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COAL RESOURCE OCCURRENCE AND COAL DEVELOPMENT POTENTIAL MAPS OF THE PAGODA QUADRANGLE, ROUTT AND MOFFAT COUNTIES, COLORADO

[Report includes 22 plates]

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By

DAMES & MOORE

DENVER, COLORADO

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INTRODUCTION

Purpose

This text is to be used in conjunction with Coal Resource Occurrence and Coal Development Potential Maps of the Pagoda quadrangle, Routt and Moffat Counties, Colorado. This report was compiled to support the land-planning work of the Bureau of Land Management (BLM) and to provide a systematic coal resource inventory of Federal coal lands in Known Recoverable Coal Resource Areas (KRCRA's) in the western United States. This investigation was undertaken by Dames & Moore, Denver, Colorado, at the request of the United States Geological Survey under contract number 14-08-0001-15789. The resource information gathered for this report is in response to the Federal Coal Leasing Amendments Act of 1976 (P.L. 94-377). Published and unpublished public information available through April, 1978, was used as the data base for this study. No new drilling or field mapping was done as part of this study, nor was any confidential data used.

Location

The Pagoda quadrangle is located in northwestern Colorado. The eastern half of the quadrangle is located in southwestern Routt County, while the western half is located in southeastern Moffat County, Colorado. The quadrangle is approximately 30 airline miles (48 km) west-southwest of the town of Steamboat Springs and 10 airline miles (16 km) south-southeast of the town Craig, Colorado. There are no major highways within the quadrangle area. With the exception of the small settlement of Pagoda in the central part of the quadrangle and several ranches, the quadrangle is unpopulated.

Accessibility

U.S. Highway 40 crosses east-west approximately 10 miles (16 km) north of the Pagoda quadrangle. Colorado Highway 317, an improved light-duty road, parallels the East Fork of the Williams Fork across the northern part of the quadrangle, joining the town of Hamilton, approximately 6 miles (10 km) west of the quadrangle, with Pagoda. Improved light-duty roads also connect Pagoda with the town of Hayden, approximately 16 miles (26 km) northeast of the quadrangle and the town of Oak Creek, approximately 28 miles (45 km) to the east. The remainder of the quadrangle is accessible by several light-duty roads and unimproved dirt roads and trails.

Railway service for the Pagoda quadrangle is provided by the Denver & Rio Grande Western Railroad from Denver to the railhead at Craig. The railroad follows U.S. Highway 40, and passes 8 to 10 airline miles (13 to 16 km) north of the quadrangle. It is the major transportation route for coal shipped east from northwestern Colorado.

Physiography

The Pagoda quadrangle lies in the southern part of the Wyoming Basin physiographic province, as defined by Howard and Williams (1972) and is approximately 41 miles (66 km) west of the Continental Divide. The Williams Fork Mountains cross the northern part of the quadrangle.

The landscape in the Williams Fork Mountains consists of moderate to steep slopes and canyons. The topography is less pronounced with broader slopes and wider stream valleys in the remainder of the quadrangle. The valley of the East Fork of the Williams Fork, the major river in the quadrangle, is broad and flat. Oklahoma Flat, a broad, relatively flat area, is located in the north-central part of the quadrangle just west of Pagoda.

Approximately 2,520 feet (768 m) of relief is present in the Pagoda quadrangle. Altitudes range from approximately 8,880 feet (2,707 m) in the southeastern corner of the quadrangle, to less than 6,360 feet (1,939 m) along the Williams Fork in the northwestern corner.

The Pagoda quadrangle is drained by the Williams Fork, a tributary of the Yampa River. The South Fork of the Williams Fork flows north through the south-central part of the quadrangle and the East Fork flows northwest across the eastern part of the quadrangle. The Williams Fork flows northwesterly across the northern half of the quadrangle, joining the Yampa River approximately 10 miles (16 km) northwest of the quadrangle. Numerous creeks, which generally flow southwest and northeast into the Williams Fork, drain the area within the quadrangle. A number of small man-made lakes and ponds are located in the southern half of the quadrangle.

Climate and Vegetation

The climate of northwestern Colorado is semiarid. Clear, sunny days prevail in the Pagoda quadrangle area, with daily temperatures typically varying from 0° to 35° F (-18° to 2° C) in January and from 42° to 80° F (6° to 27° C) in July. Annual precipitation averages approximately 19 inches (48 cm). Snowfall during the winter months accounts for the major part of the precipitation in the area, but rainfall from thundershowers during the summer months also contributes to the total. Winds, averaging approximately 3 miles per hour (5 km per hour), are generally from the west, but wind directions and velocities vary greatly depending on the local terrain (U.S. Bureau of Land Management, 1977).

The typical vegetative cover in the Pagoda quadrangle is mountain shrub, which includes serviceberry, Gambel oak, and rabbitbrush. Along the Williams Fork valley, the typical vegetation is sagebrush. Pinyon, Utah juniper, Rocky Mountain juniper, and aspen are the dominant vegetation in the southwestern corner of the quadrangle.

Land Status

The Pagoda quadrangle lies on the southern boundary of the Yampa Known Recoverable Coal Resource Area (KRCRA). The northeastern and southwestern parts of the quadrangle lie within the KRCRA boundary and the Federal government owns the coal rights for approximately 99 percent of this area as shown on plate 2. There are no active coal leases located in the KRCRA in the Pagoda quadrangle.

