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UPPER CRETACEOUS (CAMPANIAN) COAL RESOURCES OF WESTERN COLORADO

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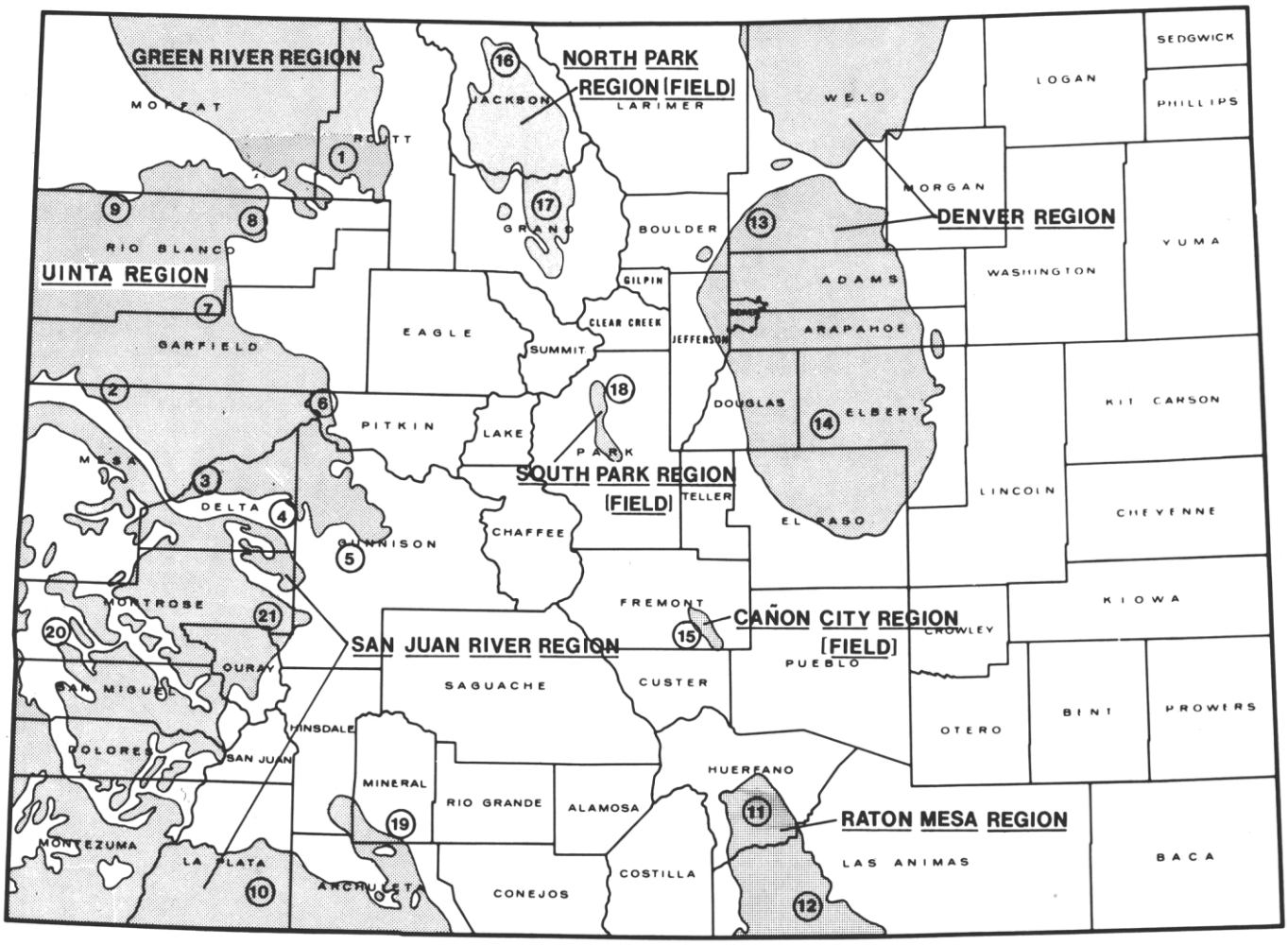
INTRODUCTION

