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COAL RESOURCE OCCURRENCE AND COAL DEVELOPMENT POTENTIAL MAPS OF THE CARBON QUADRANGLE, CARBON COUNTY, WYOMING

(Report includes 25 plates)

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GEOLOGICAL SURVEY

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INTRODUCTION

Purpose

This text is to be used along with the accompanying Coal Resource Occurrence (CRO) maps and the Coal Development Potential (CDP) maps of the Carbon quadrangle, Carbon County, Wyoming (25 plates; U.S. Geol. Survey Open-File Report 78-044), prepared by Texas Instruments Incorporated under contract to the U.S. Geological Survey. This report was prepared to support the land planning work of the U.S. Bureau of Land Management's Energy Minerals Activities Recommendation Systems (EMARS) program, and to contribute to a systematic coal resource inventory of Federal coal lands in Known Recoverable Coal Resource Areas (KRCRA) in the western United States. The Coal Resource Occurrence maps and the Coal Development Potential maps for this quadrangle cover part of the southeastern portion of the KRCRA of the Hanna coal field.

Acknowledgment

Texas Instruments Incorporated acknowledges the cooperation of the Rocky Mountain Energy Company, a wholly owned subsidiary of the Union Pacific Railroad Company, in supplying copies of survey sheets, drillers reports, electric logs, and coal analyses from the Union Pacific coal inventory program.

The Hanna and Carbon coal basins were studied as part of the Union Pacific coal inventory program and test drilling was conducted in 1970-1971. More than 650 Union Pacific coal drill holes have been evaluated as part of this contract study of 21 quadrangles in Carbon County, Wyoming, and the results and 230 coal analyses have been incorporated into these reports.

Location

The Carbon 7½-minute quadrangle is in the northeastern part of Carbon County, Wyoming. The center of the quadrangle is approximately 8 miles (13 km) southeast of Hanna and 13 miles (21 km) southwest of Medicine Bow, Wyoming (Figure 1).

Accessibility

U.S. Highway 30/287 crosses the extreme northwestern corner of Carbon quadrangle. State highway 72 from the town of Hanna to the northwest enters the quadrangle at the west-central edge and runs southwest to the southern boundary where it continues on to the town of Elk Mountain to the southeast. The State highway crosses U.S. Highway 30/287 one mile south of Hanna and crosses Interstate Highway 80 two miles south of the quadrangle boundary.

A light-duty road from the town of Medicine Bow enters the quadrangle in the northeast corner, passes the ruins of the old town of Carbon, and continues south along the east flank of Simpson Ridge (also called Saddleback Hills). This latter road joins State Highway 72 a short distance south of the quadrangle boundary. Numerous unimproved dirt roads branch off from the principle roads and provide general access to the remainder of the quadrangle.

The main east-west track of the Union Pacific Railroad is 6 miles (10 km) north of the center of the quadrangle.

Physiography

The quadrangle includes part of the southeastern portion of the Hanna structural basin, the northwestern side of the Carbon structural basin, and the intervening Saddleback Hills anticline.

Much of the quadrangle consists of undulating topography typical of high plains grasslands. The most prominent feature in the quadrangle is Simpson Ridge, the topographic expression of the Saddleback Hills anticline, which has a relief of about 600 feet (183 m). Several other less prominent low linear topographic features parallel Simpson Ridge on its west flank. Halleck Ridge, in the southwest corner of the quadrangle, with a relief of about 400 feet (122 m) is a portion of a prominent sandstone ridge to the south of the quadrangle.

The quadrangle is drained by intermittent streams which flow east and west off the topographic high of Simpson Ridge. There are a number of lakes in the south and southwest and several springs along Simpson Ridge.

Climate

Climate data for the Carbon quadrangle were obtained from the Elk Mountain weather station located 9 miles (14 km) south of the center of the quadrangle at an elevation of 7,270 feet (2,216 m). Precipitation records are available for 65 years to 1970 and temperature records are available for 22 years to 1970.

The climate is semiarid with a mean annual temperature of 41°F (5°C) and extremes ranging from 95° to -42°F (35° to -41°C). July is the warmest month with a mean monthly temperature of 63°F (17°C) and January is the coldest month with 22°F (-6°C). For seven months of the year, April to October, the mean monthly temperature exceeds 32°F (0°C). Average annual precipitation is 15 inches (38 cm) with 50 percent of this total falling in the five months from March to July. Part of the precipitation in March, April, and May is in the form of snow. Average annual snowfall is 108 inches 274 (cm) with 64 percent falling in the four months of January to April. Snow rarely falls in July and August but an inch or more of snow may fall in any other month. March is the month of maximum snowfall (18 inches or 46 cm).

High winds are common throughout most of the year. The prevailing wind direction, as recorded at four weather stations around the perimeter of the Hanna and Carbon Basins, is westerly for all twelve months of the year. The growing season is restricted to less than 100 days between late May and early September which are the average times of the last killing spring frost and the first killing fall frost, respectively.