GENERAL GEOLOGY

Previous Work

The first geologic description of the general area in which the Pagoda quadrangle is located was reported by Emmons (1877) as part of a survey of the Fortieth Parallel. The decision to build a railroad into the region stimulated several investigations of coal between 1886 and 1905, including papers by Hewett (1889), Hills (1893), and Storrs. Fenneman and Gale (1906), in a geologic report on the Yampa Coal Field, included a description of the geology and coal occurrence in the northern part of the Pagoda quadrangle. The work done by Fenneman and Gale in 1906 was expanded by Bass and others (1955) in their report on the geology and mineral fuels of parts of Routt and Moffat Counties, which includes the Pagoda quadrangle. Reports by Meyer (1977 and 1978) included geophysical logs of coal test holes drilled by the U.S. Geological Survey in the Pagoda quadrangle during 1976 and 1977.

Stratigraphy

The rock formations which crop out in the Pagoda quadrangle are Late Cretaceous and Tertiary in age and include the coal-bearing Iles and Williams Fork Formations of the Mesaverde Group.

The Mancos Shale of Late Cretaceous age crops out in a broad band across the central two thirds of the quadrangle along the axis of the Beaver Creek anticline. The upper 1,000 feet (305 m) of the formation consists predominately of gray to dark-gray marine shale, a number of thin-bedded silty tan sandstone beds, and interbedded sandy shale (Bass and others, 1955).

The Mesaverde Group of Late Cretaceous age conformably overlies the Mancos Shale and contains two formations, the Iles and Williams Fork.

The Iles Formation, approximately 1,450 feet (442 m) thick, crops out along the flanks of the Hart syncline in the southwestern corner of the quadrangle and in a narrow band across the northern and northeastern parts of the quadrangle. The formation consists of the basal Tow Creek

Sandstone Member, an overlying sequence of sandstones interbedded with sandy shale, shale, and coal, and at the top of the formation, the Trout Creek Sandstone Member (Bass and others, 1955).

The basal Tow Creek Sandstone Member consists of approximately 110 feet (34 m) of light-brown, fine-grained massive cliff-forming sandstone. In some areas it consists of two or more sandstone beds separated by shale and sandy shale. Overlying the Tow Creek Sandstone Member is a unit of light-brown, light-gray, and white massive ledge-forming sandstone interbedded with gray sandy shale and coal which is approximately 1,250 feet (381 m) thick. This unit, which contains thick sandstone beds near the base, grades upward to become more silty and shaly. The coal beds in this unit have been designated as the Lower Coal Group (Fenneman and Gale, 1906). The overlying Trout Creek Sandstone Member consists of approximately 90 feet (27 m) of white, fine-grained massive cliff-forming sandstone (Bass and others, 1955).

The Williams Fork Formation conformably overlies the Iles Formation and crops out along the axis of the Hart syncline in the southwestern corner of the quadrangle and in the northeastern corner of the quadrangle. It is approximately 2,000 feet (610 m) thick in this quadrangle and is divided into three units: a lower coal-bearing unit, the Twentymile Sandstone Member, and an upper coal-bearing unit (Bass and others, 1955).

The lower coal-bearing unit extends upward from the top of the Trout Creek Sandstone Member of the Iles Formation to the base of the Twentymile Sanstone Member of the Williams Fork Formation. In this quadrangle, it is approximately 1,050 feet (320 m) thick and consists of dark-gray to black shale, gray siltstone, sandstone, carbonaceous shale, and coal. This unit grades upward from chiefly siltstone, sandstone, shale, and coal in the lower half to shale in the upper half (Bass and others, 1955). Fenneman and Gale (1906) have designated the coal in this sequence as the Middle Coal Group.

The Twentymile Sandstone Member, which is approximately 90 feet (27 m) thick in the Pagoda quadrangle, consists of white to gray massive fine-grained sandstone (Bass and others, 1955).

The upper coal-bearing unit of the Williams Fork Formation, overlying the Twentymile Sandstone Member, is approximately 860 feet (262 m) thick. The sequence is composed of gray fine-grained sandstone, gray shale, brown carbonaceous shale, and coal (Bass and others, 1955). Coal beds occurring in the upper member are designated the Upper Coal Group (Fenneman and Gale, 1906).

A small area of Miocene-age Browns Park Formation lies unconformably on the Iles Formation in the southeastern corner of the quadrangle (Tweto, 1976). The Browns Park Formation consists of fluvial siltstone, claystone, conglomerate, and loosely consolidated eolian tuffaceous sandstone.

Basalt flows of Miocene or Pliocene age cap the Mancos Shale and the Iles Formation in several small isolated areas in the west-central and northeastern parts of the quadrangle (Bass and others, 1955; Tweto, 1976).

Holocene deposits of alluvium cover the stream valley of the Williams Fork.

The Cretaceous formations in the Pagoda quadrangle accumulated close to the western edge of a Late Cretaceous epeirogenic seaway which covered part of the western interior of North America. Several transgressive-regressive cycles resulted in the deposition of a series of offshore-marine, shallow-marine, and marginal-marine sediments in the Pagoda quadrangle area (Ryer, 1977).

The Mancos Shale was deposited in an offshore marine environment which existed east of the shifting strand line. Deposition of the Mancos Shale in the quadrangle area ended with the eastward migration of the shoreline and the subsequent deposition of the Iles Formation (Konishi, 1959; Kucera, 1959).

