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COAL RESOURCE OCCURRENCE AND COAL DEVELOPMENT POTENTIAL MAPS OF THE KIRBY QUADRANGLE, BIG HORN COUNTY, MONTANA

[Report includes 28 plates]

By

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ILLUSTRATIONS

[Plates are in pocket]

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Conversion table

To convert	Multiply by	To obtain
feet	0.3048	meters (m)
miles	1.609	kilometers (km)
acres	0.40469	hectares (ha)
tons (short)	0.907	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 Kirby quadrangle, Big Horn County, Montana, (28 plates; U.S. Geological Survey Open-File Report 79-650). 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 Kirby 7 1/2-minute quadrangle is in eastern Big Horn County, Montana, about 39 miles (62.8 km) southeast of Hardin, Montana, a town in the valley of the Bighorn River near the confluence of the Bighorn River and the Little Bighorn River. Hardin is on U.S. Highway 212, Interstate Highway 90, and on the Burlington Northern Railroad.

Accessibility

The Kirby quadrangle is accessible from Hardin, Montana, by going first southward and then eastward on U.S. Highway 212 about 39 miles (62.8 km) to the Rosebud Creek Road, thence southward on the Rosebud Creek Road 12 miles (19.3 km) to the northern border of the quadrangle. The nearest railroad is the Burlington Northern Railroad which is about 18 miles (29.0 km) west of the quadrangle beyond the Wolf Mountains. A branch of the railroad serves the Decker coal mine, which is about 15 miles (24 km) south-southeast of the quadrangle.

Physiography

The Kirby quadrangle lies within the Missouri Plateau Division of the Great Plains physiographic province. The topographic relief of this part of the Missouri Plateau is greater than is typical of the Great Plains because the plateau has been deeply dissected. Commonly in this region remnants of the gently undulating plateau are preserved only along drainage divides between entrenched streams. Much of the landscape consists of steep to precipitous slopes between the narrow, locally flat-topped drainage divides and the narrow, locally flat-bottomed valleys of the entrenched streams.

Most of the Kirby quadrangle lies within the drainage basin of Rosebud Creek, but several square miles of the quadrangle, in its southeast corner and along the southern three-quarters of its east edge, lie within the drainage basin of the Tongue River. The trend of the drainage divide between Rosebud Creek and the Tongue River is irregularly north-northeastward. Rosebud Creek flows northward through the quadrangle, generally about 0.8 mile (1.3 km) from its western edge. The Tongue River flows northeastward about 8 miles (12.9 km) southeast of the southeast corner of the quadrangle at its closest approach. Both Rosebud Creek and the Tongue River flow variably northward and northeastward to the Yellowstone River, which flows eastward about 64 miles (103.0 km) north of the quadrangle.

Rosebud Creek in the Kirby quadrangle is a meandering, perennial stream with a flood plain that varies in width from 0.1 to 0.4 mile (0.16 to 0.64 km). This flood plain is bordered by steep bluffs that typically rise 200 to 400 feet (61.0 to 121.9 m) over distances of 0.25 mile (0.40 km) or less.

The Kirby quadrangle is thoroughly dissected, mostly by the drainage networks of tributaries of Rosebud Creek. Most of these tributaries are intermittent streams, but some of the western tributaries are perennial streams. In the

Kirby quadrangle, the western tributaries of Rosebud Creek flow generally eastward; the eastern tributaries of the creek flow generally northward or northwestward in their upper reaches, but turn more westward in their lower reaches. The flood plains of the tributary streams are generally poorly developed. However, some of the more prominent western tributaries have well-developed flood plains near their confluence with Rosebud Creek, and Dry Creek, an eastern tributary, has a flood plain about 0.15 mile (0.24 km) wide that extends about 2.5 miles (4.0 km) eastward from the creek. The tributary streams, particularly in their lower reaches, are bordered by steep bluffs as high as those along Rosebud Creek. In their upper reaches, the tributary streams are bordered by generally more gradual but still locally steep slopes.