Land Status

The quadrangle is in the southeastern part of the Hanna and Carbon Basins Known Recoverable Coal Resource Area. The Federal Government owns approximately 35 percent of the coal rights in the quadrangle; the remaining 65 percent is non-federally owned. Approximately 35 percent of the area of the quadrangle is included in the KRCRA, and within this region about 40 percent of the land is federally owned. Plate 2 of the CRO maps illustrates the ownership status of land in the quadrangle and the boundary of the KRCRA.

One abandoned strip mine and seven abandoned underground mines are shown on Plate 1. The abandoned strip mine is Elk Mountain Strip 1 (Secs. 28, 29, 32, and 33, T. 21 N., R. 80 W.) operated by Elk Mountain Coal Co., J.A. Terteling and Sons. The abandoned underground mines are: Carbon No. 1 (sec. 26, T. 22 N., R. 80 W.), Carbon No. 2 (secs. 26, and 35, T. 22 N., R. 80 W.), Carbon No. 3 (sec. 26, T. 22 N., R. 80 W.), Carbon No. 5 (sec. 14, T. 22 N., R. 80 W.), and Carbon No. 6 (secs. 26 and 27, T. 22 N., R. 80 W.) operated for the Union Pacific Railway Company. The Gary Mine operated by Elk Mountain Valley Coal Company and an unnamed mine with an unknown operator in sec. 32, T. 21 N., R. 80 W. are the two additional abandoned underground mines.

GENERAL GEOLOGY

Previous Work

Dobbin, Bowen, and Hoots (1929) mapped the Carbon quadrangle as part of their study of the geology and coal and oil resources of the Hanna and Carbon Basins. Weitz and Love (1952) compiled a geologic map of Carbon County which incorporates available data, published and unpublished, to that date. Gill, Merewether, and Cobban (1970) provide a detailed description and discussion of the more important sedimentary rock formations of the area.

Stratigraphy

Rocks exposed in the Carbon quadrangle range in age from Late Cretaceous to Quaternary. The oldest formation exposed is the Mesaverde Formation of Dobbin, Bowen, and Hoots (1929) which crops out in the southwest corner in the Elk Mountain anticline (or Bloody Lake anticline) and in the south-central part of the quadrangle in the Saddleback Hills anticline (or Simpson Ridge anticline). Recent studies in south-central Wyoming by Gill, Merewether, and Cobban (1970) resulted in upgrading the unit to group status and in defining and measuring four separate formations within the group. Surface mapping delineating the formations has not been extended into the Carbon quadrangle, however, and the group is treated as a single unit. Dobbin, Bowen, and Hoots (1929) described the Mesaverde Formation from a stratigraphic section located just north of Ft. Steele, Wyoming, and give a total thickness of 2,279 feet (695 m) for the unit. In this quadrangle, it has a measured thickness of 1,950 feet (594 m) exposed in the Saddleback Hills (Simpson Ridge) anticline (Veronda, 1951).

The Mesaverde Formation contains a lower unit of indurated white to gray massive to thin-bedded and cross-bedded sandstones alternating with thinner beds of gray shales. This lower unit is of marine origin. A middle member of the formation consists of gray to brown thin-bedded to massive sandstones alternating with beds of gray carbonaceous shales and thin irregular beds of coal. The depositional environment for this unit was fresh to brackish water. The top member of the formation consists of white to gray sandstones alternating with beds of gray shales and thin beds of carbonaceous shale and coal. This unit is primarily non-marine but grades into shallow marine at the very top.

The Upper Cretaceous Lewis Shale conformably overlies the Mesaverde on the limbs of the Saddleback Hills anticline and the Elk Mountain anticline. In the eastern part of the quadrangle it is in unconformable contact with the overlying Hanna Formation. Thickness of the unit in this quadrangle is approximately 3,000 feet (914 m) and consists of medium to dark-gray silty shale, gray, sandy siltstone and light-gray to dusty yellow, fine-grained, silty sandstone. The formation is of marine origin.

The Upper Cretaceous Medicine Bow Formation conformably overlies the Lewis Shale on the limbs of the Saddleback Hills anticline in the west and north parts of the quadrangle. On the eastern limb the formation is not exposed where it is onlapped by the Tertiary Hanna Formation. The formation has a thickness of approximately 4,000 feet (1,219 m) in this quadrangle.

Medicine Bow sediments consist of yellow, gray and carbonaceous shale, beds of coal, and gray and brown sandstone. The lower part of the formation is made up of massive to cross-bedded brown sandstones, which usually form a conspicuous group of ledges, and contain numerous beds of coal. These sandstones are overlain by an intermediate group of dark-colored shales and thin-bedded fine-grained brown sandstones, with some beds of massive white sandstone. The sandstones at the top of the formation are coarse-grained, massive, friable, and easily eroded, and are interbedded with thick beds of dark gray shale.

In the northwestern part of the quadrangle, on the west limb of the Saddleback Hills anticline, the Ferris Formation conformably overlies the Medicine Bow Formation with a measured thickness of 2,600 feet (792 m). In the eastern part of the quadrangle the formation, like the Medicine Bow Formation, is not exposed where it is onlapped by the Hanna.

