UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Text to accompany:

Open-File Report 79-191

COAL RESOURCE OCCURRENCE AND COAL DEVELOPMENT POTENTIAL MAPS OF THE GOULD NW QUADRANGLE JACKSON COUNTY, COLORADO

By

AAA Engineering and Drafting, Inc.
Salt Lake City, Utah

Prepared for the U.S. Geological Survey
under contract No. 14-08-0001-17457

1980

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

CONTENTS

ILLUSTRATIONS

TABLES

Page

INTRODUCTION

Purpose

These maps were compiled to support the land-use planning work of the Bureau of Land Management and to provide a systematic coal resource inventory of Federal coal lands in the McCallum Known Recoverable Coal Resource Area (KRCRA) in response to the land-use planning requirements of the Federal Coal Leasing Amendments Act of 1976.

Published and unpublished non-proprietary data sources were used for this study. No new drilling or field mapping was done to supplement this study. No confidential or proprietary data were used.

Location

The Gould NW 7½-minute quadrangle is located in the east-central part of Jackson County in northwestern Colorado. The quadrangle is 1.5 miles (2.4 km) east of the town of Walden which is the county seat of Jackson County. The Colorado-Wyoming state line is approximately 17.5 miles (28.2 km) north of the quadrangle and the city of Denver is 81 miles (130 km) southeast of the quadrangle.

Accessibility

A light-duty road crosses the north half of the quadrangle in an east-west direction and continues westward to the town of Walden. Another light-duty road crosses the quadrangle in a northwest direction parallel to, and on the southwest side of the Michigan River. This road runs northwestward to Walden and southeastward to the towns of Lindland, Rand, and Gould. Numerous unimproved dirt roads provide accessibility to other parts of the quadrangle.

Nearly every square mile in the quadrangle is crossed, in part, by either a light-duty or an unimproved dirt road.

The main barrier to travel within the quadrangle is the flood plain of the Michigan River which contains numerous existing and abandoned meandering channels of the river.

The nearest railhead is at Walden where a branch line of the Union Pacific Railroad runs northward to Laramie, Wyoming. The Walden-Jackson County airport is 1 mile (1.6 km) west of the northwest corner of the quadrangle.

Physiography

The Gould NW quadrangle lies on the east side of a broad intermontane topographic basin called North Park. The basin is almost entirely surrounded by mountains including the Park Range to the west and the Medicine Bow Range on the east. The quadrangle lies in the lowland area of the basin where there are rolling hills, shallow creeks, and dry washes.

The relief in the quadrangle is approximately 455 ft (139 m). The low point is 8,095 ft (2,467 m) above sea level where the Michigan River leaves the northern part of the west side of the quadrangle. The high points are approximately 8,550 ft (2,606) m) above sea level on two hills in the northeast quarter of the quadrangle. Several other hills in the area including one on the south edge of the quadrangle also nearly reach that elevation. The northeast corner of the quadrangle is 4 miles (6.4 km) from the base of the Medicine Bow Mountains which rise sharply to elevations above 10,000 ft (3,048 km).

The main drainage in the area is the Michigan River which flows northwestward through the central part of the quadrangle to its confluence with the North Platte River on the north side of the basin. The area in the northeast part of the quadrangle drains northeastward toward the Canadian

River. The southwest part of the quadrangle drains into Spring Creek which flows northwestward through that part of the quadrangle.

Climate

The Gould NW quadrangle has a mid-latitude steppe climate and semi-arid conditions prevail in the area. The normal annual precipitation for the quadrangle ranges from about 13 inches (33 cm) on the southwest corner to 17 inches (43 cm) on the northeast corner (U.S. Department of Commerce, (1964)).

The nearest weather data-recording station is at Walden where a record high temperature of 91° F (33° C) and a record low temperature of -49° F (-45° C) were recorded (Colorado State Climatology Office, personal communication). The mean annual temperature at Walden is 36.5° F (2.5° C). The temperatures in the Gould NW quadrangle are expected to be in the range of those recorded at Walden.

Land Status

The Gould NW quadrangle lies in the northeast part of the McCallum Known Recoverable Coal Resource Area (KRCRA). The KRCRA covers approximately 29,180 acres (11,809 ha) of the quadrangle. Plate 2 shows areas of non-Federal land and the KRCRA boundary. There was one existing Federal coal lease in this quadrangle when the land check for this report was made on the date shown on plate 2. A comparison of the area of Federal coal ownership and the non-Federal lands in the quadrangle area is shown in table 1.