Colorado encompasses parts or all of eight distinct coal-bearing regions, which cover nearly 30 percent of the total area of the State (fig. 1). These eight regions, within which are located 21 designated coal fields, contain more than 10 percent of the total coal reserves of the United States above a depth of 1,830 m (6,000 ft), or at least 434 billion short (394 billion metric) tons of in-place coal. Of this resource, more than 273 billion short (248 billion metric) tons, or 63 percent of the total, have been estimated for the Green River, San Juan River, and Uinta coal regions of western Colorado (see Murray, 1980a, 1980b). Although most of this resource is believed to consist of coals of Cretaceous age, no data presently are available regarding the breakdown of coal resources in Colorado by geologic age or formation. However, based on the known distribution and thicknesses of the widespread, multiple (often numbering 20 to 30 or more) coal beds encountered in the Mesaverde Group and equivalents (essentially, Campanian in age), there is little doubt that the bulk of the coal resources of Colorado lies within this sequence. In the southeast part of the Uinta region, for example, total net thickness of Mesaverde coals in places exceeds 24 m, based on an evaluation of oil and gas well geophysical logs in the area (see Murray and others, 1977, p. 389). In the Dan-



1. Yampa
2. Book Cliffs
3. Grand Mesa
4. Somerset
5. Crested Butte
6. Carbondale
7. Grand Hogback
8. Danforth Hills
9. Lower White River
10. Durango
11. Walsenburg
12. Trinidad
13. Boulder-Weld
14. Colorado Springs
15. Canon City
16. North Park
17. Middle Park
18. South Park
19. Pagosa Springs
20. Nucla-Naturita
21. Tongue Mesa

Figure 1. Coal-bearing regions and fields in Colorado.

forth Hills coal field, Rio Blanco and Moffat Counties (fig. 1), total coal thicknesses in the 30-47 m range have been noted, based upon subsurface information. To date, western Colorado coal fields have produced more than 224 million short (203 million metric) tons of coal, which amounts to nearly 33.5 percent of the State's cumulative production, from 1864 through 1980, of nearly 670 million short (608 million metric) tons. During 1980, the three western Colorado coal regions produced more than 17 million short (15.4 million metric) tons of coal, or 90 percent of the State's total. Virtually all of the historic coal production from western Colorado has come from Cretaceous-age sequences; and all of the present production consists of coals of this age. Based on preliminary data from the Colorado Division of Mines, nearly 12 million short (10.9 million metric) tons of coal was surface-mined in western Colorado during 1980, which comprises 70 percent of all coal mined in that region and nearly 93 percent of all surface-mined coal in Colorado.

COAL-BEARING ROCKS

Colorado coals range in age from early Late Cretaceous to Eocene. The higher rank bituminous coals, which comprise the largest reserves, generally are found in the Upper Cretaceous Dakota and Mesaverde Groups in western Colorado, especially in the region extending from Garfield County south to the New Mexico state line. The oldest coals in Colorado occur in the Dakota Group in the southwestern part of the State (northern San Juan River region, Durango to Nucla-Naturita field areas). Successively younger coals were laid down as the Late Cretaceous Western Interior sea retreated eastward and northeastward from the region (Murray, 1980a).

The youngest coals, generally of lower rank (subbituminous A to lignite), are found in latest Cretaceous and early Tertiary rocks in the Green River, North and South Park, Raton Mesa and Denver coal regions. Subbituminous coals occur in the Cretaceous Lance, Laramie, and Vermejo formations; in the Paleocene Fort Union and Raton formations; and in the Paleocene-Eocene Wasatch and Coalmont formations. Lignite is restricted to the Paleocene-age upper part of the Denver Formation in the central Denver coal region (Murray, 1980a).

The Cretaceous-age coal-bearing sequences (fig. 2) and coal ranks present in the western Colorado regions can be generalized as follows (units presently being mined are in bold-face type) (Murray, 1980a):

GREEN RIVER REGION:

Lance Formation (Upper Cretaceous)-probably mostly subbituminous B and C.

Mesaverde Group (Upper Cretaceous)-mostly high-volatile C bituminous, some high-volatile B bituminous and subbituminous A.

SAN JUAN RIVER REGION:

Fruitland Formation (Upper Cretaceous)-high-volatile B and C bituminous.

Menefee Formation of Mesaverde Group (Upper Cretaceous)-high-volatile A and B bituminous (locally of coking quality).

Dakota Group (Upper Cretaceous)-high-volatile B and C bituminous (currently mined only in Nucla-Naturita field; may locally be of coking quality).