The formation consists of a thick sequence of continental rocks that can be divided into two parts: a lower unit of Late Cretaceous age and an upper unit of Paleocene age. The basal section of the lower unit consists of dark gray shales and buff to yellow coarse-grained friable massive sandstones with irregular thin beds of conglomerate. The upper part of the lower unit is made up largely of conglomerate which occurs as pockets, lenses, and thin beds irregularly distributed throughout the sandstone. The upper unit of the Ferris Formation consists of gray brown and yellow sandstones normally interbedded with numerous thick beds of coal. In this quadrangle, no coal beds in the Ferris have been mapped.

Overlying the Ferris Formation is the Paleocene Hanna Formation that occupies the central portions of the Hanna and Carbon Basins and contains many of the thick coal beds of the region. The Hanna Formation is normally not only unconformable on the underlying Ferris Formation but also transgresses across all underlying formations. In this quadrangle, in the western part, the Hanna overlies the Ferris Formation. In the eastern part, on the east flank of the Saddleback Hills anticline, the Hanna overlaps onto both the Medicine Bow Formation and the Lewis Shale. Dobbin, Bowen, and Hoots (1929) report an approximate thickness of 7,000 feet (2,134 m) for the Hanna Formation. The Hanna consists of conglomerate, conglomeratic sandstone, sandstone, shale, and many thick beds of coal. The conglomerate occurs throughout the formation but is most abundant in the lower half. Thick conglomeratic sandstone and, locally, massive conglomerate mark the base of the formation. The sandstones of the formation range from coarse-grained massive or thick-bedded varieties to fine-grained thin-bedded sandstones which weather brown and split into thin slabs. The coarse-grained varieties are buff to grayish-white, commonly conglomeratic, and highly feldspathic. The conglomerates of the Hanna Formation differ from those of the Ferris in color and in the size and composition of the clasts.

Quaternary alluvium occurs in the valleys of the major drainage channels.

Structure

The Carbon quadrangle contains parts of both the Hanna and Carbon Basins. The Saddleback Hills anticline, trending north-south and located in the central part of the quadrangle, separates the two basins.

The Hanna Basin is comparatively small in areal extent but it is one of the deeper structural basins in the Rocky Mountain region. The basin extends about 40 miles (64 km) east-west, 25 miles (40 km) north-south, and in its deepest part in the southeastern part of T. 24 N., R. 82 W. contains approximately 30,000-35,000 feet (9,140-10,670 m) of sediments overlying crystalline basement, (Glass, 1972).

The Carbon Basin extends approximately 10 miles (16 km) in an east-west direction, fifteen miles (24 km) in a north-south direction, and in its deepest part in the east-central part of T. 21 N., R. 80 W., it contains approximately 15,000 feet (4,572 m) of sediments (Knight, 1951). In this quadrangle, it is bounded on the west by the Saddleback Hills anticline.

The principal deformation defining the present structural basins occurred during the Laramide Orogeny. The bordering highlands were raised and deformed, and the sediments accumulated rapidly in the basins; consequently, the present basins have complexly folded and faulted borders, with mild deformation within the basins expressed by a few broad folds and normal faults.

Principal structural features in the quadrangle are the Elk Mountain anticline (or Bloody Lake anticline) located in the extreme southwest corner, and the Saddleback Hills anticline (or Simpson Ridge anticline), located in the central part of the quadrangle. Dip angles in areas strongly affected by the folds are in the range of 25^{o}-60^{o}. Toward the center of the Carbon Basin, dip angles decrease to approximately 2^{o}.

Other structural features in the quadrangle are a series of normal faults located in the western part of the quadrangle. These faults have offset the Lewis Shale-Medicine Bow, Medicine Bow-Ferris, and Ferris-Hanna contacts with a maximum horizontal displacement of 1,500 feet (457 m).

COAL GEOLOGY

Previous Work

The coal deposits of the Hanna and Carbon Basins have been studied by Veatch (1907), Dobbin, Bowen, and Hoots (1929), Berryhill and others (1950), and Glass (1972 and 1975).

Twenty-six coal analyses have been published since 1913 for coal beds of the Mesaverde Group and the Medicine Bow, Ferris, and Hanna Formations within the Hanna and Carbon Basins (Appendices 1 and 2). Samples collected and analyzed prior to 1913 have not been considered in this report (American Society for Testing and Materials, 1977, p. 218). An average analysis of coal beds in each of these four stratigraphic units has also been calculated from the 230 analyses included in the Union Pacific coal inventory program (Appendices 1 and 2).

Glass (1975) published not only proximate analyses for 12 samples collected in the Hanna Basin, but also assays for 10 major and minor oxides, 12 major and minor elements, and 32 trace elements. He stresses (Glass, 1975, p. 1) that these data are insufficient to characterize the chemical and physical properties of any individual coal bed, but this will be possible at a later date as the study continues. Assay results of the 12 Hanna Basin samples show that these coals contain no significantly greater amounts of trace elements of environmental concern than are found in the 42 samples collected in six other Wyoming coal fields.

