal bed, a noncoal interval of about 80 to 180 feet (24.4 to 54.9 m), the Knobloch coal bed, a noncoal interval of about 40 to 65 feet (12 to 20 m), the King coal bed, a mainly noncoal interval of about 80 to 127 feet (24 to 39 m) containing a local coal bed, the Odell coal bed, a noncoal interval of about 100 to 170 feet (30 to 52 m), the Dunning (Pawnee) coal bed, a noncoal interval of about 70 to 120 feet (21 to 37 m), the Elk coal bed, a non-coal interval of about 50 to 140 feet (15 to 43 m), the lower split of the Cook coal bed, a noncoal interval of about 30 to 90 feet (9.1 to 27.4 m), the upper split of the Cook coal bed, a mainly noncoal interval of about 50 to 150 feet (15 to 46 m) containing a local coal bed, the Ferry coal bed, a mainly noncoal interval of about 50 to 100 feet (15 to 30 m) containing a local coal bed, the Canyon coal bed, a mainly noncoal interval of about 100 feet (30 m) containing a local coal bed, the Dietz coal bed, a noncoal interval of about 75 feet (23 m), the Anderson clinker 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).

## Contact coal bed

The Contact coal bed was first described by Bass (1932, p. 53) from exposures of coal about 37 miles (59.5 km) north-northeast of the Goodspeed Butte quadrangle in the Kirkpatrick Hill quadrangle in the Ashland coal field. The Contact coal bed does not crop out in the Goodspeed Butte quadrangle but is recognized at a depth of 1,383 to 1,387 feet (421.5-422.8 m) in the oil-and-gas test hole in sec. 30, T. 6 S., R. 47 E. (pl. 3) where it occurs about 40 feet (12.2 m) above the base of the Tongue River Member. Here the Contact coal bed is about 4 feet (1.2 m) thick. Because of its thinness and limited known areal extent, the Contact coal bed has not been assigned economic coal resources.

## Broadus coal bed

The Broadus coal bed was first described by Warren (1959, p. 570) from exposures of coal in the Epsie NE quadrangle near the town of Broadus, about 29 miles (46.6 km) east-northeast of the Goodspeed Butte quadrangle in the Birney-Broadus coal field. The Broadus coal bed does not crop out in the Goodspeed Butte quadrangle but has been recognized in the oil-and-gas test hole in sec. 30, T. 6 S., R. 47 E. (pls. 1 and 3). Here the Broadus coal bed occurs about 165 feet (50.3 m) above the Contact coal bed. The isopach and structure contour map (pl. 34) shows that the Broadus coal bed ranges from about 5 to 15 feet (1.5 to 4.6 m) in thickness and dips westward at an angle of less than half a degree. Overburden on the Broadus coal bed (pl. 35) ranges from about 1,000 to 1,400 feet (305 to 417 m) in thickness.

There is no known, publicly available chemical analysis of the Broadus coal in or close to the Goodspeed Butte quadrangle. It is assumed that the Broadus coal is similar in rank to other closely associated coals in the Goodspeed Butte quadrangle and is subbituminous C in rank.

## Flowers-Goodale coal bed

The Flowers-Goodale coal bed was first described by Bass (1932, p. 53) from two small mines about 31 miles (50 km) north-northwest of the Goodspeed Butte quadrangle in the Brandenberg quadrangle. The Flowers-Goodale coal bed does not crop out in the Goodspeed Butte quadrangle, but it has been penetrated by an oil-and-gas test hole in sec. 30, T. 6 S., R. 47 E. (pls. 1 and 3) where it occurs about 227 feet (69 m) above the Broadus coal bed. The isopach and structure contour map (pl. 31) shows that the Flowers-Goodale coal bed ranges from about 5 to 12 feet (1.5 to 3.7 m) in thickness and dips westward at an angle of less than half a degree. Overburden on the Flowers-Goodale coal bed (pl. 32) ranges from about 400 to 1,200 feet (122 to 366 m) in thickness.