UINTA REGION:

Mesaverde Group (Upper Cretaceous)-anthracite and semi-anthracite (restricted to areas of igneous activity in southeastern part of area, especially in Crested Butte field); medium-volatile bituminous (high-grade coking coal, chiefly in Coal Basin area of Carbondale field); high-volatile A, B, and C bituminous (of coking quality in parts of Carbondale and Somerset fields); subbituminous A and B(?) (only in local areas near outcrops).

STRUCTURE OF COAL-BEARING REGIONS

The San Juan River, Uinta and Green River coal regions, for the most part, are located within Laramide-age structural basins. The interior areas of these basins appear to be relatively free from structural complications; here the coal beds probably are not highly folded, faulted or otherwise disturbed. However, some margins of these structural basins are moderately to severely

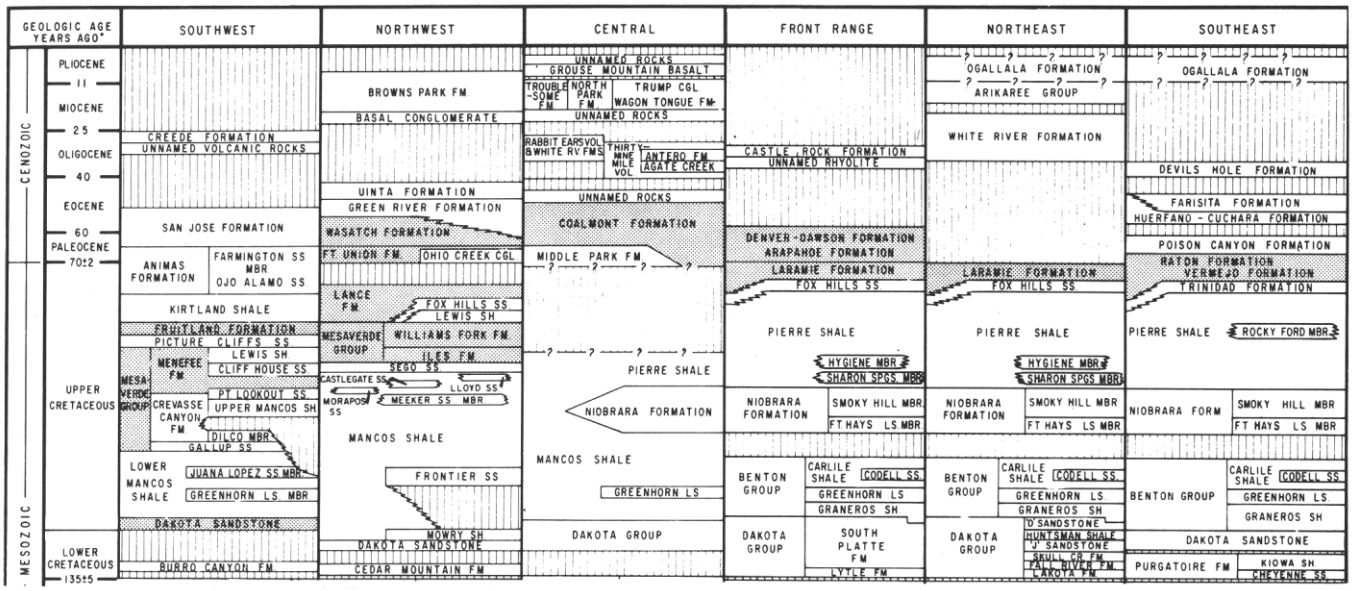


Figure 2. Colorado stratigraphic correlation chart, parts of Mesozoic and Cenozoic Eras. Coal-bearing units are shaded.

folded and faulted. In places, Tertiary igneous activity has metamorphosed the coal to anthracite, and even to coke. The Uinta region, which is located partially within the Piceance Creek basin, and the Green River region, the Colorado portion of which includes the Sand Wash basin, each contains significant coal resources to depths exceeding 3000 m. The Piceance Creek and Sand Wash basins are the deepest structural depressions in the State (Murray, 1980a).

Only a small part, possibly 5 to 10 percent, of the coal resources of Colorado today are considered to be surface-minable due to the limited areas within the coal-bearing regions in which the coal beds are both of gentle dip and under "shallow" cover (Murray, 1980a).

CHARACTERISTICS OF UPPER CRETACEOUS COALS

Coal Rank

Statewide, Colorado coals range in rank from lignite to anthracite; however, western Colorado coals vary from subbituminous to anthracite in rank, but are predominantly bituminous. More than 70 percent of the State's coal resources are bituminous, approximately 23 percent subbituminous, five percent lignite (in the Denver coal region), and less than 2 percent anthracite (Murray, 1980b).