The interbedded sandstone, shale, and coal of the Mesaverde Group were deposited as a result of minor changes in the position of the shoreline. Near-shore marine, littoral, brackish tidal, brackish and fresh water supratidal, and fluvial environments existed during the deposition of the Iles and Williams Fork Formations. The major sandstone members of the Iles and Williams Fork Formations, including the Tow Creek, Trout Creek and Twentymile Sandstone Members, were deposited in shallow marine and near-shore environments. Coal beds of limited areal extent were generally deposited in environments associated with fluvial systems, such as back-levee and coastal plain swamps, interchannel basin areas, and abandoned channels. The major coal beds which have wide areal extent were deposited near the seaward margin of the non-marine environments, probably in large brackish-water lagoons or swamps. The slow migration of this depositional environment is responsible for the wide distribution of some of the coal beds in the Yampa study area (Konishi, 1959; Kucera, 1959).

The coarse, conglomeratic nature of the base of the Browns Park Formation and the fine wind-blown tuffaceous sands of the upper part of the formation suggest that it was deposited during a time when the climate of the region was changing from one of relatively high rainfall to one of semi-aridity such as is found in the region today (Carey, 1955).

Structure

The Yampa KRCRA lies in the southern extension of the Washakie/Sand Wash structural basin of south-central Wyoming. The basin is bordered on the east by the Park Range, approximately 38 miles (61 km) northeast of the Pagoda quadrangle, and on the southwest by the Axial Basin anticline, approximately 7 miles (11 km) west of the quadrangle (Tweto, 1976).

The northwest-trending Hart syncline and Beaver Creek anticline cross the southwestern corner of the Pagoda quadrangle. The Pagoda Dome is in the southeastern part of the quadrangle. Dips of the coal beds range from approximately 6° west-southwest to about 17° south-southwest in the northeastern part of the quadrangle and from 4° north-northeast to about 16° northwest in the southwestern part of the quadrangle. One fault, which strikes northwest, offsets the Cretaceous rocks in the northwestern part of the quadrangle (Bass and others, 1955).

The structure contour maps of the isopached coal beds are based on a regional structure map of the top of the Trout Creek Sandstone Member by Bass and others (1955), and it is assumed that the structure of the coal beds duplicates that of the Trout Creek Sandstone Member. Modifications were made where necessary in accordance with outcrop and drill-hole data. Drill holes for which the rock interval is unknown between the ground surface and the first coal bed penetrated are not shown on the structure maps and were not used in their construction.

COAL GEOLOGY

Coal beds in the Lower, Middle, and Upper Coal Groups of the Mesaverde Group have been identified in the Pagoda quadrangle. The Lower Coal Group includes all coal beds in the Iles Formation. The Middle Coal Group includes the coal beds in the lower coal-bearing zone of the Williams Fork Formation, which is stratigraphically above the Trout Creek Sandstone Member of the Iles Formation and below the Twentymile Sandstone Member. The Upper Coal Group includes the coal beds in the upper Williams Fork Formation, which are stratigraphically above the Twentymile Sandstone Member. Coals of the Upper and Lower Groups are characteristically lenticular and of limited areal extent, while some of the coal beds in the Middle Group persist over a large area.

None of the coal beds in this quadrangle are formally named, but where the coal beds exceed Reserve Base thickness (5.0 feet or 1.5 meters) they have been given bracketed numbers for identification purposes. In instances where coal beds greater than Reserve Base thickness are measured at one location only, they are treated as isolated data points (see Isolated Data Points section of this report).

Dotted lines shown on some of the derivative maps represent a limit of confidence beyond which isopach, structure contour, overburden isopach, and areal distribution and identified resources maps are not drawn because of insufficient data, even where it is believed that the coal beds may continue to be greater than Reserve Base thickness beyond the dotted lines.

Chemical analyses of coal.--Analyses of the coal samples tested in this area are listed in table 1. In general, chemical analyses indicate that the Lower, Middle and Upper Coal Group coals are high-volatile C bituminous in rank on a moist, mineral-matter-free basis according to ASTM Standard Specification D 388-77 (American Society for Testing and Materials, 1977).

Locations of coal samples tested in this quadrangle are listed in table 1 and include those for an undifferentiated Lower Group coal bed and coals in Middle Group zones F, G, and H. Chemical analyses were not available for any Upper Group coals. However, the analyses shown in the table from the Cary mine in the Breeze Mountain quadrangle is believed to be representative of coals in the Upper Coal Group in the Pagoda quadrangle.

Lower Coal Group

The Lower Coal Group includes all coal beds in the Iles Formation between the Tow Creek and Trout Creek Sandstone Members, and coal beds in this group crop out in the northeast, north-central, and southwest parts of the quadrangle. Two coal zones, C and D, within the Lower Coal Group were identified by Bass and others (1955), but only zone D is known to contain coal beds exceeding Reserve Base thickness in this quadrangle. Other thin coal beds in this group have been penetrated by drill holes and cannot be located in the stratigraphic section with enough accuracy to place the coal beds within specific zones.

Zone D

Two coal beds that exceed Reserve Base thickness in this zone have been identified in outcrops in the northeastern part of the quadrnagle, but only the LGD[1] (i.e., Lower Coal Group, zone D, coal bed [1]) coal bed has been isopached. The other coal bed, the LGD[2], was identified at only one location and is treated as an isolated data point.