Table 1.--Approximate distribution of Federal and non-Federal land areas in the Gould NW quadrangle, Jackson County, Colorado

Category	Approximate area[1] (acres)	Percent of quadrangle area
Leased Federal coal land	170	0.5
Non-Federal land	20,580	56.9
Unleased Federal coal ownership[2]	15,430	42.6
Total	36,180	100.00

[1]To convert acres to hectares, multiply acres by 0.4047
[2]Coal is known to be present in only part of this area.

Previous Work

Beekly (1915) made a geological study of North Park and published a report which included a description of the coal occurrences. Guidebooks by the Wyoming Geological Association and the Rocky Mountain Association of Geologists contain papers on the geology of North Park (Severy and Thompson, 1953; Henkes, 1957; Montagne and Barnes, 1957). Hail (1965, 1968) published studies on the areal geology of the west side of North Park and Middle Park basins, Jackson and Grand Counties, Colorado. Madden (1976, 1977a) prepared drilling and administrative reports showing all coal geology and bed correlations in North Park basin, and geologic maps and coal sections for the Gould NW quadrangle. Madden (1977b) published the results of exploratory drilling in the McCallum coal field.

Miller (1934) described the north and south McCallum anticlines. Kinney (1970a, 1970b, 1971), Kinney and Hail (1970a, 1970b), and Kinney and others (1970) mapped the geology of the eastern part of North Park. Tweto (1976) compiled a geologic map of the Craig 1° x 2° quadrangle. Behrendt and others (1969) made a geophysical study of the North Park area. Hail and Leopold (1960) published a paper on the age of the Coalmont Formation.

GENERAL GEOLOGY

Stratigraphy

The oldest formation exposed in the Gould NW quadrangle is the Pierre Shale of Late Cretaceous age. The formation crops out in the northeast part of the quadrangle in the South McCallum anticline and on the northeast side of the Johnny Moore syncline. The Pierre is composed of dark-gray marine shale, a few thick beds of fine-grained sandstone, and minor coal (Madden, 1977a). The maximum preserved thickness beneath the pre-Coalmont or pre-Middle Park unconformity in North and Middle Parks is 5,300 ft (1,615 m) (Tweto, 1976).

The Pierre Shale is unconformably overlain by the Coalmont Formation in the quadrangle. The Coalmont Formation is Paleocene and Eocene age and is composed of sandstone, conglomerate, carbonaceous shale, and coal beds. The estimated maximum thickness of the formation is 11,000 ft (3,355 m) (Tweto, 1976).

In the central part of the Gould NW quadrangle along the Michigan River the Coalmont Formation is partly overlain by Quaternary terrace and pediment gravels and alluvium (Tweto, 1976).

Structure

The rocks in the Gould NW quadrangle have been folded into the Johnny Moore syncline and the South McCallum anticline in the northeast part of the quadrangle, and the Walden syncline in the southwest part. These folds plunge southward (Madden, 1976) and their axial traces are shown on plate 1. They generally trend in a northwest-southeast direction. The Johnny Moore syncline and the South McCallum anticline are tightly folded and their flanks have steep dips up to more than 80° (pl 1).

There are several steeply-dipping faults along the north-central edge of the quadrangle. Most of these are less than 1 mile (1.6 km) in length and generally involve the Pierre Shale except in two places where the Sudduth coal bed is offset (pl. 1).

In the southwest corner of the quadrangle the Spring Creek fault (2 segments) is about 4 miles (6.4 km) in length. The rock and coal beds in the Coalmont Formation are drastically offset by this fault. Based on geophysical data interpreted by Behrendt and others (1969) the Spring Creek fault has a displacement of 4,900 ft (1,494 m). Because of the lack of drilling in the area, it is not known if coals are present on the upthrown side of the fault.

COAL GEOLOGY

The Sudduth coal bed is the most important coal bed in the Gould NW quadrangle. The bed is higher quality, thicker, and more extensive than the other beds. The Capron coal zone occurs above the Sudduth bed and is lower quality, thinner, and less persistent than the Sudduth. An outcrop trace of the coal zone B occurs in the northern part of the west side of the quadrangle, but no thickness measurements of coal in this zone are available. Madden (1976) reports that the coal in coal zone B is greater than 4 ft (1.2 m) thick near the town of Walden, based on proprietary data.

In this quadrangle the lenticular coal beds of very limited lateral extent are called "local" coal beds and have been designated by the letter "L" on plates 1 and 3.