Generally, the older a coal, the higher its rank. However, geologic factors such as above-normal geothermal gradient and burial to great depths (say, below 1500 to 3000 m) can significantly increase the rank of even the youngest coals. This is especially true in the relatively deep structural basins of western Colorado, parts of which are characterized by notably high geothermal heat flow resulting from Tertiary-age igneous activity.

Coal Analyses

Since 1975, the Colorado Geological Survey and the U.S. Geological Survey have been conducting cooperative programs to sample and analyze most of the producing coal mines in Colorado, together with coals likely to be mined in the future that have been cored by both Federal and private industry drilling programs.

Results of the first of these programs have been published (Boreck and others, 1977), and analytical results of additional coal sampling efforts by the Colorado Geological Survey are in press (Khalsa and others, 1981). A significant percentage of these analyses pertain to western Colorado coals. Table 1 compares certain chemical characteristics of coals from the Green River region, in northwest Colorado, with coals from the entire Rocky Mountain coal province (of which Colorado is a part), Interior province (Illinois, Iowa, Kansas, etc.), and Northern Great Plains province (Montana, North and South Dakota, and northeastern Wyoming).

Table 1. Arithmetic mean of proximate, ultimate, and heating value analyses for the Yampa coal *field, Green River region, Colorado; compared with the arithmetic means for the* Rocky *Mountain, Interior, and Northern* Great *Plains coal provinces (modified from Boreck and others, 1977).*

	Green River Region -- Yampa Field	Rocky Mountain Province	Interior Province	Northern Great Plains Province
Moisture (%)	8.0	12.9	7.2	24.5
Volatile Matter (%)	37.4	36.0	32.2	31.7
Fixed Carbon (%)	45.9	42.0	48.0	35.4
Ash (%)	9.0	9.1	12.6	8.3
Hydrogen (%)	5.4	5.6	4.9	6.2
Carbon (%)	63.9	59.7	65.2	49.2
Nitrogen (%)	1.6	1.2	1.2	0.9
Oxygen (%)	19.8	23.8	12.2	34.2
Sulfur (%)	0.5	0.6	3.9	1.2
Heating Value (Btu/lb.)	11,203	10,480	11,580	8,480

None of the Colorado coals sampled to date, which include coals from all of the larger producing mines in the State, appears to contain significant quantities of toxic or radioactive elements (such as arsenic, mercury, selenium, strontium, thorium, and uranium). In fact, most appear to contain smaller amounts of these substances than do coals from other regions of the United States (Murray, 1980b).

Moisture, volatile matter, and fixed carbon contents of Colorado coals vary considerably with rank from region to region. Moisture content is generally in the 1- to 20-percent range, as-received. An overall average of about 12 percent moisture is a general value for Colorado coals. Statewide, volatile matter content varies from 6.9 percent (in anthracite in Crested Butte field) to approximately 45 percent, with most coals being in the 31-40 percent range. Fixed carbon content typically varies between 39 and 69 percent.

The ash content of coal beds in Colorado varies considerably as a result of different environments of deposition, even within the same coal "zone." The range typically is from approximately two to 20 percent, averaging about six percent. Locally, however, ash content may reach 25-30 percent, as-received (Murray, 1980b).

Sulfur content of most Colorado coal beds varies from 0.2 to 1.2 percent, as-received. More than 99 percent of the coals analyzed contain less than 1.0 percent, and more than 50 percent contain less than 0.7 percent sulfur. The bulk of the coal being surface-mined in Colorado at present contains between 0.2 and 0.5 percent sulfur; on the other hand, much of the underground-mined metallurgical-grade coal in Colorado contains 0.5-1.0 percent sulfur, still low in comparison with many Eastern coals.

In terms of pounds of sulfur per million Btu, most of the coal being surface-mined in Colorado today for use in steam-electric power plants contains between approximately 0.2 and 0.5 lb/million Btu (0.04 and 0.10 kg/million kJ), well within the definition of low-sulfur coal: specifically, one which contains 0.6 lb or less sulfur per million Btu (0.12 kg or less/million kJ) (Murray, 1980b).