The LGD[1] coal bed (plate 4) ranges in thickness from 3.8 to 6.7 feet (1.2 to 2.0 m) where measured along the outcrop. The coal bed is believed to exceed Reserve Base thickness over only a small area in the central part of sec. 35, T. 5 N., R. 89 W., and contains a thin rock parting 0.3 feet (0.1 m) thick.

Middle Coal Group

The Middle Coal Group is located between the top of the Trout Creek Sandstone Member of the Iles Formation and the base of the Twentymile Sandstone Member of the Williams Fork Formation. In quadrangles to the east, Bass and others (1955) indicate that most of the coal beds can be placed in three main zones (F, G, and H) and that two other coal beds (I and J), which may also be zones farther west, overlie the main zones in the coal-bearing sequence of strata. All zones except zone I contain coal beds exceeding Reserve Base thickness in this quadrangle.

Zone F

Only one coal bed, the MGF [3] (plate 4), is known to exceed Reserve Base thickness within zone F, and it ranges in thickness from 5.1 to 6.8 feet (1.6 to 2.1 m) where measured along the outcrop and in one drill hole in the northeast corner of the quadrangle.

Zone G

Coal beds in zone G have been identified in outcrops and drill holes in the northeastern and southwestern parts of the quadrangle, and 11 coal beds are known to exceed Reserve Base thickness. Three coal beds, the MGG[5], MGG[9], and MGG[11], were isopached while each of the other eight coal beds, the MGG[4], MGG[6], MGG[7], MGG[8], MGG[10], MGG[12], MGG[13], and MGG[14], were each identified at one location only and are treated as isolated data points.

The MGG[5] coal bed (plate 4) was penetrated by two drill holes in the southwestern corner of the quadrangle where measured thicknesses were reported to be 8.0 and 9.0 feet (2.4 and 2.7 m). However, this coal bed is inferred to thin rapidly to 5.0 feet (1.5 m) because of the uncertainty of correlations in other nearby drill holes.

The MGG[9] coal bed (plate 7) was identified in the same two drill holes that penetrated the MGG[5] coal bed. Its measured thicknesses are 7.0 and 8.0 feet (2.1 and 2.4 m). This coal bed has also been inferred to thin rapidly because of doubtful correlations in nearby drill holes.

The MGG[11] coal bed (plate 7) crops out in the northeastern part of the quadrangle and ranges in thickness from 4.5 to 7.0 feet (1.4 to 2.1 m) where measured along the outcrop. Its maximum measured thickness of 9.2 feet (2.8 m) was recorded in a drill hole in sec. 21, T. 5 N., R. 89 W., and included a shale parting 0.2 feet (0.6 m) thick. This coal bed extends into the adjacent Hayden Gulch quadrangle to the east where it ranges from 5.3 to 7.0 feet (1.6 to 2.1 m) in thickness.

Zone H

Coal beds in zone H have been identified in drill holes and an outcrop in the southwestern part of the quadrangle. Of the six coal beds known to exceed Reserve Base thickness, only two, the MGH[22] and MGH[24], were identified at more than one location and have been isopached. The remaining four coal beds, including the MGH[15], MGH[17], MGH[25], and MGH[27], were treated as isolated data points. In addition, two other coal beds in zone H (the MGH[19] and MGH[21] coal beds) have been projected into this quadrangle based on the extrapolation of geologic data in adjacent quadrangles.

The MGH[22] coal bed (plate 14) has been penetrated by drill holes in the southwestern corner of the quadrangle where it ranges in thickness from 2.4 to 9.0 feet (0.7 to 2.7 m), attaining its maximum measured thickness in this quadrangle in sec. 4, T. 3 N., R. 90 W. This coal bed thickens to the west and varies from 5.8 to 14.0 feet (1.8 to 4.3 m) where measured in outcrops and drill holes in the adjacent Hamilton quadrangle.

The MGH[24] coal bed (plate 17) ranges in thickness from 11.2 to 26.7 feet (3.4 to 8.1 m) where measured along the outcrop and penetrated by drill holes in the southwestern corner of the quadrangle. Thin rock partings ranging from 0.2 to 1.1 feet (0.6 to 0.3 m) in cumulative thickness were recorded in the Cedar Creek mine, where the coal bed has been mined locally, and in a drill hole about 1 mile (1.6 km) to the south-southeast of the mine. This coal bed is quite extensive in the southern half of the Hamilton quadrangle to the west and ranges from 13.0 to 25.5 feet (4.0 to 7.8 m) in thickness where measured in drill holes.

Although the MGH[19] coal bed (plate 14) has not been identified in the Pagoda quadrangle, it is believed to extend into the northeastern corner of this quadrangle based on the projection of coal-bed measurements made in the Breeze Mountain quadrangle to the north. This coal bed extends over much of the southernpart of the Breeze Mountain quadrangle and ranges from 3.0 to 12.0 feet (0.9 to 3.7 m) in thickness where measured in numerous outcrops and drill holes. Based on these measurements, the coal bed is inferred to range from 5 to 8 feet (1.5 to 2.4 m) in thickness in the area where it is projected into this quadrangle.