There is no known, publicly available chemical analysis of the Flowers-Goodale coal from the Goodspeed Butte quadrangle. However, a chemical analysis of this 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., 25.5 miles (41 km) north-northwest of the Goodspeed Butte quadrangle in the Cook Creek Reservoir quadrangle (Matson and Blumer, 1973, p. 121), shows ash 8.144 percent, sulfur 0.961 percent, and heating value 8,102 Btu per pound (18,845 kJ/kg) on an as-received basis. 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 in rank. Because the Goodspeed Butte quadrangle is deeper in the basin, the Flowers-Goodale in this quadrangle would be higher in heating value and would be either subbituminous C or subbituminous B in rank.

## Nance coal bed

The Nance coal bed is named for its occurrence at a depth of 242 feet (73.8 m) in Nance and Hayes drill hole M11-2, SE¼ SE¼ sec. 25, T. 5 S., R. 42 E., about 17 miles (27.4 km) west of the Goodspeed Butte quadrangle in the Browns Mountain quadrangle (Mapel and Martin, 1978, p. 21).

The Nance coal bed does not crop out in the Goodspeed Butte quadrangle but has been penetrated by the oil-and-gas test hole in sec. 30, T. 6 S., R. 47 E. (pls. 1 and 3), where it occurs about 120 feet (36.6 m) above the Flowers-Goodale coal bed. The isopach and structure contour map (pl. 28) shows that the Nance coal bed ranges from about 4 to 6 feet (1.2 to 1.8 m) in thickness and dips southward at an angle of less than half a degree. Overburden on the Nance coal bed (pl. 29) ranges from about 150 to 1,100 feet (46 to 335 m) in thickness.

There is no known, publicly available chemical analysis of the Nance coal in the Goodspeed Butte quadrangle. However, an analysis of the upper, middle, and lower (Nance) benches of the Knobloch coal from a depth of 216 to 218 feet (65.8 to 66.4 m) in coal test hole SH-7055, sec. 6, T. 4 S., R. 45 E., about 10 miles (16 km) northwest of the Goodspeed Butte quadrangle in the Willow Crossing quadrangle (Matson and Blumer, 1973, p. 64), shows ash 6.381 percent, sulfur 0.154 percent, and heating value 8,558 Btu per pound (19,906 kJ/kg) on an as-received basis. This heating value converts to about 9,141 Btu per pound on a moist, mineral-matter-free basis, indicating that the Nance coal at that location is subbituminous C in rank. Because of the proximity of that location to the Goodspeed Butte quadrangle, it is assumed that the Nance coal in the Goodspeed Butte quadrangle is similar and is also subbituminous C in rank.

## Knobloch coal bed

The Knobloch coal bed was first described by Bass (1924) from exposures of coal along the Tongue River on the Knobloch Ranch in secs. 17 and 18, T. 5 S.,

R. 43 E. about 18 miles (29 km) west-northwest of the Goodspeed Butte quadrangle in the Birney Day School quadrangle. The Knobloch coal bed does not crop out in the Goodspeed Butte quadrangle, but it is penetrated by two test holes in the quadrangle (pls. 1 and 3). The Knobloch coal bed occurs about 80 to 180 feet (24.4 to 54.9 m) above the Nance coal bed. The isopach and structure contour map (pl. 25) shows that the Knobloch coal bed ranges from about 16 to 26 feet (4.9 to 7.9 m) in thickness and generally dips westward at an angle of less than half a degree but has been affected by low-relief folding. Overburden on the Knobloch coal bed (pl. 26) ranges from about 120 to 980 feet (37 to 299 m) in thickness.

A chemical analysis of the Knobloch coal from a depth of 178 to 187 feet (54 to 57 m) in coal test hole SH-7044, sec. 30, T. 5 S., R. 46 E., in the Goodspeed Butte quadrangle (Matson and Blumer, 1973, p. 68), shows ash 5.423 percent, sulfur 0.157 percent, and heating value 8,515 Btu per pound (19,806 kJ/kg) on an as-received basis. This heating value converts to about 9,003 Btu per pound (20,942 kJ/kg) on a moist, mineral-matter-free basis, indicating that the Knobloch coal in the Goodspeed Butte quadrangle is subbituminous C in rank.