Fifteen samples of Hanna Basin coals, collected by the U.S. Geological Survey as part of the EMRIA (Energy Mineral Rehabilitation Inventory and Analysis) study in the Hanna Basin (U.S. Dept. of Interior, 1975, p. 48-59), were also assayed for 10 major and minor oxides, 12 major and minor elements, and 32 trace elements. Proximate analyses of five of the coal samples are included in Appendices 1 and 2.

General Features

In this quadrangle, 24 coal beds and 40 local coal lenses have either been mapped by Dobbin, Bowen, and Hoots (1929) or identified in the subsurface from drill hole data (Plates 1 and 3). Five coal beds and two local coal lenses occur in the Mesaverde Formation, 7 coal beds and 3 local coal lenses occur in the Medicine Bow Formation and 12 coal beds and 35 local coal lenses occur in the Hanna Formation.

Plates 1 and 3 were reviewed by U.S. Geological survey and four coal beds were selected for the production of derivative maps. The selected coal beds include coal bed 96 in the Medicine Bow Formation and the following Hanna Formation coal beds: the Johnson coal bed (probably equivalent to Carbon 5), the Finch coal bed (probably equivalent to Carbon 4) and coal bed Carbon 6 (probably equivalent to coal bed 108).

Analyses of eight samples taken in the Carbon quadrangle are shown in Appendix 3; the samples were collected during the Union Pacific coal inventory program.

Mesaverde Coal Beds

Mesaverde coal beds crop out on the Saddleback Hills anticline and are encountered in three drill holes. Measured thicknesses of the coal beds range from 1 to 10.2 feet (0.3 to 3.1 m) with the majority being less than 5 feet (1.5 m) and an approximate average of 3 feet (0.9 m). The coal beds dip steeply off the anticline with a range of 25° to 60°.

Medicine Bow Coal Beds

Coal beds in the Medicine Bow Formation crop out on the west and northeast flanks of the Saddleback Hills anticline. Six coal beds in the Medicine Bow have measured thicknesses of less than 5 feet (1.5 m) with the exception of coal bed 95-A which has one measurement of 5.3 feet (1.6 m).

Coal bed 96 which was selected for evaluation has measured thicknesses ranging from 2.1 to 11 feet (0.6 to 3.3 m) with an average thickness of 5 feet (1.5 m). On the west flank of Saddleback Hills anticline coal bed 96 is dipping west at angles from 45° to 70° and on the northeast flank it is dipping east at 39°.

One analysis of coal bed 96 and analyses for two Medicine Bow local coal lenses encountered in drill hole 17 are shown in Appendix 3.

Hanna Coal Beds

In the Hanna Formation 12 coal beds and 35 local coal lenses have been mapped or identified in the subsurface. Of these coal beds three were selected for evaluation.

The Johnson coal bed (probably equivalent to Carbon 5 coal bed) occurs near the base of the Hanna Formation. The coal bed crops out in the southeast corner of the quadrangle where it dips east and northeast at approximately 4°. Measured thicknesses on the bed range from 8.6 to 32 feet (2.6 to 9.7 m). The Johnson coal bed was mined in the Elk Mountain strip mine in sec. 32, T. 21 N., R. 80 W.

The Finch coal bed (probably equivalent to the Carbon 4 coal bed) occurs 200 feet (61 m) stratigraphically above the Johnson coal bed. The Finch coal bed crops out in the southeast part of the quadrangle and dips to the east and northeast at angles ranging from 4° to 16°. Measured thicknesses of the bed range from 1.1 to 33 feet (.3 to 10 m). The Finch coal bed has been mined in the Elk Mountain strip mine and in the Gary underground mine in sec. 32, T. 21 N., R. 80 W. Three analyses of the Finch coal bed are given in Appendix 3.

The Carbon 6 coal bed (probably equivalent to coal bed 108) is 450 feet (137 m) stratigraphically above the Finch coal bed. The Carbon 6 coal bed crops out along the eastern side of the quadrangle and dips to the east and northeast at angles ranging from 6° to 18°. Measured thicknesses on the coal bed range from 1.2 to 9.8 feet (.4 to 3 m). The Carbon 6 coal bed was mined in Carbon No.s 1, 2, 3, and 6 mines in secs. 26, 27, and 35, T. 22 N., R. 80 W. Analyses for coal bed Carbon 6 and 108 are shown in Appendix 3.

COAL RESOURCES AND RESERVES

Previous Work

Coal reserves of the Hanna and Carbon Basins have been estimated or calculated by Dobbin, Bowen, and Hoots (1929), Berryhill and others (1950), and Glass (1972).

Method of Calculating Resources and Reserves

Data from Dobbin, Bowen, and Hoots (1929), oil and gas well logs, and coal drill holes (written communication, Rocky Mountain Energy Company, 1977 and U.S. Geological Survey, 1978), were used to construct a coal data map (Plate 1) and a coal data sheet (Plate 3). U.S. Geological Survey reviewed these two plates and on the basis of Reserve Base criteria, selected four coal beds for the calculation of coal resources in the Carbon quadrangle. In addition, calculation of coal resources was requested for isolated or noncorrelatable data points.