Based on outcrop and drill-hole data to the north and east in the Breeze Mountain and Hayden Gulch quadrangles, respectively, the MGH[21] coal bed is believed to extend into the northeastern corner of this quadrangle as shown on plate 11. In the Breeze Mountain quadrangle, the coal bed ranges in thickness from 1.5 to 9.0 feet (0.5 to 2.7 m) and commonly contains rock partings that vary from 1.0 to 1.8 feet (0.3 to 0.5 m) thick. This coal bed is not, however, of Reserve Base thickness where projected from the Breeze Mountain quadrangle. In the Hayden Gulch quadrangle to the east, coal thicknesses range from 5.0 to 13.0 feet (1.5 to 4.0 m) and rock partins are also common, varying from 0.2 to 1.5 feet

(0.06 to 0.5 m) in thickness. In the area where the MGH[21] coal bed has been projected from the Hayden Gulch quadrangle, its thickness is inferred to be from 5 to 6 feet (1.5 to 1.8 m).

Zone J

Zone J has not been identified in drill holes or outcrops in the Pagoda quadrangle. However, based on data from numerous drill holes and outcrop measurements in the Breeze Mountain quadrangle, the MGJ[26] coal bed (plate 11) is believed to extend into the northeastern part of this quadrangle and to range from 5 to 9 feet (1.5 to 2.7 m) thick in that area. The coal bed ranges in thickness from 1.7 to 18.0 feet (0.5 to 5.5 m) in the southern part of the Breeze Mountain quadrangle.

Undifferentiated Middle Coal Group Coal Beds

The MG[20] and MG[35] coal beds have not been observed in the Pagoda quadrangle, but are believed to extend into this quadrangle based on the projection of coal bed measurements made in the Hamilton quadrangle to the west. Because of incomplete geologic data, the coal beds cannot be located in the stratigraphic section with enough accuracy to place the coal beds within a specific zone, and they are just designated as belonging to the Middle Coal Group.

The MG[20] coal bed (plate 4) ranges from 8.0 to 10.0 feet (2.4 to 3.0 m) thick where measured in the Hamilton quadrangle. Based on these measurements, the coal bed is inferred to range from 5 to 9 feet (1.5 to 2.7 m) thick near the southwestern corner of this quadrangle.

Where penetrated by drill holes in the Hamilton quadrangle, measured thicknesses of the MG[35] coal bed range from 5.5 to 13.0 feet (1.7 to 4.0 m), and the coal bed is believed to be as much as 13 feet (4.0 m) thick in the southwestern part of this quadrangle (plate 7).

Upper Coal Group

The Upper Coal Group extends upward from the top of the Twentymile Sandstone Member to the base of the Lewis Shale. Three coal-bearing zones (zones K, M and N), sometimes referred to as beds by Bass and others (1955), in the Upper Coal Group have been identified in the northeastern corner of the Pagoda quadrangle, but only zones K and M contain coal beds exceeding Reserve Base thickness.

Zone K

Only one coal bed, the UGK[16], has been identified within this zone in this quadrangle. It crops out in the northeastern corner (plate 17) where it ranges in thickness from 3.0 to 6.8 feet (0.9 to 2.1 m) and contains a rock parting 1.8 feet (0.5 m) thick at one location. This coal bed extends into adjacent quadrangles to the north, northeast, and east. To the north in the Breeze Mountain quadrangle, the UGK[16] coal bed varies in thickness from 1.5 to 7.0 feet (0.5 to 2.1 m); it has a maximum reported thickness of 9.0 feet (2.7 m) in the Hayden quadrangle to the northeast; and it is believed to be 7.0 feet (2.1 m) thick in the extreme northeastern corner of the Hayden Gulch to the east based on data projected into that quadrangle from the Hayden quadrangle.

Zone M

The UGM [33] is the only coal bed that has been identified within this zone in this quadrangle and it crops out in the extreme northeastern corner of the quadrangle (plate 4). It ranges in thickness from 2.3 to 7.2 feet (0.7 to 2.2 m) where measured along the outcrop in sec. 21, T. 5 N., R. 89 W., and contains cumulative rock partings of 1.2 feet (0.4 m) thick at one location. This coal bed extends northward into the Breeze Mountain quadrangle where it ranges in thickness from 2.0 to 13.8 feet (0.6 to 4.2 m).

Isolated Data Points

In instances where single or isolated measurements of coal beds thicker than 5 feet (1.5 m) 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 correlations with other, better known coal beds. For this reason, isolated data points are included on a separate sheet (in U.S. Geological Survey files) for non-isopached coal beds. Descriptions and Reserve Base tonnages for the isolated data points occurring in this quadrangle and the influences from isolated data points in the adjacent Breeze Mountain and Hayden quadrangles are listed in table 5.

COAL RESOURCES

Data from drill holes, mine measured sections, and outcrop measurements (Bass and others, 1955; Meyer, 1977 and 1978) were used to construct outcrop, isopach, and structure contour maps of the coal beds in the Pagoda quadrangle. The source of each indexed data point shown on plate 1 is listed in table 6.

Coal resources for Federal land were calculated using data obtained from the coal isopach maps (plates 4, 7, 11, 14, and 17) and the ADIR maps (plates 6, 10, 13, 16, and 20). The coal bed acreage (measured by planimeter), multiplied by the average thickness of the coal bed and by a conversion factor of 1,800 short tons of coal per acre-foot (13,238 metric tons per hectare-meter) for bituminous coal, yields the coal resources in short tons of coal for each coal bed. Coal beds exceeding Reserve Base thickness (5 feet or 1.5 meters) that lie less than 3,000 feet (914 m) below the ground surface are included. These criteria differ somewhat from those stated in U.S. Geological Survey Bulletin 1450-B which call for a minimum thickness of 28 inches (70 cm) and a maximum depth of 1,000 feet (305 m) for bituminous coal.