Sudduth Coal Bed

The Sudduth coal bed occurs in the lower part of the Coalmont Formation in the Gould NW quadrangle (pl. 3). It is the only coal that is being mined in the Johnny Moore quadrangle at the date of this report. The Sudduth bed occurs near the contact between the Coalmont Formation and the underlying Pierre Shale. The coal bed crops out on the southwest flank of the South McCallum anticline where the rocks dip up to 40° southwest. The bed also crops out on both sides of Johnny Moore syncline in the northeast corner of the quadrangle (pl. 1) where the dips are up to 80°.

The Sudduth coal bed ranges from 8.0 to 44.6 ft (2.4 to 13.6 m) thick at various points in the quadrangle. Based on the coal isopach map (pl. 4) the bed thickens and thins from less than 20 ft (6.1 m) to more than 40 ft (12.2 m) along its 6.8 mile- (10.9 km-) outcrop trace on the southwest side of the South McCallum anticline (pl. 4).

Because of the lack of control points down dip from the outcrop and shallow drilling area, an insufficient data line was drawn about ½ mile from the outcrop trace and the coal isopach lines were oriented perpendicular to the outcrop on plate 4. The Reserve Base tonnage (discussed below) was calculated for the area between the outcrop trace and the insufficient data line.

Capron Coal Bed

The Capron coal bed is the main bed in the Capron coal zone which occurs in the Coalmont Formation approximately 1,850 ft (564 m) stratigraphically above the base of the formation. The Capron coal zone exposure extends for 5.5 miles (8.8 km) on the southwestern flank of the South McCallum anticline (pl. 1). "The Capron coal is shaly and weathered at the surface" (Madden, 1976).

Measurements of the Capron bed (pl. 1 and 3) show net coal thicknesses ranging from 9.1 to 13.0 ft (2.8 to 4.0 m) with 1 to 2.8 ft (0.3 to 0.9 m) of interbedded rock and bony coal.

Isolated Data Points

In instances where isolated measurements of coal beds greater than 5 ft (1.5 m) thick are encountered, the standard criteria for construction of isopach, structure contour, mining ratio, and overburden isopach maps are not available. The lack of data concerning these beds limits the extent to which they can be reasonably projected in any direction and usually precludes correlation with other coal beds. For this reason, isolated data point maps are included on a separate sheet (in U.S. Geological Survey files) for non-isopachable coal beds. Resource data for these isolated data points were calculated for areas within ¼ mile (0.4 km) of the points of measurement and are given in table 2 and are shown by asterisks on plate 2.

PROXIMATE ANALYSES OF THE COAL

Tables 3 and 4 show the proximate analyses of coal samples taken from the Sudduth coal bed in two mines located in the adjoining Johnny Moore Mtn. quadrangle. Table 5 lists the moisture, ash and heating value for three coal samples obtained in the Gould NW quadrangle.

Table 2.--Isolated data points in the Gould NW quadrangle, Jackson County, Colorado

Index Number (pl. 1,3)	Location	Coal Bed Name	Outcrop or Drill Hole	Coal Thickness (ft)[1]	Measured area (ac)[2]	Resource Tonnage (s.t.)[3]
10	NE¼NW¼ sec. 24, T. 9 N., R. 79 W.	Local	Drill hole	5.4	92(82)[4]	800,000
13	NE¼SW¼ sec. 4, T. 8 N., R. 78 W.	Local	Drill hole	9.0	91	1,300,000
13	NE¼SW¼ sec. 4 T. 8 N., R. 78 W.	Local	Drill hole	5.0	91	700,000
			Total resource tonnage			2,800,000

[1]To convert feet to meters, multiply feet by 0.3048

[2]To convert acres to hectares, multiply acres by 0.4047

[3]To convert short tons to metric tons, multiply short tons by 0.9072

[4]Horizontal plane area is 82 acres; true bedding plane area is 92 acres based on a dip of 27°.