The coal data map and coal data sheet were used to construct structure contour, coal isopach, and overburden isopach maps of the correlatable coal beds (Plates 4-6, 9-11, 14-16, 19-21). For single coal beds, the maps were drawn using, as control points, thicknesses measured at outcrop and subsurface data from drill hole information. Where coal beds are split, cumulative coal thicknesses were used, excluding non-coal partings.

Plates 4-6, 9-11, 14-16, 19-21 provide the data for calculating the coal resources and reserves within the KRCRA boundary of the quadrangle in accordance with the classification system given in U.S. Geological Survey Bulletin 1450-B and the instructions provided by U.S. Geological Survey on approval of these 12 plates. Calculation of the resources and reserves is in accordance with the following criteria:

- Identified coal resources of the quadrangle, as selected by U.S. Geological Survey, are contained within coal beds 96, Johnson, Finch, and Carbon 6, and the resources defined by isolated or noncorrelatable data points.

- Coal bed thicknesses from surface mapping are true thicknesses; thicknesses from subsurface data are apparent thicknesses. Apparent thickness is corrected to true thickness if the dip of the selected coal bed exceeds 25°.

- Strippable coal resources (the resources capable of being extracted by strip-mining methods) are comprised of single coal beds at least 5 feet (1.5 m) thick and having 200 feet (61 m) or less of overburden.

- Nonstrippable coal resources (subsurface resources capable of being mined by underground methods) are single or multiple coal beds with a minimum thickness of 5 feet (1.5 m); a maximum dip of 15°; an overburden, or combined overburden and interburden, thickness of 0 to 3,000 feet (914 m). To avoid duplicating strippable coal Reserve Base and reserve values, no nonstrippable coal Reserve Base values are calculated where a coal bed(s) occurs above the stripping limit. When calculating nonstrippable coal Reserve Base values, an average thickness for each coal bed is determined from the coal bed thicknesses at control points within a measured area. When calculating nonstrippable coal reserve values, the average thickness for each coal bed is determined in a like manner after coal bed thicknesses greater than 12 feet (3.7 m) have been reduced to 12 feet (3.7 m).

- All coal deeper than 3,000 feet (914 m) is excluded.

- Reliability or geologic assurance categories (measured, indicated, and inferred resources) are defined according to proximity of the coal to a data point. Measured resources occur within 0.25 mile (402 m) of a data point; indicated resources occur within an area that is 0.25 to 0.75 mile (402 m to 1.2 km) from a data point; inferred resources occur within an area that is 0.75 to 3 miles (1.2 to 4.8 km) from a data point. A data point is either a measured coal thickness in a drill hole or a measured coal thickness location on a mapped outcrop.

- Coal resources from isolated or noncorrelatable data points are calculated for a single coal bed at least 5 feet (1.5 m) thick or for an aggregate thickness of multiple coal beds each at least 5 feet (1.5 m) thick. The single coal bed, or the stratigraphically highest bed in an aggregate of coal beds, is locally projected up dip to the surface to establish an inferred outcrop. Strippable coal resources for the projected bed or beds are considered to occur from surface to a depth of 200 feet (61 m); nonstrippable coal resources are considered to occur from surface to a depth of 3,000 feet (914 m). Only the coal resources underlying an area within 0.5 miles (804 m) of a drill hole or a measured surface outcrop are considered, and they are assigned to the inferred category of reliability.

- Coal resources are calculated for unleased Federal land within the KRCRA boundary (Plate 2). Information pertaining to leased or fee acreage and to private land is considered proprietary and not for publication.

In preparing a map for evaluating the areal distribution of identified resources for the isolated or noncorrelatable coal beds, some data require a unique solution. For example:

- Where short segments of coal bed outcrop have data points that indicate a coal thickness of 5 feet (1.5 m) or more, an arc with a radius equal to half the outcrop length is drawn down dip from the outcrop, connecting to the ends of the outcrop. The resulting contained area defines the total coal resource, segmented into strippable and nonstrippable resource sections.

- Where a coal bed outcrop has data points with coal thicknesses less than 5 feet (1.5 m), a 5-foot (1.5 m) cut-off point is interpolated and the resulting segments with values greater than 5 feet (1.5 m) are used to generate arcs (radii equal to half the outcrop length) for defining the extent of the coal resources. When several data points occur on the outcrop of a resource area, an average of their coal thickness values is used to calculate a tonnage of coal.

- Where areas within outcrop segment arcs and areas within 0.5 mile (804 m) of a drill hole coincide, the areas are combined and drill hole coal thickness values are averaged with outcrop coal thickness values.

- When evaluating multiple coal beds of an isolated or noncorrelatable data point, the interburden between subsurface coal beds may be too great to allow the aggregate thickness of coal to be considered as one planar unit. In such instances, a conservative judgment is made and the resources for each coal bed are calculated separately and then totaled.