In the southeastern part of the Kirby quadrangle tributaries of the Tongue River flow generally southeastward. These are intermittent streams, without well-developed flood plains, in valleys with steep but generally not precipitous slopes.

The Kirby quadrangle is so thoroughly dissected that nearly all of the landscape is in moderately steep to very steep slopes. The divides between the streams are mostly rounded ridges; flat-topped divides, which are common in the Taintor Desert and Birney SW quadrangles to the east, are uncommon in the Kirby quadrangle. The largest relatively flat upland area covers about 0.4 square mile (1.0 km^2); most such areas are considerably smaller.

The lowest elevation in the Kirby quadrangle, about 3,730 feet (1,137.0 m), occurs where Rosebud Creek crosses the north edge of the quadrangle near the northwest corner. The highest elevation, about 4,790 feet (1,460.0 m), is found at the summit of an unnamed peak along the divide between Rosebud Creek and the Tongue River in the southeastern part of the quadrangle. Topographic relief in the quadrangle is about 1,060 feet (323.1 m).

Climate

The climate of Big Horn 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 Kirby quadrangle. The northern 1.4 tiers of sections are within the Northern Cheyenne Indian Reservation, which is considered non-Federal coal land. The remainder of the quadrangle is entirely within the Northern Powder River Basin Known Recoverable Coal Resource Area (KRCRA). There were no outstanding Federal coal leases or prospecting permits recorded as of 1977.

GENERAL GEOLOGY

Previous work

Baker (1929, pl. 28) mapped that part of the Kirby quadrangle south of the Northern Cheyenne Indian Reservation as part of the northward extension of the Sheridan coal field. Matson and Blumer (1973, pls. 5A, 5B, and 5C) remapped the coal beds in the same area.

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 upper part of the Tongue River Member, the uppermost member of the Fort Union Formation of Paleocene age.

The Tongue River Member is made up mainly of yellow sandstone, sandy shale, carbonaceous shale, and coal. Much coal has burned along outcrops, baking the overlying sandstone and shale and forming thick, reddish-colored clinker beds. The uppermost part of the Tongue River Member has been removed by erosion. The remaining part of the member is estimated to be as much as 1,800 feet (549 m) thick (Lewis and Roberts, 1978), but its exact thickness has not been determined.

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 Kirby quadrangle is in the western part of the Powder River structural basin. The coal beds and other strata dip regionally eastward to southeastward at an angle of about 1 degree. However, this dip is modified by minor, low-relief folds and in the southern part of the quadrangle by faults, as shown by the structure contour maps (pls. 4, 7, 11, 15, 19, 22, and 25). Some of the nonconformity in structure may be due to differential compaction and to irregularities in deposition of the coals and other beds as a result of their continental orgin.

COAL GEOLOGY

The coal beds in the Kirby 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 belong to the upper part of the Tongue River Member of the Fort Union Formation.

The lowermost recognized coal bed is the King coal bed which is projected into the subsurface of the Kirby quadrangle from the Half Moon Hill quadrangle to the south. The King coal bed is overlain successively by a noncoal interval of about 100 feet (30 m), the Brewster-Arnold coal bed, a mainly noncoal interval of about 235 feet (71.6 m) containing thin, local coal beds, the Wall coal bed, an essentially noncoal interval of 174 to 300 feet (53 to 91 m) containing at least one local coal bed, the Canyon coal bed, a mainly noncoal interval of 126 to 220 feet (38.4 to 67 m) containing a local coal bed, the Dietz 2 and 3 coal beds, which are locally separated by up to 27 feet (8.2 m) of rock, an essentially non-coal interval of about 75 to 105 feet (22.9 to 32.0 m) containing a local coal bed, the Anderson (Dietz 1) coal bed, an essentially noncoal interval of about 80 to 110 feet (24.4 to 33.5 m) containing a local coal bed, the Smith coal bed, a noncoal interval of about 80 feet (24.4 m), a local coal bed, a noncoal interval of about 50 feet (15.2 m), and another local coal bed.