Table 3.--Proximate analyses of coal (as-received) from the Sudduth bed in the Kerr strip mine, sec. 35, T. 9 N., R. 78 W., Jackson County, Colorado (Madden, 1976)

Lab Sample No.	Moisture %	Volatire Matter %	Fixed Carbon %	Ash %	Sulphur %	Heat Value Btu/lb[1]
K-52662	14.2	35.4	48.3	2.1	0.2	11,280
K-52663	14.4	34.4	47.9	3.3	0.2	10,830
K-52664	13.0	35.0	47.8	4.2	0.3	10,900
K-52665	12.4	34.9	41.9	10.8	0.2	10,040
K-52666	11.0	37.1	41.5	10.4	0.2	10,290
K,52667	12.0	36.0	45.5	6.5	0.3	10,790
K-52668	12.0	38.3	46.0	3.7	0.3	11,160
K-52669	12.8	37.3	44.8	5.1	0.7	11,160

[1]To convert Btu/lb to Kj/kg multiply by 2.326

Table 4.--Proximate analyses of coal (as-received) from the Sudduth bed in the Canadian strip mine, SW¼ sec 2, T. 8 N., R. 78 W., Jackson County, Colorado (Madden, 1976)

Lab Sample No.	Moisture %	Volative Matter %	Fixed Carbon %	Ash %	Sulfur %	Heat Value Btu/lb[1]
K-50383	14.5	31.9	47.2	6.4	0.2	10,730
K-50384	15.4	32.9	48.5	3.2	0.2	10,990
K-50385	16.1	31.4	43.0	3.2	0.2	9,900
K-50386	14.6	32.6	49.1	3.7	0.2	10,890
K-50387	14.5	27.4	45.5	19.2	0.2	8,580

[1]To convert Btu/lb to Kj/kg multiply by 2.326

On the basis of the analyses shown in tables 3 and 4, the Sudduth coal at the sampling sites ranges from subbituminous B to high volatile C bituminous in rank (American Society for Testing and Materials, 1977). The average of the above analyses represents a rank of subbituminous A coal. It is assumed that the Sudduth coal bed in the Gould NW quadrangle is of similar rank.

Table 5.--Partial analyses of coal from the Capron bed in lots 19 and 20, sec. 19, T. 9 N., R. 78 W., Jackson County, Colorado. (Madden, 1976).

Lab Sample No.	Moisture %	Volatile Matter %	Fixed Carbon %	Ash %	Sulphur %	Heat Value Btu/lb
1	43	---	---	7.44	---	4,580
2	11.4	---	---	9.96	---	10,669
			(air-dried)			
3	15.6	---	---	5.08	---	10,750

[1]To convert Btu/lb to Kj/kg multiply by 2.326

On the basis of the above incomplete analyses, the coal in sample numbers 2 and 3 ranges in rank from subbituminous A to high volatile bituminous C. Sample number 1 was probably a weathered surface sample as indicated by the abnormal moisture content and should not be considered a representative of the coal bed.

MINING OPERATIONS

Coal mining in North Park dates back to the late 1800's and early 1900's. Available information indicates that there are at least four abandoned coal mines in the Gould NW quadrangle (Madden, U.S.G.S., 1979, unpublished map, and Colorado Division of Mines, personal communication). The information concerning these mines is shown in table 6. Two of the mines are in the Sudduth bed and two are in the Capron bed.

Table 6.--Coal mines (abandoned) in the Gould NW quadrangle, Jackson County, Colorado.

Mine Name(s)	Approximate Location	Coal Bed Name	Coal Thickness (ft)[1]	Production (S. T.)[2]	Periods of Operation
Conrad	SE¼SE¼ sec. 29 (Madden, 1979) NE¼NE¼ sec. 32 (Colo. Div. Mines) T. 9 N., R. 78 W.	Capron	9.1	666	1927-30 1932-33
Manning (Jackson-Bourg?)	NE¼SE¼ sec. 13, T. 9. N., R. 79 W.	Sudduth	36.3	302	1936-37 1942
Monolith (Capron)	SE¼ sec. 19, T. 9 N., R. 78 W.	Capron	9.9	1,055	1952
Sudduth	NW¼SW¼ sec. 15, T. 9 N., R. 78 W.	Sudduth	28.6	1,780	1938-40 1948

[1]To convert feet to meters, multiply feet by 0.3048

2To convert short tons to metric tons, multiply short tons by 0.9072

The nearest mines operating in 1979 were the Canadian strip mine and the Marr No. 1 strip mine (formerly the Kerr No. 1 strip mine) located in the Johnny Moore Mtn. quadrangle. These mines are approximately ½ mile (0.8 km) east of the Gould NW quadrangle and produce from the Sudduth coal bed. The coal bed thickness in those mines ranges from 34 to 60 ft (10 to 18 m). Total production from the Kerr No. 1 strip mine through 1978 was 1,256,664 short tons (1,140,046 metric tons) (Colorado Division of Mines, personal communication). Total production from the Canadian strip mine through 1978 was 380,852 short tons (345,509 metric tons) (Colorado Division of Mines, personal communication).