Reserve Base and Reserve tonnages for the isopached coal beds are shown on plates 6, 10, 13, 16, and 20, and are rounded to the nearest 10,000 short tons (9,072 metric tons). Only Reserve Base tonnages (designated as inferred resources) are calculated for areas influenced by the isolated data points. Coal Reserve Base tonnages per Federal section are shown on plate 2 and total approximately 147.36 million short tons (133.68 million metric tons) for the entire quadrangle, including the tonnages for the isolated data points.

Dames & Moore has not made any determination of economic recoverability for any of the coal beds described in this report.

COAL DEVELOPMENT POTENTIAL

Coal development potential areas are drawn to coincide with the boundaries of the smallest legal land subdivisions shown on plate 2. In sections or parts of sections where no land subdivisions have been surveyed by the BLM, approximate 40-acre (16-ha) parcels have been used to show the limits of the high, moderate, or low development potentials. A constraint imposed by the BLM specifies that the highest development potential affecting any part of a 40-acre (16-ha) lot, tract, or parcel be applied to that entire lot, tract, or parcel. For example, if 5 acres (2 ha) within a parcel meet criteria for 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.

Development Potential for Surface Mining Methods

Areas where the coal beds of Reserve Base thickness are overlain by 200 feet (61 m) or less of overburden are considered to have potential for surface mining and were assigned a high, moderate, or low development potential based on the mining ratio (cubic yards of overburden per ton of recoverable coal). The formula used to calculate mining ratios for surface mining of coal is shown below:

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

where MR = mining ratio

t_o = thickness of overburden in feet

t_c = thickness of coal in feet

rf = recovery factor (85 percent for this quadrangle)

cf = conversion factor to yield MR value in terms of cubic yards of overburden per short tons of recoverable coal:
0.911 for subbituminous coal
0.896 for bituminous coal

Note: 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 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.

Areas where the coal data is absent or extremely limited between the 200-foot (61-m) overburden line and the outcrop are assigned unknown development potential for surface mining methods. This applies to areas where coal beds 5 feet (1.5 m) or more thick are not known, but may occur, and to those areas influenced by isolated data points. Limited knowledge pertaining to the areal distribution, thickness, depth, and attitude of the coal beds prevents accurate evaluation of development potential in the high, moderate, and low categories. The areas influenced by isolated data points in this quadrangle total approximately 7.96 million short tons (7.22 millon metric tons) of coal available for surface mining.

The coal development potential for surface mining methods is shown on plate 21. Of those Federal land areas having a known development potential for surface mining, 88 percent are rated high, 7 percent are rated moderate, and 5 percent are rated low. The remaining Federal lands within the KRCRA boundary are classified as having unknown development potential for surface mining methods. Reserve Base tonnages in the varous development potential categories for surface mining methods are listed in table 2.

Development Potential for Subsurface and In-Situ Mining Methods

Areas considered to have a development potential for conventional subsurface mining methods include those areas where the coal beds are between 200 and 3,000 feet (61 and 914 m) below the ground surface and have dips of 15° or less. Unfaulted coal beds lying between 200 and

3,000 feet (61 and 914 m) below the ground surface, dipping greater than 15°, are considered to have a development potential for in-situ mining methods.

Areas of high, moderate, and low development potential for conventional subsurface mining methods are defined as areas underlain by coal beds at depths ranging from 200 to 1,000 feet (61 to 305 m), 1,000 to 2,000 feet (305 to 610 m), and 2,000 to 3,000 feet (610 to 914 m), respectively.

Areas where the coal data is absent or extremely limited between 200 and 3,000 feet (61 and 914 m) below the ground surface are assigned unknown development potentials. This applies to the areas where coal beds of Reserve Base thickness are not known, but may occur, and to those areas influenced by isolated data points. The areas influenced by isolated data points in this quadrangle contain approximately 5.30 million short tons (4.81 million metric tons) of coal available for conventional subsurface mining.

The coal development potential for conventional subsurface mining methods is shown on plate 22. All of the Federal land areas having known development potential for conventional subsurface mining methods are rated high. The remaining Federal lands within the KRCRA boundary are classified as having unknown development potentials for conventional subsurface mining methods. Reserve Base tonnages in the various development potential categories for conventional subsurface mining methods are listed in table 3.

Based on criteria provided by the U.S. Geological Survey, coal beds of Reserve Base thickness dipping between 35° and 90° with a minimum Reserve Base of 50 million short tons (45.4 million metric tons) for bituminous coal and 70 million short tons (63.5 million metric tons) for subbituminous coal have a moderate potential for in-situ development; coal beds dipping from 15° to 35°, regardless of tonnage, and coal beds dipping from 35° to 90° with less than 50 million short tons (45.4

million metric tons) of coal have a low development potential for in-situ mining methods. Coal lying between the 200-foot (61 m) overburden line and the outcrop is not included in the total coal tonnages available as it is needed for cover and containment in the in-situ process.

Coal development potential for in-situ mining methods is shown on plate 22. All of the Federal lands where the dip of the coal beds exceeds 15° are rated low for in-situ development potential because only approximately 9.22 million short tons (8.36 million metric tons) of coal distributed through four different coal beds and one isolated data point are believed to be available for in-situ mining. The remaining Federal lands within the KRCRA boundary are classified as having unknown development potential for in-situ mining methods. Reserve Base tonnages in the various development potential categories for in-situ mining methods are listed in table 4.