Results

The areal distribution of leasable Federal coal resources within the KRCRA boundary is shown on Plates 7, 12, 17, and 22 for the four selected coal beds.

The coal resource acreage within each area of unleased Federal land was determined by planimeter. Coal Reserve Base values are obtained by multiplying the coal resource acreage for the planimetric portion of each area of unleased Federal land by the average isopach value of the selected coal bed, times the conversion factor for subbituminous coal, 1,770 short tons (1,606 t) of coal per acre-foot. The coal Reserve Base tonnages are recorded as follows:

- from coal beds 96, Johnson, Finch, and Carbon 6: 80.68 million short tons (73.19 million t) assigned to measured, indicated, or inferred categories; shown on Plates 7, 12, 17, and 22; included in the coal Reserve Base totals shown on Plate 2.

- from isolated or noncorrelatable data points: 3.18 million short tons (2.88 million t) of strippable resources and 15.30 million short tons (13.88 million t) of nonstrippable resources, assigned to the inferred resource category, and included in the coal Reserve Base totals shown on Plate 2.

In summary, the total Reserve Base for all coal beds thicker than 5 feet (1.5 m), that lie less than 3,000 feet (914 m) below the ground surface of unleased Federal land within the KRCRA in the Carbon quadrangle, is 99.16 million short tons (89.96 million t).

Coal reserves for the quadrangle are calculated by applying recovery factors to the measured, indicated, and inferred resources of coal beds 96, Johnson, Finch and Carbon 6.

The inferred resources determined from the isolated or noncorrelatable data points are excluded from coal reserve calculations. For strippable resources, a recovery factor of 0.85 is used, for nonstrippable resources, the recovery factor is 0.50. Reserve tonnages, to the nearest ten thousand short tons, are shown on Plates 7, 12, 17, and 22. Total coal reserves for unleased Federal land within the KRCRA in the Carbon quadrangle, are 28.42 million short tons (25.78 million t), consisting of 10.34 million short tons (9.38 million t) recoverable by strip mining or by underground mining, and 18.08 million short tons (16.40 million t) recoverable by underground mining only.

COAL DEVELOPMENT POTENTIAL

Method of Calculating Development Potential

Following the calculation of Reserve Base values and coal reserves, the coal resources of the KRCRA of the Carbon quadrangle, except those coal resources determined from isolated or noncorrelatable data points, are evaluated for their development potential in each of two mining-method categories, surface and subsurface.

Strippable and nonstrippable resources are assigned to one of four development potential categories (high, moderate, low, and unknown) according to the following criteria:

Strippable Resources

- Assignment is based on calculated mining-ratio values for subsurface data points (wells and drill holes) and for points of intersection of coal isopach (Plates 5, 10, 15, and 20) and overburden isopachs (Plates 6, 11, 16, and 21).

- The formula used to calculate mining ratios was provided by U.S. Geological Survey as follows:

$$MR = \frac{t_o\ (0.911)}{t_c\ (rf)}$$

where

MR = mining ratio

t_o = thickness of overburden, in feet

t_c = thickness of coal, in feet

rf = recovery factor (0.85 for strip mining)

0.911 = constant

- If mining ratio is 0-10, resources have high development potential.

  If mining ratio is 10-15, resources have moderage development potential.

  If mining ratio is greater than 15, resources have low development potential.

- If insufficient data prevent the construction of mining ratio contours, the resources are assigned to unknown development potential category, provided that there is reasonable assurance the coal bed is present in that area.

Nonstrippable Resources

- Coal beds must be more than 5 feet (1.5 m) thick. Coal beds less than 5 feet (1.5 m) thick are excluded from the Reserve Base coal resources; where coal beds are more than 12 feet (3.7m) thick, thickness values are reduced to 12 feet (3.7m).

- If the overburden is between 0 and 1,000 feet (0 and 305 m), resources have high development potential; if the overburden is between 1,000 and 2,000 feet (305 and 610 m), resources have moderate development potential; if the overburden is between 2,000 and 3,000 feet (610 and 914 m), resources have low development potential.

- If insufficient data prevents the construction of coal isopachs or overburden isopachs, or if the correlatable coal bed in the area is located completely above the stripping limit, the resources are assigned to the unknown development potential category, provided that there is reasonable assurance the correlatable coal bed is present in the area.

By applying the above criteria, mining-ratio maps (Plates 8, 13, 18, and 23) were prepared for coal beds 96, Johnson, Finch and Carbon 6.

Development potential acreages were then blocked out, as shown on CDP Plates 24 and 25. Acreage for strippable and nonstrippable resources of selected coal beds is shown in Table 1 for each of the four development

Table 1. — Development potential for identified resources of the selected coal beds within the KRCRA of the Carbon quadrangle

Coal bed	Development potential (acres)							
	Strippable resources			Nonstrippable resources			Unknown category	
	High	Moderate	Low	High	Moderate	Low	Strippable	Nonstrippable
96	40	40	40	0	0	0	0	0
JB	360	40	0	1,760	0	0	0	280
FB	640	0	0	1,240	0	0	360	1,160
C6	200	0	520	360	0	0	40	840
Totals	1,240	80	560	3,360	0	0	400	2,280

To convert acres to hectares, multiply by 0.4046.

potential categories. In accordance with a constraint imposed by the U.S. Bureau of Land Management, the highest development potential affecting any portion of a 40-acre (16 ha) parcel is applied to the entire parcel. For example, if 5 acres (2 ha) within a parcel are assigned a high development potential, 25 acres (10 ha) a moderate development potential, and 10 acres (4 ha) a low development potential, then the entire 40 acres (16 ha) are assigned a high development potential.