COAL RESOURCES

The principal source of data used in the construction of the coal isopach, structure contour, and coal data maps was Madden (1977b). Numerous oil and gas test wells have been drilled in the area and the available logs of these wells were inspected for reliable coal-bed data, but the logs were generally non-definitive for coal, or the wells were drilled in non-coal-bearing areas.

Coal isopach maps were constructed by using a point-data net derived from coal-thickness measurements of an individual coal bed obtained from surface exposures and correlated well logs located within the quadrangle boundary and a 3-mile (4.8-km)-wide zone around the quadrangle. Measured coal thickness values were used directly in the point-data net where the rocks dip less than 25°. In the drill holes at index numbers 2, 3, 6, 7, and 10 (pl. 1) the rocks dip greater than 25° and adjusted coal-bed thicknesses were calculated by multiplying the apparent, vertically-measured coal-bed-thickness by the cosine of the dip. The principle of uniform variation in thickness between data points was used to establish the position of the isopach lines.

Structure contour maps were constructed by using point-data nets derived from well logs and surface exposures. The elevation of the top of each contoured coal bed was based on surface altitude and measured depth to the top of the designated coal bed encountered in drill holes and referenced to mean sea level.

Each overburden isopach map was based on a point-data net derived from stratigraphic-interval thicknesses measured from the ground surface to the top of the isopached coal bed. A secondary set of data-net points was generated by laying a structure contour map over a topographic contour map and then calculating apparent overburden thickness values at the intersections of structure contour lines and surface topographic contour lines.

Coal thickness data was obtained from the coal isopach maps (pl. 1 and 8) for resource calculations. The coal-bed acreage (measured by planimeter) multiplied by the average isopach thickness of the coal bed multiplied by a conversion factor of 1,770 short tons of coal per acre-foot (13,018 metric tons of coal per hectare-meter) for subbituminous coal yields coal resources in short tons.

Reserve Base and Reserve values for the Sudduth and Capron coal beds are shown on plates 7 and 9 and are rounded to the nearest tenth of a million short tons. The Reserve values are based on a subsurface mining recoverability factor of 50 percent and a surface mining recoverability factor of 85 percent.

The following criteria for coal resource determinations are given in the U.S. Geological Survey Bulletin 1450-B: "Measured.--Resources are computed from dimensions revealed in outcrops, trenches, mine workings, and drill holes. The points of observation and measurement are so closely spaced and the thickness and extent of coals are so well defined that the tonnage is judged to be accurate within 20 percent of true tonnage. Although the spacing of the points of observation necessary to demonstrate continuity of the coal differs from region to region according to the character of the coal beds, the points of observation are no greater than ½ mile (0.4 km) wide belt from the outcrop or points of observation or measurement.

"Indicated.--Resources are computed partly from specified measurements and partly from projection of visible data for a reasonable distance on the basis of geologic evidence. The points of observation are ½ (0.8 km) to ½ miles (2.4 km) apart. Indicated coal is projected to extend as a ½ mile (0.8 km) wide belt that lies more than ¼ mile (0.4 km) from the outcrop or points of observation or measurement.

"Inferred.--Quantitative estimates are based largely on broad knowledge of the geologic character of the bed or region and where few measurements of bed thickness are available. The estimates are based primarily on an assumed continuation from Demonstrated coal [a collective term for the sum of coal in both Measured and Indicated Resources and Reserves] for which there is geologic evidence. The points of observation are 1½ (2.4 km) to 6 miles (9.5 km) apart. Inferred coal is projected to extend as a 2¼-mile (3.6 km) wide belt that lies more than 3/4 mile (1.2 km) from the outcrop or points of observation or measurement." (U.S. Bureau of Mines and U.S. Geological Survey, 1976, p. B6 and B7).

Coal resource tonnages were calculated for measured, indicated, and inferred categories in the unleased areas of Federal coal land where the coal is 5 ft (1.5 m) or more thick and lies within 3,000 ft (914 m) of the surface. The criteria cited above were used in calculating Reserve Base and Reserve data in this report and differ from those stated in U.S. Geological Survey Bulletin 1450-B, which calls for a minimum thickness of 28 in (70 cm) for bituminous coal and a maximum depth of 1,000 ft (300m). for bituminous and subbituminous coal.