### King (Sawyer) coal bed

The King coal bed was first described by Warren (1959, p. 571) probably for exposures of coal along King Creek about 13 miles (21 km) northwest of the Goodspeed Butte quadrangle in the Ashland and Green Creek quadrangles. Warren (1959, pl. 19) also mapped the King coal bed in the northwestern part of the Goodspeed Butte quadrangle. Preliminary regional mapping indicates that the King coal bed and the Sawyer coal beds are equivalent.

In the Goodspeed Butte quadrangle, the King coal bed occurs about 40 to 65 feet (12 to 20 m) above the Knobloch coal bed. Because the King coal bed is less than 5 feet (1.5 m) thick in this quadrangle, it has not been assigned economic coal resources.

## Odell (Cache) coal bed

The Odell coal bed was first described by Warren (1959, p. 572) presumably from exposures of coal along O'Dell Creek about 10 miles (16 km) west-northwest of the Goodspeed Butte quadrangle in the Green Creek quadrangle. Warren (1959, pl. 19) also mapped the Odell coal bed in the Goodspeed Butte quadrangle. McKay (1976) mapped the Cache coal bed in the same stratigraphic position in the King Mountain quadrangle just northwest of the Goodspeed Butte quadrangle. The Cache coal bed was named by Warren (1959, p. 572) for exposures along Cache Creek about 18 miles (29 km) east of the Goodspeed Butte quadrangle in the Yarger Butte and Lonesome Peak quadrangles. Preliminary regional mapping indicates that the Cache and Odell coal beds are equivalent.

The Odell coal bed crops out in the northwestern part of the Goodspeed Butte quadrangle and has been penetrated by the oil-and-gas test hole in the southeastern part of the quadrangle (pls. 1 and 3). It occurs about 80 to 127 feet (24 to 39 m) above the King coal bed. The isopach and structure contour map (pl. 22) shows that the Odell coal bed ranges from about 5 to 11 feet (1.5 to 3.4 m) in thickness and generally dips westward or southwestward at an angle of less than half a degree but has been somewhat affected by low-relief folding. Overburden on the Odell coal bed ranges from 0 feet at the outcrops to about 780 feet (0-238 m) in thickness.

There is no known, publicly available chemical analysis of the Odell coal in or close to the Goodspeed Butte quadrangle. It is assumed that the Odell coal is similar to other closely associated coals in the Goodspeed Butte quadrangle and is subbituminous C in rank.

## Dunning (Pawnee) coal bed

The Dunning (Pawnee) coal bed was first described by Warren (1959, p. 572) from exposures of coal in the Birney-Broadus coal field which includes the

Goodspeed Butte quadrangle. Warren (1959, pl. 19) and Matson and Blumer (1973, pl. 23A) mapped the Dunning (Pawnee) coal bed in the quadrangle. The Dunning (Pawnee) coal bed, and a clinker bed formed by burning of the coal, crop out in the western and northern parts of the quadrangle (pl. 1). It occurs about 100 to 170 feet (30 to 52 m) above the Odell coal bed. The isopach and structure contour map (pl. 19) shows that the Dunning (Pawnee) coal bed ranges from about 2 to 18 feet (0.6 to 5.5 m) in thickness and generally dips westward at an angle of less than half a degree but has been somewhat affected by low-relief folding. Overburden on the Dunning (Pawnee) coal bed (pl. 20) ranges from 0 feet at the outcrops to about 600 feet (0-183 m) in thickness.

We have used the name Dunning for this coal bed in the Goodspeed Butte, Threemile Buttes, Yager Butte, and Reanus Cone quadrangles based upon usage in early day geological reports on those areas by previous authors (Warren 1959; and others). However, in twenty-one adjacent quadrangles surrounding these four quadrangles we have mapped a coal bed at this same stratigraphic horizon which we, and others, have called the 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 Goodspeed Butte quadrangle. Based upon our present-day coal isopachs and structure contours, the Dunning and Pawnee appear to be the same coal bed.