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

King coal bed

The King coal bed was first described by Warren (1959, p. 571) from exposures in the Birney-Broadus coal field, probably along King Creek about 28 miles (45 km) east-northeast of the Kirby quadrangle in the Ashland and Green Creek quadrangles. The King coal bed has been projected into the subsurface of the Kirby quadrangle from the Half Moon Hill quadrangle to the south. The isopach and structure contour map of the King coal bed (pl. 25) shows a projected thickness of 5 to 10 feet (1.5 to 3 m) and a dip of about 1 degree to the south. Overburden on the King coal bed (pl. 26) ranges from about 500 to 900 feet (152 to 274 m) in thickness. Underground-minable resources of subbituminous coal have been assigned to this bed.

Brewster-Arnold coal bed

The Brewster-Arnold coal bed was named by Baker (1929, p. 37-38) from a small mine on the Brewster-Arnold ranch about 22 miles (6.7 km) east of the Kirby quadrangle in the Browns Mountain quadrangle. This bed does not crop out in the Kirby quadrangle and is not penetrated by test holes. However, it has been projected into the subsurface in the southern part of the quadrangle from the quadrangles to the south and east. The isopach and structure contour map (pl. 22) shows that the Brewster-Arnold coal bed is about 5 feet (1.5 m) in thickness and dips southeastward at an angle of about 1 degree. Overburden on the Brewster-Arnold coal where it is more than 5 feet (1.5 m) thick ranges from about 300 to 1,060 feet (91 to 323 m) in thickness. There are no known, publicly available chemical analyses of the Brewster-Arnold coal bed in the Kirby quadrangle. It is assumed that this coal is similar to other closely associated coals in the quadrangle and is subbituminous C in rank.

Wall coal bed

The Wall coal bed was named by Baker (1929, p. 37), probably from exposures along Wall Creek, a tributary of the Tongue River, about 13 miles (21 km) east of the Kirby quadrangle in the Birney quadrangle. In the Kirby quadrangle, the Wall coal bed is marked by a prominent clinker that extends along both sides of the valley of Rosebud Creek in the western part of the quadrangle. Only at one locality was this bed found unburned, and there Baker (1929, p. 47) reports that the coal is 5.5 feet (1.7 m) thick. As shown by the isopach and structure contour map (pl. 18), the Wall coal bed thickens southward and eastward from this location and is as much as 55 feet (16.8 m) thick in the southern part of the quadrangle where it has been penetrated by a number of coal test holes. The structure contour map (pl. 19) shows that the Wall coal bed in general dips southeastward at an angle of less than 1 degree, but that this dip is considerably modified by low-relief folding and by faulting. Overburden on the Wall coal bed ranges in thickness from zero at the one local outcrop to about 840 feet (256 m).

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

Canyon coal bed

The Canyon coal bed was first described by Baker (1929, p. 36) from exposures in the northern 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. This coal bed occurs 174 to 300 feet (53 to 91 m) above the Wall coal bed. The Canyon coal bed has been burned almost everywhere near the land surface. A thick clinker bed marks its position on the valley slopes of streams tributary to Rosebud Creek in the western part of the quadrangle. The isopach map of the Canyon coal bed (pl. 14) shows that this bed ranges from about 5 to about 30 feet (1.5 to 9.1 m) in thickness. Although the regional dip in this quadrangle is toward the southeast, the structure contour map (pl. 15) shows that this dip is considerably modified by faulting and low-relief folding.

Overburden on the Canyon coal bed (pl. 16) ranges from zero at the outcrops to about 750 feet (229 m) in thickness.