Table 1. -- Chemical analyses of coals in the Pagoda quadrangle, Routt and Moffat Counties, Colorado.

Location	COAL BED NAME	Form of Analysis	Proximate				Ultimate						Heating Value	
			Moisture	Volatile Matter	Fixed Carbon	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen	Calories	Btu/Lb
NE¼ sec. 29, T. 5 N., R. 89 W., Core hole (Bass and others, 1955)	Lower Coal Group	A	9.1	34.9	49.0	7.0	0.6	-	-	-	-	-	11,560
		B	5.7	36.3	50.8	7.2	0.6	-	-	-	-	-	12,000
		C	-	38.5	53.8	7.7	0.6	-	-	-	-	-	12,720
NW¼ sec. 28, T. 5 N., R. 89 W., Core hole (Bass and others, 1955)	Middle Coal Group zone F	A	10.3	33.2	49.5	7.0	0.7	-	-	-	-	-	11,320
		B	8.1	34.0	50.7	7.2	0.7	-	-	-	-	-	11,590
		C	-	37.0	55.2	7.8	0.8	-	-	-	-	-	12,620
SW¼ sec. 21, T. 5 N., R 89 W., Core hole (Bass and others, 1955)	Middle Coal Group zone G	A	11.6	36.8	46.3	5.3	0.7	-	-	-	-	-	11,160
		B	7.8	38.4	48.3	5.5	0.7	-	-	-	-	-	11,650
		C	-	41.7	52.3	6.0	0.8	-	-	-	-	-	12,630
SW¼ sec. 21, T. 5 N., R. 89 W., Core hole (Bass and others, 1955)	Middle Coal Group zone H	A	11.3	37.5	42.3	8.9	0.5	-	-	-	-	-	10,590
		B	8.2	38.8	43.8	9.2	0.5	-	-	-	-	-	10,960
		C	-	42.3	47.7	10.0	0.5	-	-	-	-	-	11,940
Sec. 31, T. 6 N., R. 89 W., Cary Mine (George and others, 1937) from Breeze Mountain quadrangle	Upper Coal Group zone M coal bed {33}	A	13.4	34.0	47.8	4.8	0.6	-	-	-	-	-	10,910
		C	-	39.3	59.2	5.5	0.7	-	-	-	-	-	12,600

Form of Analysis: A, as received
B, air dried
C, moisture free

Note: To convert Btu/pound to kilojoules/kilogram, multiply by 2.326

Table 2. -- Coal Reserve Base data for surface mining methods for Federal coal lands (in short tons) in the Pagoda quadrangle, Routt and Moffat Counties, Colorado.

Coal Bed or Zone	High Development Potential	Moderate Development Potential	Low Development Potential	Unknown Development Potential	Total
UGM {33}	50,000	20,000	10,000	-	80,000
UGK {16}	450,000	60,000	150,000	-	660,000
MGJ {26}	590,000	290,000	830,000	-	1,710,000
MG {35}	1,070,000	420,000	230,000	-	1,720,000
MGH {24}	8,990,000	1,580,000	350,000	-	10,920,000
MGH {22}	170,000	130,000	300,000	-	600,000
MG {20}	480,000	30,000	80,000	-	590,000
MGH {19}	510,000	240,000	460,000	-	1,210,000
MGG {11}	2,350,000	630,000	2,890,000	-	5,870,000
MGG {9}	100,000	90,000	250,000	-	440,000
MGG {5}	270,000	140,000	360,000	-	770,000
MGF {3}	690,000	320,000	1,240,000	-	2,250,000
LGD {1}	40,000	40,000	70,000	-	150,000
Isolated Data Points	-	-	-	7,960,000	7,960,000
Totals	15,760,000	3,990,000	7,220,000	7,960,000	34,930,000

NOTE: To convert short tons to metric tons, multiply by 0.9072.

Table 3. -- Coal Reserve Base data for subsurface mining methods for Federal coal lands (in short tons) in the Pagoda quadrangle, Routt and Moffat Counties, Colorado.

Coal Bed or Zone	High Development Potential	Moderate Development Potential	Low Development Potential	Unknown Development Potential	Total
JGK {16}	230,000	-	-	-	230,000
MGJ {26}	3,420,000	-	-	-	3,420,000
MG {35}	1,880,000	-	-	-	1,880,000
MGH {24}	52,270,000	-	-	-	52,270,000
MGH {22}	11,180,000	-	-	-	11,180,000
MGH {21}	700,000	-	-	-	700,000
MG {20}	3,470,000	-	-	-	3,470,000
MGH {19}	2,340,000	-	-	-	2,340,000
MGG {11}	10,910,000	120,000	-	-	11,030,000
MGG {9}	3,280,000	-	-	-	3,280,000
MGF {5}	4,890,000	-	-	-	4,890,000
MGF {3}	3,220,000	-	-	-	3,220,000
LGD {1}	-	-	-	-	-
Isolated Data Points	-	-	-	5,300,000	5,300,000
Totals	97,790,000	120,000	-	5,300,000	103,210,000

NOTE: To convert short tons to metric tons, multiply by 0.9072.

Table 4. -- Coal Reserve Base data for in-situ mining methods for Federal coal lands (in short tons) in the Pagoda quadrangle, Routt and Moffat Counties, Colorado.