A chemical analysis of the Dunning (Pawnee) coal from a depth of 106 to 110 feet (32 to 33.5 m) in drill hole SH-7146, sec. 20, T. 4 S., R. 46 E. about 6.5 miles (10.5 km) north of the Goodspeed Butte quadrangle in the Yager Butte quadrangle (Matson and Blumer, 1973, p. 105), shows ash 4.356 percent, sulfur 0.210 percent, and heating value 7,991 Btu per pound (18,587 kJ/kg) on an as-received basis. This heating value converts to about 8,355 Btu per pound (19,434 kJ/kg) on a moist, mineral-matter-free basis, indicating that the Dunning (Pawnee) coal at that location is subbituminous C in rank. Because of the proximity of that location to the Goodspeed Butte quadrangle, it is assumed that the Dunning (Pawnee) coal in this quadrangle is similar and is also subbituminous C in rank.

### Elk coal bed

The Elk coal bed was first described by Warren (1959, p. 573) from exposures of coal along Elk Creek in the northern part of the Goodspeed Butte quadrangle. Warren (1959, pl. 19) and Matson and Blumer (1973, pl. 23A) mapped the Elk coal bed in the Goodspeed Butte quadrangle. This coal bed crops out in the western part of the quadrangle (pl. 1). It occurs about 70 to 120 feet (21 to 37 m) above the Dunning (Pawnee) coal bed. The isopach and structure contour map (pl. 16) shows that the Elk coal bed ranges from about 4 to 12.7 feet (1.2 to 3.9 m) in thickness and generally dips westward or southwestward at an angle of less than half a degree, although it has been affected a little by broad, low-relief folding. Overburden on the Elk coal bed (pl. 17) ranges from 0 feet to about 500 feet (0-152 m) in thickness.

A chemical analysis of the Elk coal from a depth of 98 to 102 feet (29.9 to 31.1 m) in coal test hole SH-7144, sec. 15, T. 5 S., R. 46 E., about 2 miles (3.2 km) north of the Goodspeed Butte quadrangle in the Yager Butte quadrangle (Matson and Blumer, 1973, p. 104) shows ash 3.538 percent, sulfur 0.271 percent, and heating value 7,852 Btu per pound (17,636 kJ/kg) on an as-received basis. This heating value converts to about 8,140 Btu per pound (19,934 kJ/kg) on a moist, mineral-matter-free basis, indicating that the Elk coal at that location is lignite A in rank. Because of the proximity of that location to the Goodspeed Butte quadrangle, it is assumed that the Elk coal in this quadrangle is similar and is also lignite A in rank.

## Lower split of the Cook coal bed

The Cook coal bed was first described by Bass (1932, p. 59-60) from exposures of coal on Cook Mountain in the Cook Creek Reservoir quadrangle about 20 miles (32 km) north-northwest of the Goodspeed Butte quadrangle. Preliminary regional mapping indicates that the Cook coal bed in places splits into two coal beds, and that both the upper and lower splits of the Cook coal beds are present in the Goodspeed Butte quadrangle. Matson and Blumer (1973, pl. 20) mapped the Upper and Lower Cook coal beds in this quadrangle. Warren (1959, pl. 19) mapped the lower split of the Cook coal bed as the Wall coal bed in the Birney-Broadus coal field which includes the Goodspeed Butte quadrangle.

The lower split of the Cook coal bed occurs about 50 to 140 feet (15 to 43 m) above the Elk coal bed and crops out high on the steep hill slopes in the Goodspeed Butte quadrangle. The isopach and structure contour map (pl. 13) shows that the lower split of the Cook coal bed ranges from about 2.3 to 10 feet (0.7 to 3.0 m) in thickness and generally dips southwestward at an angle of half a degree or less, although this dip is somewhat affected by low-relief folding. Overburden on the lower split of the Cook coal bed (pl. 14) ranges from 0 feet to about 400 feet (0-122 m) in thickness.

A chemical analysis of the lower split of the Cook coal from a depth of 72 to 76 feet (22 to 23 m) in coal test hole SH-7048, sec. 25, T. 5 S., R. 46 E., in the northern part of the Goodspeed Butte quadrangle (Matson and Blumer, 1973, p. 104), shows ash 3.724 percent, sulfur 0.465 percent, and heating value 7,541 Btu per pound (17,540 kJ/kg) on an as-received basis. This heating value converts to about 7,833 Btu per pound (18,217 kJ/kg) on a moist, mineral-matter-free basis, indicating that the lower split of the Cook coal in this part of the Goodspeed Butte quadrangle is lignite A in rank.