A chemical analysis of the Canyon coal from a depth of 104 to 113 feet (31.7 to 34.4 m) in coal test hole SH-36, sec. 16, T. 6 S., R. 39 E., in the Kirby quadrangle (Matson and Blumer, 1973, p. 34) shows ash 3.243 percent, sulfur 0.026 percent, and heating value 9,113 Btu per pound (21,197 kJ/kg) on an as-received basis. This heating value converts to about 9,418 Btu per pound (21,906 kJ/kg) on a moist, mineral-matter-free basis indicating that the Canyon coal in the Kirby quadrangle is subbituminous C in rank.

Dietz 2 and 3 coal beds

The Dietz 1, 2, and 3 coal beds were first described by Taft (1909, p. 139-140) from exposures in the Sheridan coal field, Wyoming. The coal bed which Baker (1929, pl. 28) mapped as the Anderson coal bed in the Kirby quadrangle was remapped by Matson and Blumer (1973, pl. 5B) as the Dietz coal beds (upper or combined benches). Matson and Blumer (1973, pl. 5A) mapped a higher coal bed as the Anderson coal bed. Faults, unsuspected by Baker, were revealed by coal test holes drilled to support the field mapping of Matson and Blumer. These authors (1973, p. 31) state, "Extensive field work and interpretations were required on the Kirby area because of the structural complexity. Drilling was begun during the 1969 field season, and additional holes were drilled during the 1970 field season. In midwinter 1972-73, more holes were drilled to verify some of the interpretations and to assist in final preparation of the maps." The compiled maps accompanying this report follow the interpretations of Matson and Blumer (1973, pls. 5A and 5B). We believe that the two combined Dietz benches mapped by Matson and Blumer are equivalent to the Dietz 2 and 3 coal beds of Taft, and that the Anderson coal bed is equivalent to the Dietz 1 of Taff.

In the Kirby quadrangle, the Dietz 2 and 3 coal beds occur 126 to 220 feet (38.4 to 67 m) above the Canyon coal bed. The Dietz coal beds have been extensively burned near the land surface. The isopach map of the combined Dietz 2 and 3 coal beds (pl. 10) shows that the coal ranges from 5 to 35 feet (1.5 to 10.7 m) in thickness. The structure contour map (pl. 11) shows that the regional southeastward dip of about 1 degree has been considerably modified by faulting and low-relief folding. Overburden on the combined Dietz 2 and 3 coal beds (pl. 12) ranges from zero at the outcrops to about 450 feet (137 m) in thickness.

A chemical analysis of the Dietz coal from a depth of 89 to 99 feet (27 to 30 m) in coal test hole SH-35, sec. 14, T. 6 S., R. 39 E., in the Kirby quadrangle (Matson and Blumer, 1973, p. 34) shows ash 6.684 percent, sulfur 0.000 percent, and heating value 8,383 Btu per pound (19,499 KJ/kg) on an as-received basis. This heating value converts to about 8,983 Btu per pound (20,894 kJ/kg) on a moist, mineral-matter-free basis, indicating that the Dietz coal in the Kirby quadrangle is subbituminous C in rank.

Anderson (Dietz 1) coal bed

The Anderson coal bed was first described by Baker (1929, p. 35) from exposures in the northern extension of the Sheridan coal field which includes the Kirby quadrangle. The Dietz 1 coal bed was named by Taft (1909, p. 129-140) for exposures at the abandoned No. 1 mine at the old mining town of Dietz, in the Sheridan coal field, Wyoming, about 25 miles (7.6 km) south of the Kirby quadrangle in the Acme quadrangle. The Dietz 1 coal bed is equivalent to the Anderson coal as mapped by Baker (1929, pl. 28) and Matson and Blumer (1973, pl. 5A).

The Anderson-Dietz coal bed has been extensively burned near the surface in the Kirby quadrangle, and unburned coal is believed to be present only in the eastern part of the quadrangle. The isopach and structure contour map of this coal bed (pl. 7) shows that the coal ranges from about 5 to 25 feet (1.5 to 7.6

m) in thickness and dips southeastward at an angle of 1 degree or less, although this dip has been considerably modified by faulting and low-relief folding. Overburden on the Anderson (Dietz 1) coal bed (pl. 8) ranges from zero at the outcrops to about 400 feet (122 m) in thickness where the coal is more than 5 feet (1.5 m) thick.