Most of the subbituminous and bituminous steam coal being produced today in Colorado ranges from about 10,000 to 13,600 Btu/lb (23,260 to 31,634 kJ/kg); and coking coal, from 12,070 to over 14,000 Btu/lb (28,075 to over 32,564 kJ/kg), as-received. On a dry, ash-free basis, most Colorado coals vary between 13,300 and 14,500 Btu/lb (30,936 and 33,727 kJ/kg) in heat content. On a moisture- and ash-free basis, an average of approximately 14,000 Btu/Ib (32,564 kJ/kg) is reasonable for most Colorado coals; and on an as-received basis, about 11,370 Btu/Ib (26,447 kJ/kg) (Murray, 1980a).

Coking Coal

Studies indicate that the original, identified, in-place coking-coal reserves in the State of Colorado total over 4.3 billion short (3.9 billion metric) tons (Goolsby and others, 1979). These reserves include the highest quality and rank coking coals in the West, and account for Colorado's prominence as an important source of low-sulfur coking coal.

Coal produced from mines in Colorado has served as an important source of coking coal since the Nineteenth Century, when coal was coked in beehive ovens to fuel the State's early metal foundries. Production also was utilized by the railroads, and, eventually, in blast furnaces for the manufacture of steel. Economic and

environmental factors led to the gradual abandonment of beehive ovens in favor of modern byproduct processes for the production of coke. Today, Colorado coals are primarly coked in byproduct ovens operated by CF & I Steel Corporation (Pueblo, Colorado), United States Steel Corporation (Provo, Utah), and Kaiser Steel Corporation (Fontana, California).

Significant reserves of coking, or metallurgical, coal are located in the Raton Mesa, San Juan River, and Uinta coal regions (fig. 1). Although a large percentage of Colorado's historic coking coal production has come from the Trinidad coal field, in the Raton Mesa region, today more than 73 percent (or some 2 million short, 1.8 million metric tons) of the State's coking coal is produced in the Uinta region, from the Carbondale and Somerset fields. Nearly 30 percent of the coal mined in the Uinta region in 1980 was used to make steel or for smelting purposes. Western Colorado coal regions contain approximately 52 percent of the original identified in-place coking-coal reserves in the State, or 2.23 billion short (1.81 billion metric) tons, out of a total of 4.3 billion short (3.9 billion metric) tons (Goolsby and others, 1979), The San Juan River region contains 1.78 billion short (1.61 billion metric) and the Uinta region 0.45 billion short (0.41 billion metric) tons of this in-place reserve. All of the western Colorado coking coals are found in the Dakota and Mesaverde Groups (and equivalents), of Cretaceous age. The highest grade metallurgical coal mined in the western United Sta comes from the Mesaverde Group in the Coal Basin area, Pitkin County, in the Carbondale field of the Uinta region (Murray, 1980b).

Methane from Coal Beds

The Carbondale and Somerset coal fields, located in the southeastern part of the Uinta coal region, are characterized by being the sites of the gassiest producing coal mines in Colordo (fig. 1; see Fender and Murray, 1978; Boreck and Strever, 1980; and Murray, 1980a). According to U.S. Bureau of Mines records, active mines in these two fields emiited (i.e., wasted) a total of approximately 10.65 million cu ft (MMCF) (0.30 million rn^3) of methane per day, diluted to approximately one percent by ventilated air (see Fender and Murray, 1977, Table 3). More than 8.2 MMCFPD (0.23 million m^3/day) methane was ventilated in 1977 from the five Mid-Continent Resources ccking coal mines located in the Coal basin area, near Redstone, Pitkin County, in the Carbondale field. Current methane ventilation figures probably exceed that amount. The Dutch Creek No. 1 mine in Coal Basin, scene of the recent tragic mine explosion that claimed 15 lives, is listed (Fender and Murray, 1977) as having the highest average daily methane emission—more than 2.23 MMCFGPD (0.06 million m^3/day)—of any coal mine in Colorado. This may well be the gassiest coal mine in the western United States. Dutch Creek No. 1 also experienced a "dust" explosion in 1957, and a severe gas explosion in 1965 that claimed several lives. The Coal Basin mines produce the highest grade (premium) coking coal (medium-volatile bituminous) in the West. The deeper portions of the Uinta (Piceance Creek basin), Green River (Sand Wash basin), and San Juan River (San Juan basin) coal regions in Colorado are believed to contain very large, in-place resources of coal-bed methane, numbering in the *trillions* of cubic feet (tcf). In the Piceance Creek basin, Colorado, this gas resource is believed to exceed 12 tcf (340 x 10^9m). An aggressive program of unconventional (i.e., methane-from-coal-beds) gas exploration by the petroleum industry, now just getting underway in this and several other coal-bearing basins in the Rocky Mountain region, is expected eventually to recover a signifiiant part of this valuable energy resource.