In this study, coal 5 ft (1.5 m) or more thick lying between the ground surface and a depth of 200 ft (61 m) is considered amenable to surface mining methods; coal 5 ft (1.5 m) or more thick lying between 200 ft (61) and 3,000 ft (914 m) below ground level in beds having dips of less than 15° is considered minable by conventional subsurface methods. Coal of Reserve Base thickness lying between 200 ft (61 m) and 3,000 ft (914 m) below ground level with dips greater than 15° is assumed to be suitable for in situ coal gasification.

Reserve Base tonnages of Federal coal per section for all isopached coal beds are shown on plate 2 and total approximately 264.0 million short tons (239.5 million metric tons) for the unleased Federal coal lands within the quadrangle. Reverve Base (in short tons) in the various development potential categories for surface and subsurface mining methods are shown in tables 7 and 8.

Resource tonnages calculated for isolated data points (non-isopached coal beds) are classified as inferred coal and placed in the unknown

Table 7.--Coal Reserve Base data for surface mining methods for Federal coal lands in the Gould NW quadrangle, Jackson County, Colorado. (in short tons)[1]

Coal Bed Name	High development potential (0-10 mining ratio)	Moderate development potential (10-15 mining ratio)	Low development potential (>15 mining ratio)	Total
Sudduth coal bed	28,700,000	- 0 -	- 0 -	28,700,000
Capron coal bed	7,800,000	*	100,000	7,900,000
TOTALS	36,500,000	*	100,000	36,600,000

[1]To convert short tons to metric tons, multiply by 0.9072

*Less than 50,000 short tons

Table 8.--Coal Reserve Base data for subsurface mining methods and in situ coal gasification for Federal coal lands in the Gould NW quadrangle, Jackson County, Colorado.
(in short tons)[1]

Coal Bed Name	High development potential	In situ coal gasification	Total
Sudduth coal bed	5,400,000	176,500,000	181,900,000
Capron coal bed	- 0 -	45,500,000	45,500,000
TOTALS	5,400,000	222,000,000	227,400,000

[1]To convert short tons to metric tons, multiply by 0.9072

development potential category. The coal resources for the isolated data points are shown in table 2 and total 2.8 million short tons (2.5 million metric tons). In this quadrangle, coal resources of unknown development potential are projected to extend as a ¼ mile (0.4 km) wide belt from the outcrop or points of measurement at the isolated data points.

AAA Engineering and Drafting, Inc. has not made any determination of economic recovery for any of the coal beds described in this report.

COAL DEVELOPMENT POTENTIAL

Coal development potential areas are drawn (pl. 10 and 11) so as to coincide with the boundaries of smallest legal land subdivisions shown on plate 2. In sections or parts of sections where no land subdivisions have been surveyed by the BLM (U.S. Bureau of Land Management), approximate 40-acre (16-ha) parcels have been used to show the limits of high-, moderate-, or low-development-potential areas.

The designation of a coal-development-potential classification is based on the occurence of the highest rated coal-bearing area that may occur within any fractional part of a 40-acre (16-ha) BLM land grid-area, lot, or tract of unleased Federal coal land. For example, a certain 40-acre (16-ha) parcel is totally underlain by a coal bed of "moderate-" development-potential. If a small corner of the same 40-acre (16-ha) area is also underlain by another coal bed of "high-" development-potential, the entire 40-acre (16-ha) area is given a "high-" development-potential rating even though most of the area is rated "moderate".

Development Potential Using Surface Mining Methods

Areas where the coal beds 5 ft (1.5 m) or more in thickness are overlain by 200 ft (61 m) or less of overburden are considered to have a surface mining potential and were assigned a high-, moderate-, or low-development-potential on the basis of the mining ratio (cubic yards of overburden per ton of recoverable coal). The following formula is used to calculate mining ratios:

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

Where MR = mining ratio (cubic yards of overburden per ton of recoverable coal)

t_o = thickness of overburden (in feet)

t_c = thickness of coal (in feet)

rf = recovery factor

0.911 = factor for subbituminous coal

To convert mining ratio to cubic meters of overburden per metric ton of recoverable coal, multiply MR by 0.8428.

Areas of high-, moderate-, and low-development-potential for surface mining methods are here defined as areas underlain by coal beds having respective mining-ratio values of 0 to 10, 10 to 15, and greater than 15. These mining-ratio values for each development-potential category are based on economic and technological criteria and were provided by the U.S. Geological Survey (1979, unpublished data).