A chemical analysis of the Anderson (Dietz 1) coal from a depth of 108 to 117 feet (33 to 35.7 m) in coal test hole SH-38, sec. 11, T. 7 S., R. 39 E., about 0.5 miles (0.8 km) south of the Kirby quadrangle in the Half Moon Hill quadrangle shows (Matson and Blumer, 1973, p. 34) ash 3.162 percent, sulfur 0.000 percent, and heating value 8,422 Btu per pound (19,590 kJ/kg) on an as-received basis. This heating value converts to about 8,697 Btu per pound (20,229 kJ/kg) on a mineral-matter-free basis, indicating that the coal at this location is subbituminous C in rank. Because of the proximity of this location to the Kirby quadrangle, it is assumed that the Anderson (Dietz 1) coal in the Kirby quadrangle is similar and is also subbituminous C in rank.

Smith coal bed

The Smith coal bed was first described by Taft (1909, p. 130) for exposures in the Sheridan coal field in the northern part of the Sheridan quadrangle, Wyoming, about 28 miles (45.1 km) south of the Kirby quadrangle. In the Kirby quadrangle, the Smith coal bed occurs 80 to 110 feet (24.4 to 33.5 m) above the Anderson (Dietz 1) coal bed. The Smith coal and its clinker bed crop out in the western part of the quadrangle (pl. 1). The isopach and structure contour map (pl. 4) shows that the Smith coal bed ranges from 2 to 20 feet (0.6 to 6.1 m) in thickness and dips southeastward at an angle of 1 degree or less, although this dip is greatly modified by faulting and low-relief folding. Overburden on the Smith coal bed ranges in thickness from zero at the outcrops to about 300 feet (91.4 m).

There is no known, publicly available chemical analysis of the Smith coal in or close to the Kirby quadrangle. It is assumed that the Smith coal bed is similar in the Kirby quadrangle and is subbituminous C in rank.

Local coal beds

The local coal beds which occur at various stratigraphic positions in the Kirby quadrangle are of limited areal extent and are generally less than 5 feet (1.5 m) thick. 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 2,247.18 million short tons (2,038.64 million t). The total tonnage of federally owned, surface-minable Hypothetical coal is estimated to be 36.78 million short tons (33.37 million t). As shown by table 2, the total federally owned, underground-minable Reserve Base coal is estimated to be 1,225.93 million short tons (1,112.16 million t). The total federally owned, underground-minable Hypothetical coal is estimated to be

28.40 million short tons (25.76 million t). The total tonnage of surface- and underground-minable Reserve Base coal is 3,473.11 million short tons (3,150.80 million t), and the total of surface- and underground-minable Hypothetical coal is 65.18 million short tons (59.13 million t).

About 8 percent of the surface-minable Reserve Base tonnage is classed as Measured, 44 percent as Indicated, and 48 percent as Inferred. About 2 percent of the underground-minable Reserve Base tonnage is Measured, 25 percent is Indicated, and 73 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, 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 of the Federal coal lands for surface-mining is shown on the Coal Development Potential map (pl. 28). Almost all of the Federal coal lands in this quadrangle have a high development potential for surface mining. A few small tracts near Rosebud Creek in the northwestern part of the quadrangle have no development potential because the coal here has been eroded or burned. A few scattered small tracts have only a moderate development potential.

The lowermost recognized coal beds, the King and Brewster-Arnold coal beds (pls. 26 and 23), have only small areas of low development potential in the valley of Rosebud Creek. Most of the King and Brewster-Arnold coals have no development potential for surface mining as their overburden is more than 500 feet (152 m) thick, and thus the beds are beyond the arbitrarily assigned stripping limit.