COAL-BEARING REGIONS

The coal-bearing regions of western Colorado—the Green River, San Juan River, and Uinta—all lie west of the Continental Divide and are included within the Rocky Mountain coal province. The Green River and Uinta regions fall within the Laramide-age Sand Wash and Piceance Creek basins, respectively (fig. 1). The San Juan River coal region occupies parts of the Chama platform, San Juan basin, Four Corners platform, and Paradox basin, and laps onto the San Juan and Uncompahgre uplifts.

Table 2 includes representative analyses of coal beds from each of the major coal fields in the three western Colorado coal regions.

Green River Region

The southeast arm of the large Green River coal region is located in Moffat and Routt Counties of northwestern Colorado (fig. 1). The larger part of this important coal region covers most of southwestern Wyoming (Averiit, 1972, fig. 3). The Colorado part of this region is comprised of the Sand Wash structural basin, of Laramide age, and the north flank of the Axial Basin uplift, which includes the Williams Fork Mountains and forms the southern edge of the basin. The perimeter of the Green River coal region is defined, except where faulted, by the base of the Upper Cretaceous Mesaverde Group. The oldest coals in the region are found in the Iles Formation, lower Mesaverde Group (fig. 2).

Coal-bearing Upper Cretaceous, Paleocene, and Eocene rocks crop out along the Yampa River-Williams Fork Mountains area, in the southeastern part of the region. This area constitutes the Yampa Coal field, the only named field in the region. The southern flank of the Sand Wash basin consists of gently northward-dipping sediments that are locally folded, especially in the southeastern part of the basin, and complicated by late Tertiary faults and igneous intrusives, which, in places, have upgraded some of the coals to anthracite.

Virtually all of the coals mined to date in the Green River region have come from the Iles and Williams Fork Formations of the Mesaverde Group (fig. 2). Younger coal-bearing rocks (Lance, Fort Union, and Wasatch formations) are preserved toward the interior of the basin, away from outcrops of the Mesaverde, on or near which most of the coal mining to date has taken place. A major part of the region contains multiple coal beds in several formations below a depth of 900 m; in the central part of the Sand Wash basin, coals are present to depths in excess of 3000 m (Jones and others, 1978).

The Mesaverde coals in the Green River region, for the most part, are high-volatile C bituminous in rank and vary in thickness from approximately 1 to 6 m. The younger Lance Formation coals, which have been only locally mined in the past (not mined at present), appear to be subbituminous B or C and range up to about 3 m in thickness.

This region to date has produced more than 114 million short (103 million metric) tons of coal (or approximately 17 percent of the State's coal) from nearly 200 mines. Most of the coal (all of it low-sulfur) currently being mined in the Green River region is burned in steam-electric generating plants located either within the region or elsewhere in Colorado, mostly in the Denver area. Some of the coal is exported to states such as Illinois, Iowa, Nebraska, and Texas.

Total in-place coal resources in the Colorado part of the Green River region probably far exceed 60 billion short (54 billion metric) tons above a depth of 1830 m, although very little work has been done to date in evaluating the coals below "minable" depths.

Table 2. Range of analyses of Cretaceous-age coals of western Colorado, as-received (modified from Murray, 1980b, Table 14).