## Upper split of the Cook coal bed

The upper split of the Cook coal bed (pl. 1) crops out on the steep hill slopes in the Goodspeed Butte quadrangle. It occurs about 30 to 90 feet (9.1 to 27.4 m) above the lower split of the Cook coal bed. The isopach and structure contour map (pl. 10) shows that the upper split of the Cook coal bed ranges from about 1.7 to 16 feet (0.5 to 4.9 m) in thickness and generally dips westward at an angle of less than half a degree, although this dip is considerably affected by low-relief folding. Overburden on the upper split of the Cook coal bed (pl. 8) ranges from 0 feet to about 300 feet (0-91 m) in thickness.

A chemical analysis of the upper split of the Cook coal from a depth of 62 to 72 feet in coal test hole SH-7048, sec. 25, T. 5 S., R. 46 E., in the northern part of the Goodspeed Butte quadrangle (Matson and Blumer, 1973, p. 104), shows ash 6.638 percent, sulfur 0.672 percent, and heating value 7,496 Btu per pound (17,436 kJ/kg) on an as-received basis. This heating value converts to about 8,029 Btu per pound (18,675 kJ/kg) on a moist, mineral-matter-free basis, indicating that the upper split of the Cook coal in this part of the Goodspeed Butte quadrangle is lignite A in rank.

## Ferry coal bed

The Ferry coal bed was first described by Warren (1959, p. 573) from exposures of coal in the Birney-Broadus coal field which includes the Goodspeed Butte quadrangle. This coal bed crops out high on the hill slopes in the southern part of the quadrangle (pl. 1). It occurs about 50 to 150 feet (15 to 46 m) above the upper split of the Cook coal bed. The isopach and structure contour map (pl. 7) shows that the Ferry coal bed ranges from about 2.5 to 5.2 feet (0.8 to 1.6 m) in thickness and generally dips westward or southward at an angle of less than half a degree. Overburden on the Ferry coal bed (pl. 8) ranges from 0 feet to about 140 feet (0-43 m) in thickness.

There is no known, publicly available chemical analysis of the Ferry coal in or close to the Goodspeed Butte quadrangle. It is assumed that the Ferry coal is similar to other closely associated coals in this quadrangle and is lignite A 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 28 miles (45 km) west of the Goodspeed Butte quadrangle. Warren (1959, pl. 19) and Matson and Blumer (1973, pl. 19) mapped the Canyon coal bed in the Goodspeed Butte quadrangle. It crops out near the crests of the uplands about 50 to 100 feet (15 to 30 m) above the Ferry coal bed. The isopach and structure contour map (pl. 4) shows that the Canyon coal bed ranges from about 1.8 to 12 feet (0.5 to 3.7 m) in thickness and has been folded into a low-relief anticline in the central part of the quadrangle. Overburden on the Canyon coal bed ranges from 0 feet to about 200 feet (0-61 m) in thickness.

A chemical analysis of the Canyon coal from a depth of 56 to 63 feet (17 to 19 m) in coal test hole SH-7124, sec. 30, T. 6 S., R. 47 E., in the Goodspeed Butte quadrangle (Matson and Blumer, 1973, p. 96), 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 in the Goodspeed Butte quadrangle is lignite A in rank.

### Dietz and Anderson coal beds

The Dietz and Anderson coal beds crop out near the crest of a hill at the western border of the quadrangle. Both have a very limited areal extent. The Dietz coal bed is of unmeasured thickness, and the Anderson coal bed has been entirely burned. Therefore, economic coal resources have not been assigned to these beds.

### Local coal beds

In the Goodspeed Butte quadrangle, local coal beds occur above the Broadus, King, Upper Cook, Ferry, and Canyon coal beds (pl. 3). Because these local coal beds are thin and of limited known 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 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 1,819.6 million short tons (1,650.80 million t). The total tonnage of federally owned, surface-minable Hypothetical coal is estimated to be 91.19 million short tons (82.73 million t). As shown by table 2, the total federally owned, underground-minable Reserve Base coal is estimated to be 1,450.31 million short tons (1,315.72 million t). The total federally owned, underground-minable Hypothetical coal is estimated to be

471.51 million short tons (421.79 million t). The total tonnage of surface- and underground-minable Reserve Base coal is 3,269.98 million short tons (2,966.53 million t), and the total of surface- and underground-minable Hypothetical coal is 562.74 million short tons (510.52 million t).