The coal development potential using surface mining methods is shown on plate 10. Approximately 25 percent of the unleased Federal land area in this quadrangle is classified as having a high-development-potential using surface mining methods, less than 1 percent has a moderate-development potential; and less than 1 percent has a low development potential. The remaining Federal land in the quadrangle has an unknown surface mining development potential or no development potential. Areas of unknown surface mining development potential are those not known to contain coal beds 5 ft (1.5 m) or more thick that are within 200 ft (61.0 m) of the surface; however, coal beds 5 ft (1.5 m) or more thick could be present in the area. Lands where it is known that no coal beds occur within 200 ft (61.0 m) of the surface have no surface-mining development potential.

The tonnage of Reserves recoverable by surface mining methods are calculated on a recoverability factor of 85 percent (specified by the U.S. Geological Survey, unpublished data, 1979) of the Reserve Base tonnage.

Development Potential Using Subsurface Mining Methods and In Situ Coal Gasification

The coal development potential for areas in which subsurface development of coal is assumed possible is shown on plate 11. In this quadrangle, areas where coal beds dip 15° or less, are 5 ft (1.5 m) or more thick and are overlain by 200 to 1,000 ft (61 to 305 m) of overburden are considered to have a high-development-potential for conventional subsurface mining methods. Approximately 3 percent of the unleased Federal land in this quadrangle has a "high" classification. Areas where such beds are overlain by 1,000-2,000 ft (305-610 m) and 2,000-3,000 ft (610-914 m) of overburden are rated as having moderate- and low-development-potentials, respectively. In this quadrangle there are no areas classified with a moderate- or low-develoment-potential using conventional subsurface mining methods, but a large area has a low-development potential for in situ coal gasification and is discussed below. Areas that contain no known coal in beds 5 ft (1.5 m) or more thick but do contain coal-bearing units at depths between 200 to 3,000 ft (61-914 m) are classified as areas of unknown coal development potential. Areas where it is known that no coal beds occur or where coal beds are present at depths greater than 3,000 ft (914 m) have no coal-development potential.

Reserve Base tonnages have been calculated for all areas within the quadrangle where the coal beds are 5 ft (1.5 m) or more thick. Reserves are based on a recoverability factor of 50 percent (specified by the U.S. Geological Survey, unpublished data, 1979) and have been calculated for only that part of the Reserve Base considered to be suitable for conventional subsurface mining methods. An arbitrary dip limit of 15° is assumed to be the maximum dip suitable for conventional subsurface mining methods.

The development potential using in situ coal gasification applies to areas that contain coal beds 5 ft (1.5 m) or more thick dipping in excess of 15°. The coal beds in much of the area of this quadrangle have dips greater than 15° and are classified as having a low-development-potential for using in situ coal gasification methods. Approximately 48 percent of the unleased Federal land in the quadrangle is so classified.

Reserves have not been calculated for the nonisopached coal beds at isolated data points. The areas controlled by those points have been assigned an unknown development potential. Resource tonnages included in the unknown development potential category for areas within ¼ mile (0.4 km) of isolated data points are shown in table 2. No distinction has been made between surface and subsurface mining resources in the areas controlled by isolated data points.

Table 9.--Sources of data used on plate 1.

Source	Plate 1 Index No.	Drill hole or measured section No. in reference source
Madden, 1977a	1	3
Madden, 1977b	2	G- 9, p. 36
Do.	3	G-10, p. 38
Madden, 1977a	4	2
Madden, 1977b	5	G-15, p. 47
Do.	6	G-16, p. 48
Do.	7	G-50, p. 25
Do.	8	G-6C, p. 29
Madden, 1977a	9	1
Madden, 1977b	10	G-22, p. 63
Madden, 1977a	11	4
Do	12	5
Madden, 1977b	13	G- 4, p. 23

REFERENCES

1. American Society for Testing and Materials, 1977, Standard specifications for classification of coals by rank, in Gaseous fuels, coal, and coke; atmospheric analysis: ASTM Publication D 388-77.

2. Beekly, S. L., 1915, Geology and coal resources of North Park Colorado: U.S. Geol. Survey Bull. 596.

3. Behrendt, J. C., and others, 1969, A geophysical study of North Park and the surrounding ranges, Colorado: Geol. Soc. American Bull., v. 80, no. 8.

4. Erdmann, E. C., 1941, Preliminary report on the geology of the Coalmont district, Jackson County, Colorado: U.S. Geol. Survey open-file report.