REGION, Field, Formation (Coal bed)	Moisture (%)	Volatile Matter (%)	Ash (%)	Sulfur (%)	Heating Value (Btu/lb)	Ash Fusion Temperature (°F)	FSI
GREEN RIVER							
Yampa							
Lance Fm. (Lorella, Kimberly)	19.6-21.8	-	4.1- 6.5	0.5-0.7	9,660- 9,720	2,010-2,260	0
Williams Fork Fm., "Upper Coal Gp." (Dry Creek, Crawford, Fish Creek)	9.8-16.9	34.9-39.2	4.1-17.2	0.4-1.8	9,800-11,680	2,070-2,480	0
Williams Fork Fm., "Middle Coal Gp." (Lennox, Wadge)	6.4-11.8	33.8-39.0	3.0-20.2	0.3-0.9	9,871-12,440	2,140-2,890	0-0.5
Iles Fm., "Lower Coal Gp." (E,D,C,B,A or Pinnacle)	6.3-12.2	-	4.3-11.3	0.3-0.9	11,090-12,560	2,250-2,780	0
SAN JUAN RIVER							
Durango							
Fruitland Fm.	0.9- 2.3	20.8-23.6	19.5-26.6	0.7-0.8	11,230-12,140	-	-
Menefee Fm. (9 beds)	1.6-10.7	36.2-42.1	3.4-16.6	0.6-1.3	10,860-14,700	2,020-3,000	0.5.5
Nucla-Naturita							
Dakota Ss. (Fm.) (3 beds)	2.5-13.5	32.6-36.1	6.1-12.8	0.5-1.1	10,010-13,380	2,620-2,910	0-1.5
Tongue Mesa							
Fruitland Fm. (Cimarron)	14.2-16.0	36.0-47.3	6.7- 8.4	0.5-0.9	9,350-10,200	2,450-2,480	0
UINTA							
Book Cliffs							
Mt. Garfield Fm. (Mesaverde Gp.) (Carbonera, Cameo, Palisade, Thomas, Anchor Mine)	3.3-14.0	29.8-35.4	4.9-23.3	0.4-1.7	9,833-13,560	2,130-2,960	0-1.0
Carbondale							
Williams Fork Fm. ("South Canon Gp.", Dutch Creek, Allen, Anderson)	0.8- 3.4	22.0-28.1	3.4-10.0	0.3-1.3	12,470-15,190	2,140-2,505	8.5-9.0
("Fairfield Gp." or A,B,C,D, Coal Basin A-B)	0.8- 4.0	21.8-39.3	3.4- 6.7	0.4-1.5	12,609-15,088	2,180-2,455	1-9
Crested Butte							
Williams Fork Fm., Paonia Mbr.(6 beds)	2.5-13.3	-	3.2- 9.1	0.4-1.9	11,400-14,170	2,130-2,480	0
Danforth Hills							
Williams Fork Fm. (Lion Cyn., Goff, Fairfield Gps.)	8.9-15.5	-	2.2- 9.6	0.3-1.4	10,140-11,790	2,210-2,910	-
Iles Fm. ("Black Diamond Gp.")	9.2-13.4	-	3.7-10.0	0.4-0.6	11,200-11,970	2,210-2,990	-
Grand Hogback							
Williams Fork Fm. (E, Sunnyridge)	4.0- 4.8	37.2-39.8	6.1-10.4	0.6-0.7	12,060-12,581	2,230-2,910	1.0-1.5
Grand Mesa							
Mt. Garfield Fm. (Mesaverde Gp.) (6-8 beds)	3.1-19.5	30.4-35.0	2.1-17.9	0.5-2.2	8,298-13,489	2,060-2,970	-
Lower White River							
Williams Fork Fm.	11.2-14.1	-	4.4- 8.5	0.4-0.5	10,800-11,230	2,060-2,910	0-1.5
Somerset							
Williams Fork Fm. (F,E,D,C,B,A beds)	3.2-13.6	35.3-37.7	3.2-11.4	0.5-0.8	10,040-13,453	2,145-2,810	0-3.0

Speltz (1976) estimates that nearly one billion short (0.9 billion metric) tons of potentially surface-minable coal may exist in this part of the region.

San Juan River Region

The San Juan River coal region is located in southwestern Colorado and in part of west-central Colorado as far north as the Grand Valley-Grand Junction area and the southern part of Delta County (fig. 1; also see maps by Jones and others, 1978; and Averitt, 1972). The larger part of this region lies in northwestern New Mexico and includes the San Juan structural basin, the Red Mesa-Mesa Verde platform, the Cortez saddle, and the eastern part of the Paradox basin, which extends into Utah. The region also includes parts of the Gunnison and Uncompahgre uplifts in Colorado.

Since the late 1800's, the San Juan River region has produced more than 9.5 million short (8.6 million metric) tons of coal from nearly 200 mines, which represents 1.4 percent of the total production of Colorado.

Durango field (fig. 1) includes the Colorado part of the San Juan structural basin, the Hesperus-Red Mesa-Cortez area, and the Mesa Verde area, in La Plata and Montezuma Counties. Coals in the field are found in the Dakota Group, Menefee Formation, and Fruitland Formation, all of Cretaceos age (fig. 2).