About 4 percent of the surface-minable Reserve Base tonnage is classed as Measured, 24 percent as Indicated, and 72 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 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 in the Federal coal lands is shown on the Coal Development Potential Map (pl. 42).Most of the Federal lands have a high development potential for surface mining.

The Canyon coal bed (pl. 5) has quite widely separated areas of development potential for surface mining near the crests of the hills. There are some fairly wide areas and some narrow areas of high development potential (mining-ratio values less than 10). There are generally narrow areas of moderate development potential (mining-ratio values 10-15) and an area of low development potential for surface mining extending from the 15 mining-ratio contour to the 200-foot overburden isopach, the stripping limit for beds of lignite.

The Ferry coal bed (pl. 8) has only three small areas of development potential for surface mining. There are small areas of high development potential (mining-ratio values less than 10), of moderate development potential (mining-ratio values 10-15), and of low development potential for surface mining (mining-ratio values greater than 15) extending to the crests of the hills.

The upper split of the Cook coal bed (pl. 11) has fairly wide to narrow areas of high development potential for surface mining (mining-ratio values less than 10), and narrow bands of moderate development potential (mining-ratio values 10-15). There are quite wide areas of low development potential for surface mining extending from the 15 mining-ratio contour.

The lower split of the Cook coal bed (pl. 14) has narrow to wide areas of high development potential for surface mining (mining-ratio values less than 10) on the hill slopes. There are narrow to fairly wide bands of moderate development potential (mining-ratio values 10-15). Wider areas of low development potential for surface mining extend from the 15 mining-ratio contour.

The Elk coal bed (pl. 17) has narrow bands of high development potential for surface mining (mining-ratio values less than 10) and narrow bands of moderate development potential (mining-ratio values 10-15) on the hill slopes. There are wider areas of low development potential extending from the 15 mining-ratio contour.

The Dunning (Pawnee) coal bed (pl. 20) has narrow bands of high development potential for surface mining (mining-ratio values less than 10) and narrow bands of moderate development potential (mining-ratio values 10-15). There are extensive areas of low development potential for surface mining extending from the 15 mining-ratio contour to the 500-foot (152 m) overburden isopach, the stripping limit for miltiple beds of subbituminous coal.

The Odell coal bed (pl. 23) has narrow bands of high development potential for surface mining (mining-ratio values less than 10) on hill slopes in the northern part of the quadrangle. There are even narrower bands of moderate development potential (mining-ratio values 10-15). Extensive areas of low development potential extend from the 15 mining-ratio contour to the 500-foot (152 m) overburden isopach, the stripping limit for multiple beds of subbituminous coal. There are also wide areas of no development potential for surface mining above the 500-foot (152-m) overburden isopach.

The Knobloch coal bed (pl. 26) has rather limited areas of high development potential for surface mining (mining-ratio values less than 10) under flood plains in the northern part of the quadrangle. There are areas of moderate development potential (mining-ratio values 10-15) under the flood plains or on the adjacent hill slopes in the northern and western parts of the quadrangle. There are wider areas of low development potential for surface mining (mining-ratio values greater than 15) on the hill slopes extending from the 15 mining-ratio contour to the 500-foot (152-m) overburden isopach, the stripping limit for multiple beds of subbituminous coal. There are very extensive areas of no development potential for surface mining above the 500-foot (152-m) overburden isopach.

The Nance coal bed (pl. 29) has no areas of high or moderate development potential for surface mining as all of the Nance coal in this quadrangle has mining-ratio values greater than 15. There is an area of low development potential in the northern part of the quadrangle extending from the bottom of the valleys to the 500-foot (152-m) overburden isopach, the stripping limit for multiple beds of subbituminous coal. Most of the Nance coal has no development potential for surface mining, as it has more than 500 feet (152 m) of overburden and is thus beyond the stripping limit.