5. Hail, W. J., Jr., 1965, Geology of northwestern North Park, Colorado: U.S. Geol. Survey Bull. 1188.

6. __________ 1968, Geology of southwestern North Park and vicinity: U. S. Geol. Survey Bull. 1257.

7. Hail, W. J., Jr., and Leopold, E. B., 1960, Paleocene and Eocene age of the Coalmont Formation, North Park, Colorado, in Short papers in the geological sciences: U.S. Geol. Survey Prof. Paper 400-B.

8. Hendricks, M. L., 1978, Stratigraphy of the Coalmont Formation near Coalmont, Jackson County, Colorado, in Proceedings of the second symposium of the geology of Rocky Mountain coal-1977: Colorado Geol. Survey.

9. Henkes, W. C., 1957, Coalmont area, Jackson County, Colorado, in Geology of North and Middle Park basins, Colorado: Rocky Mtn. Assoc. Geologists Guidebook, 1957.

10. Kinney, D. M., 1970a, Preliminary geologic map of the Gould quadrangle, North Park, Jackson County, Colorado: U.S. Geol. Survey open-file report.

11. __________ 1970b, Preliminary gologic map of the Rand quadrangle North Park, Jackson and Grand Counties, Colorado: U.S. Geol. Survey open-file report.

12. __________ 1971, Preliminary geologic map of "southwest third" of Kings Canyon quadrangle, North Park, Jackson County, Colorado: U.S. Geol. Survey open-file report.

13. Kinney, D. M., and Hail, W. J., Jr., 1959, Upper Cretaceous rocks in North Park, Jackson, County, Colorado in Symposium on Cretaceous rocks of Colorado and adjacent areas: Rocky Mtn. Assoc. Geologists Guidebook.

14. ________ 1970a, Preliminary geologic map of the Walden quadrangle, North Park, Jackson County, Colorado: U.S. Geol. Survey open-file map.

15. ________ 1970b, Preliminary geologic map of the Hyannis Peak quadrangle, North and Middle Parks, Jackson and Grand Counties, Colorado: U.S. Geol. Survey open-file report.

16. Kinney D. M., and others, 1970, Preliminary geologic map of Cowdrey quadrangle, North Park, Jackson County, Colorado: U.S. Geol. Survey prelim. map, open-file.

17. Madden, D. H., 1976, Coal resource occurrence in the McCallum area (Cowdrey, Eagle Hill, Gould NW, Johnny Moore Mountain, and Walden quadrangle), Jackson County, Colorado: U.S. Geol. Survey unpublished report.

18. ________ 1977a, Unpublished field notes and maps.

19. ________ 1977b, Exploratory drilling in the McCallum coal field, Jackson County, Colorado: U.S. Geol. Survey Open-File Report 77-888.

20. Madden, D. H., and others, 1977, McCallum Known Recoverable Coal Resource Area, Jackson County, Colorado: U.S. Geol. Survey, Minutes of the Mineral Land Evaluation Committee, unpublished report.

21. ________ 1978, Revision of the McCallum Known Recoverable Coal Resource Area, Jackson County, Colorado: U.S. Geol. Survey, Minutes of the Mineral Land Evaluation Committee, unpublished report.

22. Miller, J. C., 1934, Geology of the North and South McCallum anticlines, Jackson County, Colorado, with special reference to petroleum and carbon dioxide: U.S. Geol. Survey Circ. 5.

23. Montagne, J. M. de la, and Barnes, W. C., 1957, Stratigraphy of the North Park Formation in the North Park area, Colorado, in Geology of North and Middle Park Basins, Colorado: Rocky Mtn. Assoc. Geologists Guidebook, 1957.

24. Severy, C. L., and Thompson, R. M., 1953, Coalmont area, Jackson County, Colorado, in Laramie Basin, Wyoming, and North Park, Colorado: Wyoming Geol. Assoc. Guidebook 8th Ann. Field Conf.

25. Tweto, Ogden, 1976, Geologic map of the Craig $1^o \times 2^o$ quadrangle, northwestern Colorado: U.S. Geol. Survey Misc. Inv. Series Map I-972.

26. U.S. Bureau of Mines and U.S. Geological Survey, 1976, Coal resource classification system of the U.S. Bureau of Mines and U.S. Geological Survey: U.S. Geol. Survey Bull. 1450-B.

27. U.S. Department of Commerce, (1964), Normal annual precipitation, 1931-1960, Colorado: Environmental Science Services Admin., Weather Bureau.