Coal Bed or Zone	Moderate Development Potential	Low Development Potential	Unknown Development Potential	Total
UGK {16}	-	-	-	-
MGJ {26}	-	-	-	-
MG {35}	-	-	-	-
MGH {24}	-	7,040,000	-	7,040,000
MGH {22}	-	140,000	-	140,000
MGH {21}	-	-	-	-
MG {20}	-	310,000	-	310,000
MGH {19}	-	-	-	-
MGG {11}	-	-	-	-
MGG {9}	-	-	-	-
MGG {5}	-	-	-	-
MGF {3}	-	-	-	-
LGO {1}	-	50,000	-	50,000
Isolated Data Points	-	-	1,680,000	1,680,000
Totals	-	7,540,000	1,680,000	9,220,000

NOTE: To convert short tons to metric tons, multiply by 0.9072.

Table 5.--Descriptions and Reserve Base tonnages (in million short tons) for isolated data points

Coal Bed	Source	Location	Thickness	Reserve Base Tonnages Surface	Reserve Base Tonnages Subsurface
LGD[2]	Bass and others (1955)	sec. 29, T. 5 N., R. 89 W.	5.6 ft (1.7 m)	0.92	0
MGG[4]	Meyer (1977)	sec. 27, T. 4 N., R. 90 W.	8.4 ft (2.6 m)	0.72	0.37
MGG[6]	Meyer (1977)	sec. 27, T. 4 N., R. 90 W.	7.3 ft (2.2 m)	0.71	0.37
MGG[7]	Bass and others (1955)	sec. 21, T. 5 N., R. 89 W.	5.1 ft (1.6 m)	0.59	0.12
MGG[8]	Meyer (1977)	sec. 4, T. 3 N., R. 90 W.	7.0 ft (2.1 m)	0.11	0.59
MGG[10]	Bass and others (1955)	sec. 21, T. 5 N., R. 89 W.	7.5 ft (2.3 m)	0.86	0.06
MGG[12]	Meyer (1977)	sec. 27, T. 4 N., R. 90 W.	8.8 ft (2.7 m)	0.87	0.07
MGG[13]	Meyer (1977)	sec. 4, T. 3 N., R. 90 W.	13.4 ft (4.1 m)	0.54	0.84
MGG[14]	Meyer (1978)	sec. 3, T. 3 N., R. 90 W.	14.8 ft (4.5 m)	0	1.83
MGH[15]	Meyer (1977)	sec. 4, T. 3 N., R. 90 W.	17.2 ft (5.2 m)	0.19	1.68*
MGH[17]	Meyer (1977)	sec. 34, T. 4 N., R. 90 W.	7.6 ft (2.3 m)	0.49	0.05

NOTE: To convert short tons to metric tons, multiply short tons by 0.9072

*Tonnage for coal bed dipping greater than 15°

Table 5.--Continued

Coal Bed	Source	Location	Thickness	Reserve Base Tonnages Surface	Reserve Base Tonnages Subsurface
MGH[25]	Meyer (1977)	sec. 4, T. 3 N., R. 90 W.	7.3 ft (2.2 m)	0.63	0.05
MGH[27]	Meyer (1978)	sec. 3, T. 3 N., R. 90 W.	8.5 ft (2.6 m)	0	1.16
MG[32]	Meyer (1977)	sec. 28, T. 4 N., R. 90 W.	28.0 ft (8.5 m)	0.92	0
		From Breeze Mountain quadrangle			
UG[37]	Brownfield (1977)	sec. 21, T. 5 N., R. 89 W.	5.5 ft (1.7 m)	0.29	0
		From Hayden quadrangle			
UGM[11]	Brownfield (1976)	sec. 21, T. 5 N., R. 89 W.	6.0 ft (1.8 m)	0.05	0
UGN[12]	Brownfield (1976)	sec. 21, T. 5 N., R. 89 W.	8.0 ft (2.4 m)	0.07	0

Table 6. -- Sources of data used on plate 1

Plate 1 Index Number	Source	Data Base
1	Meyer, 1977, U.S. Geological Survey Open-File Report No. 77-118	Drill hole No. H-29-P
2	↓	Drill hole No. H-18-P
3	↓	Drill hole No. H-19-P
4	↓	Drill hole No. H-24A-P
5	↓	Drill hole No. H-5-P
6	↓	Drill hole No. H-7A-P
7	Meyer, 1978, U.S. Geological Survey Open-File Report No. 78-366	Drill hole No. H-31-P
8	Bass and others, 1955, U.S. Geological Survey Bulletin 1027-D, pl. 23	Mine-Measured Section No. 374
9	Meyer, no date, U.S. Geological Survey, unpublished data	Drill hole No. H-41-P
10	Bass and others, 1955, U.S. Geological Survey Bulletin 1027-D, pl. 23	Measured Section No. 286
11	↓	Measured Section No. 284
12	↓	Drill hole No. 312b
13	↓	Measured Section No. 278
14	↓	Measured Section No. 280
15	↓	Measured Section No. 314
16	↓	Measured Section No. 313
17	↓	Drill hole No. 313a

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Table 6. -- Continued

Plate 1 Index Number	Source	Data Base
18	Bass and others, 1955, U.S. Geological Survey Bulletin 1027-D, pl. 23	Measured Section No. 320
19		Measured Section No. 322
20		Measured Section No. 315
21		Measured Section No. 321
22		Measured Section No. 279
23		Measured Section No. 312
24	Meyer, 1977, U.S. Geological Survey Open-File Report No. 77-118	Drill hole No. H-6A-P

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