The Flowers-Goodale coal bed (pl. 32) has no areas of high or moderate development potential for surface mining, as the mining ratio values for this coal bed in this quadrangle are greater than 15. There are limited areas of low development potential for surface mining under flood plains in the northeastern part of the quadrangle extending from the bottoms of the valleys to the 500-foot (152-m) overburden isopach, the stripping limit for multiple beds of subbituminous coal. Most of the Flowers-Goodale coal in this quadrangle has no potential for surface mining, as it lies above the 500-foot (152-m) overburden isopach and is thus beyond the stripping limit.

The Broadus coal bed (pl. 35) has no potential for surface mining in this quadrangle, as the overburden on this coal bed is greater than 500 feet (152 m) in thickness. The Broadus coal bed is thus beyond the stripping limit for multiple beds of subbituminous coal in this quadrangle.

About 92 percent of the Federal coal lands in the Goodspeed Butte quadrangle has a high development potential for surface mining, 5 percent has a moderate development potential, and 3 percent has a low 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 Goodspeed Butte 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 | | | | |
| Canyon | 27,400,000 | 5,910,000 | 5,000,000 | 38,350,000 |
| Ferry | 1,290,000 | 580,000 | 730,000 | 2,600,000 |
| Upper Cook | 135,210,000 | 78,530,000 | 107,560,000 | 321,300,000 |
| Lower Cook | 93,780,000 | 68,090,000 | 160,280,000 | 322,150,000 |
| Elk | 23,200,000 | 17,620,000 | 131,760,000 | 172,530,000 |
| Dunning (Pawnee) | 52,150,000 | 45,350,000 | 396,220,000 | 493,720,000 |
| Odell (Cache) | 7,470,000 | 3,210,000 | 121,600,000 | 132,280,000 |
| Knobloch | 34,300,000 | 73,790,000 | 197,510,000 | 305,600,000 |
| Nance | 0 | 0 | 21,690,000 | 21,690,000 |
| Flowers-Goodale | 0 | 0 | 9,400,000 | 9,400,000 |
| Total | 374,840,000 | 293,080,000 | 1,151,750,000 | 1,819,670,000 |
| Hypothetical Resource tonnage | | | | |
| Elk | 240,000 | 310,000 | 30,000 | 580,000 |
| Odell (Cache) | 0 | 120,000 | 19,050,000 | 19,170,000 |
| Knobloch | 0 | 1,740,000 | 64,390,000 | 66,130,000 |
| Nance | 0 | 0 | 1,710,000 | 1,710,000 |
| Flowers-Goodale | 0 | 0 | 3,600,000 | 3,600,000 |
| Total | 240,000 | 2,170,000 | 88,780,000 | 91,190,000 |
| Grand Total | 375,080,000 | 295,250,000 | 1,240,530,000 | 1,910,860,000 |

Table 2.--Underground-minable coal resource tonnage (in short tons) by development-potential category for Federal lands in the Goodspeed Butte 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 | | | | |
| Elk | 0 | 0 | 1,560,000 | 1,560,000 |
| Dunning (Pawnee) | 0 | 0 | 53,180,000 | 53,180,000 |
| Odell (Cache) | 0 | 0 | 81,780,000 | 81,780,000 |
| Knobloch | 0 | 0 | 696,580,000 | 696,580,000 |
| Nance | 0 | 0 | 47,960,000 | 47,960,000 |
| Flowers-Goodale | 0 | 0 | 357,660,000 | 357,660,000 |
| Broadus | 0 | 0 | 211,590,000 | 211,590,000 |
| Total | 0 | 0 | 1,450,310,000 | 1,450,310,000 |
| Hypothetical Resource tonnage | | | | |
| Odell (Cache) | 0 | 0 | 7,920,000 | 7,920,000 |
| Knobloch | 0 | 0 | 182,750,000 | 182,750,000 |
| Nance | 0 | 0 | 15,320,000 | 15,320,000 |
| Flowers-Goodale | 0 | 0 | 265,560,000 | 265,560,000 |
| Total | 0 | 0 | 471,550,000 | 471,550,000 |
| Grabd Total | 0 | 0 | 1,921,860,000 | 1,921,860,000 |

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