The Wall coal bed (pl. 20) has a large area of high development potential in the western part of the quadrangle extending from the boundary of the unburned coal to the 10 mining-ratio contour or in many places to the 500-foot overburden isopach, the arbitrarily assigned stripping limit. There are relatively narrow bands of moderate development potential between the 10 and 15 mining-ratio contours or between the 10 mining-ratio contour and the 500-foot overburden isopach. There are some areas of low development potential on the hills between the 15 mining-ratio contour and the 500-foot overburden isopach. In the very large area in the eastern part of the quadrangle above the 500-foot overburden isopach, the Wall coal bed has been assigned no development potential for surface mining because it is beyond the stripping limit.

The Canyon coal bed (pl. 16) has a considerable area of high development potential on the hill slopes in the western part of the quadrangle extending from the boundary of the unburned coal to the 10 mining-ratio contour. There is also a fairly large area of moderate development potential between the 10 and 15 mining-ratio contours. A large area of low development potential extends from the 15 mining-ratio contour to the crests of some hills or to the 500-foot overburden isopach, the arbitrarily assigned stripping limit. A considerable area under the drainage divide in the eastern part of the quadrangle has been assigned no development potential as it is beyond the 500-foot overburden isopach.

The Dietz 2 and 3 coal beds (pl. 12) have a wide area of high development potential extending from the boundary of the unburned coal to the 10 mining-ratio contour. There is a fairly wide area of moderate potential between the 10 and 15 mining-ratio contours, and small areas of low development potential extending from the 15 mining-ratio contour to the crests of the hills.

The Anderson (Dietz 1) coal bed (pl. 8) has a moderately wide band of high development potential on the hill slopes extending from the boundary of the coal to the 10 mining-ratio contour. There is a narrow band of moderate development potential between the 10 and 15 mining-ratio contours, and wider areas of low development potential extending from the 15 mining-ratio contour to the crests of the hills.

In the eastern part of the quadrangle, the Smith coal bed (pl. 5) has narrow bands of high development potential (0 to 10 mining-ratio values) on the high hill slopes. There are narrow bands of moderate development potential (10 to 15 mining ratio values). Wider areas of low development potential (mining ratio values greater than 15) extend to the crests of the hills.

About 96 percent of the Federal coal lands have a high potential for surface mining, 2 percent have a moderate development potential, and 2 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 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 Kirby quadrangle, Big Horn 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				
Smith	47,260,000	11,270,000	13,290,000	71,820,000
Anderson (Dietz 1)	83,490,000	18,910,000	33,190,000	135,590,000
Dietz 2 and 3	473,230,000	96,360,000	23,850,000	593,440,000
Canyon	299,240,000	146,400,000	290,480,000	736,120,000
Wall	503,180,000	164,090,000	40,300,000	707,570,000
Brewster-Arnold	0	0	2,340,000	2,340,000
King	0	0	300,000	300,000
Total	1,406,400,000	437,030,000	403,750,000	2,247,180,000
Hypothetical Resource tonnage				
Anderson (Dietz 1)	730,000	0	0	730,000
Wall	22,030,000	14,020,000	0	36,050,000
Total	22,760,000	14,020,000	0	36,780,000
Grand Total	1,429,160,000	451,050,000	403,750,000	2,283,960,000

Table 2.--Underground-minable coal resource tonnage (in short tons) by development-potential category for Federal lands in the Kirby quadrangle, Big Horn 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				
Canyon	0	0	124,200,000	124,200,000
Wall	0	0	1,029,820,000	1,029,820,000
Brewster-Arnold	0	0	57,800,000	57,800,000
King	0	0	14,110,000	14,110,000
Total	0	0	1,225,930,000	1,225,930,000
Hypothetical Resource tonnage				
Wall	0	0	11,810,000	11,810,000
Brewster-Arnold	0	0	16,590,000	16,590,000
Total	0	0	28,400,000	28,400,000
Grand Total	0	0	1,254,330,000	1,254,330,000

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