Additionally, at the direction of the U.S. Geological Survey, an unknown development potential is assigned to coal resources calculated for any coal bed that, although not selected for coal resource evaluation, is either wholly, or partly, of Reserve Base thickness, or of unknown thickness.

Development Potential for Strippable Resources

Development potential for strippable coal resources within unleased Federal land in the KRCRA of this quadrangle, is shown in Table 1 for each selected coal bed. Plate 24 and Table 2 show the highest surface development potentials for the selected coal beds. The totals are obtained after assigning the highest assessed development potential for any coal bed within the smallest legal subdivision to each subdivision.

There are approximately 5,080 acres (2,055 ha) of unleased Federal land within the KRCRA of this quadrangle. Of this area, 1,600 acres (647 ha) or 31.5 percent of the total, are estimated to be underlain by coal resources, from the selected coal beds, with development potential for surface mining. Of the 1,600 acres (647 ha), a high development potential is assigned to 880 acres (356 ha), a moderate development potential is assigned to 40 acres (16 ha), a low development potential to 520 acres (210 ha), and an unknown development potential to 160 acres (65 ha).

Of the 5080 acres (2,055 ha) of unleased Federal land, there are 1560 acres (631 ha) or 31 percent of the total, which are classifiable as of unknown surface mining potential on the basis of both (a) the presence of outcrops of non-correlatable coal beds of unknown thickness and (b) data gaps on beds selected for coal resource evaluation.

Table 2. — Highest development potential for identified resources of the selected coal beds within the KRCRA of the Carbon quadrangle

Development potential (acres)							
Strippable resources			Nonstrippable resources			Unknown category	
High	Moderate	Low	High	Moderate	Low	Strippable	Nonstrippable
880	40	520	1,980	0	0	160	480

To convert acres to hectares, multiply by 0.4046.

Development Potential for Nonstrippable Resources

Development potential for nonstrippable coal resources within unleased Federal land in the KRCRA of this quadrangle, is shown in Table 1 for each selected coal bed. Plate 25 and Table 2 show the highest subsurface development potentials for the selected coal beds. The totals are obtained after assigning the highest assessed development potential for any coal bed within the smallest legal subdivision to each subdivision.

Of the 5,080 acres (2,055 ha) of unleased Federal land within the KRCRA of this quadrangle, 1,920 acres (777 ha) or 37.8 percent of the total, are estimated to be underlain by coal resources from the selected coal beds, with development potential for underground mining. Of the 1,920 acres (777 ha), a high development potential is assigned to 1,440 acres (583 ha), and an unknown development potential to 480 acres (194 ha).

Of the 5,080 acres (2,055 ha) of unleased Federal land, there are 620 acres (251 ha) or 12 percent of the total, which are classifiable as of unknown subsurface mining potential on the basis of both (a) the presence of outcrops of non-correlatable coal beds of unknown thickness and (b) data gaps on beds selected for coal resource evaluation.

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Appendix 1. — Average analyses of coal samples from the Hanna and Carbon Basins

Source of Data	Number of samples (1)	Total footage		Average analyses — as received basis						Calorific Value, Btu/lb	Apparent rank of coal (3)
				Percent							
		Ft	in	Moisture	Ash	Volatile matter	Fixed carbon	Sulfur	Btu/lb	Moist, mineral-matter-free basis (2)	
Published analyses	26	318	6	12.5	7.1	36.2	44.2	0.6	10,553	11,438	sub A or hvCb
Union Pacific coal inventory program	230	1,605	10	12.48	8.74	35.12	43.68	0.82	10,398	11,494	sub A or hvCb

Notes:

(1) Published data from USBM (1931, p. 40-45, sample nos. 2623, 2624, 22800, 22972, 93486, 93488, 93541, A14123, A14124); Glass (1975, p. 16-19, sample nos. 74-23 to 74-34, inclusive); Dept. of Interior (1975, p. 38, sample nos. D169597-99, D169607-08). Union Pacific coal inventory program data from company files, Rocky Mountain Energy Company (1977).

(2) Moist, mineral-matter-free Btu/lb calculated from average analyses, as received basis, using Parr formula (ASTM, 1977, p. 216, sec. 8.2).

(3) Sub A — subbituminous A; hvCb — high volatile C bituminous (ASTM, 1977, p. 215, sec 4.2, and p. 217).

[To convert feet and inches to meters, multiply feet by 0.3048 and inches by 0.0254. To convert Btu/lb to kilojoule/kilogram, multiply by 2.326].

Appendix 2. — Average analyses of coal grouped by coal-bearing formations in the Hanna and Carbon Basins

Source of data	Formation or Group	Number of samples (1)	Total footage Ft	Total footage in	Average analyses — as received basis: Percent: Moisture	Ash	Volatile matter	Fixed carbon	Sulfur	Btu/lb	Calorific Value, Btu/lb: Moist, mineral-matter-free basis (2)	Apparent rank of coal (3)
Published analyses	Mesaverde	1	4	0	14.1	7.8	36.5	41.6	1.1	10,290	11,251	sub A or hvCb
	Medicine Bow	2	10	1	12.8	3.8	33.3	50.2	0.8	11,050	11,534	hvCb
	Ferris	10	93	1	.13.0	8.3	34.3	44.3	0.4	9,970	10,956	sub A or hvCb
	Hanna	13	211	4	12.0	6.6	38.1	43.3	0.7	11,946	11,797	hvCb
Union Pacific coal inventory program	Mesaverde	13	70	5	9.45	8.41	35.42	46.72	0.77	11,112	12,237	hvCb
	Medicine Bow	16	93	4	13.09	4.03	35.46	47.42	0.80	10,927	11,446	sub A or hvCb
	Ferris	114	863	1	12.69	7.96	34.39	44.97	0.44	10,331	11,309	sub A or hvCb
	Hanna	87	579	0	12.51	10.67	35.96	40.85	1.33	10,280	11,640	hvCb

Notes:

(1) Published data from USBM (1931, p. 40-45, sample nos. 2623, 2624, 22800, 22972, 93486, 93488, 93541, A14123, A14124); Glass (1975, p. 16-19, sample nos. 74-23 to 74-34, inclusive); Dept. of Interior (1975, p. 38, sample nos. D169597-99, D169607-08). Union Pacific coal inventory program data from company files, Rocky Mountain Energy Company (1977).

(2) Moist, mineral-matter-free Btu/lb calculated from average analyses, as received basis, using Parr formula (ASTM, 1977, p. 216, sec. 8.2).

(3) Sub A — subbituminous A; hvCb — high volatile C bituminous (ASTM, 1977, p. 215, sec. 4.2, and p. 217).

[To convert feet and inches to meters, multiply feet by 0.3048 and inches by 0.0254. To convert Btu/lb to kilojoule/kilogram, multiply by 2.326].

Appendix 3. — Coal analyses, Carbon quadrangle

Drill hole	Location			Coal bed	Sample interval				Sample width		Analyses — as received basis					
					From		To				Percent					
	Sec.	Twp.	Rge.		Ft	in	Ft	in	Ft	in	Moisture	Ash	Volatile matter	Fixed carbon	Sulfur	Btu/lb
16	31	22	80	96	170	4	179	10	9	6	13.45	2.06	37.93	46.56	0.40	11,374
17	29	22	80	L	55	0	60	6	5	6	13.35	3.43	36.96	46.26	0.56	11,313
17	29	22	80	L	73	0	77	1	4	1	15.10	2.37	39.49	43.04	0.64	11,113
1	27	22	80	C6	77	3	82	3	5	0	8.60	12.92	39.21	39.27	2.44	10,850
6	11	21	80	108	111	3	114	11	3	8	7.37	12.21	38.14	42.28	2.15	11,060
13	10	21	80	FB	121	10	125	2	3	4	5.35	14.52	41.22	38.91	0.65	11,137
14	15	21	80	FB	195	6	204	4	8	10	6.74	8.70	40.65	43.91	1.04	11,743
14	15	21	80	FB	207	0	211	3	4	3	7.73	7.80	37.76	46.71	0.65	11,622

Data from Rocky Mountain Energy Company (1977).

[To convert feet and inches to meters (m), multiply feet by 0.3048 and inches by 0.0254.
To convert Btu/lb to kilojoules/kilogram (kJ/kg), multiply by 2.326].

Appendix 4. — Coal Reserve Base Data for Federal coal lands (in short tons) in the Carbon quadrangle, Carbon County, Wyoming.

Strippable coal Reserve Base data for Federal coal lands (in short tons) in the Carbon quadrangle, Carbon County, Wyoming [Development potentials are based on mining ratios (cubic yards of overburden/ton of underlying 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
96	0	0	110,000	110,000
C6	210,000	150,000	570,000	930,000
FB	7,600,000	1,680,000	0	9,280,000
JB	1,880,000	720,000	20,000	2,620,000
Total	9,690,000	2,550,000	700,000	12,940,000

Non-strippable coal Reserve Base data for Federal coal lands (in short tons) in the Carbon quadrangle, Carbon County, Wyoming. (To convert short tons to metric tons, multiply by 0.9072)

Coal Bed	High Development Potential (0-1000 ft of overburden)	Moderate Development Potential (1000-2000 ft of overburden)	Low Development Potential (2000-3000 ft of overburden)	Total
C6	750,000	0	0	750,000
FB	30,570,000	0	0	30,570,000
JB	45,720,000	0	0	45,720,000
Total	77,040,000	0	0	77,040,000