Dakota coals are relatively thin, discontinuous, and of high ash content in and near the areas of outcrop (the Hogback) north and northeast of the town of Durango. In the subsurface to the south and west, Dakota coals have been mined to some extent at relatively shallow depths; the resource exists to a depth of 2440 m or more in the Colorado part of the San Juan basin.

Coal beds in the Menefee Formation comprise the most significant coal resource in the Durango field and are the only ones being mined at present. In local areas of structural complexity near Durango, they are of coking quality (Goolsby and others, 1979).

To date, La Plata and Montezuma Counties have produced more than 6.76 million short (6.13 million metric) tons of coal, which is more than 75 percent of the total for the Colorado part of the San Juan River region. Most of the coal currently being mined in the field is used locally for domestic and industrial purposes.

Nucla-Natura field (fig. 1) extends from Dolores County northward to just south of the Colorado River, in Mesa County. Throughout this large, highly dissected area (the "Dakota coal subregion" of Hornbaker and others, 1976), most of the post-Dakota coal-bearing rocks, and even much of the Dakota Group itself, have been stripped away by erosion. The single currently producing mine in this field furnishes approximately 100,000 short (90,700 metric) tons of coal per year to the nearby Nucla Power Plant. Three minable coal beds, 0.9 to 1.5 m thick, occur in the Dakota sequence in this area. The Nucla-Naturita coal field to date has produced over 2.1 million short (1.9 million metric) tons of coal, or about 24 percent of the total for the San Juan River region (Colorado portion).

Pagosa Springs field, located in Archuleta County (fig. 1), has pro-

duced a total of only 75,000 short (68,025 metric) tons of bituminous coal over the years. One small surface mine currently operates in the field.

Tongue Mesa *field* consists of an isolated erosional remnant of Upper Cretaceous sediments (equivalent to at least part of the Mesaverde Group) capped by volcanic rocks of Late Cretaceous and early Tertiary ages. The coal-bearing "Mesaverde" sequence has been eroded west of Tongue Mesa field.

The coals in this field occur within a 275-m thick sequence that correlates with the Kirtland-Fruitland-Pictured Cliffs Formations in the San Juan basin to the south (fig. 2). At least four coal beds, ranging from 0.6 to 12 m in thickness, occur on Tongue Mesa in the lower 60 m of the Fruitland Formation. The most persistent and thickest coal bed, the Cimarron (or Lou Creek), together with several thinner coals, were underground-mined intermittently from the 1890's until the 1940's. No mines presently are active in the field. Tongue Mesa coals generally are subbituminous B in rank and commonly are considerably oxidized and "bony."

Uinta Region

Approximately one-half of the large Uinta coal region lies in west-central Colorado; the remainder constitutes the main coal-bearing region of eastern Utah (fig. 1; Averitt, 1972). Most of that part of the region located in Colorado coincides with the Piceance Creek structural basin of Laramide age and is located in the eastern part of the Colorado Plateau physiographic province. The Uinta region in Colorado is bounded by the Grand Hogback monocline on the east, Axial Basin uplift on the north (which separates this region from the Green River coal region), the Utah State line on the west, Grand Valley and Colorado River on the southwest, and the North Fork Valley and Gunnison uplift on the south and southeast.

The Piceance Creek basin is the largest structural basin in western Colorado, covering an area exceeding 11,500 km', as defined by the base of the Upper Cretaceous Mesaverde Group. The basin is asymmetric in shape, with the steep flank on the east; its long axis trends northwest. This is one of the deepest basins in the Rocky Mountain region, with an estimated 7,600+ m of sediments filling its deepest part, which is located at the north end of the basin, in Rio Blanco county. The southeastern part of the region, in Gunnison and Pitkin Counties, is marked by the Elk and West Elk mountains igneous intrusive complexes of Tertiary age—sills, laccoliths, dikes, etc., and associated folds and faulting. The high geothermal heat flow characteristic of this part of the region has increased the rank of much of the coal that occurs here. As a result, the southeast part of the Uinta region contains large resources of coking coal, much of it of premium grade and high in methane content, and commonly lying under more than 300 m of overburden (Murray and others, 1977; Goolsby and others, 1979). The eight coal fields in the Uinta region that exist around its periphery are briefly discussed below in alphabetical order (fig. 1). All of these fields are, or have been, productive from the Mesaverde Group (fig. 2). The Lower White River field is the only one not presently producing.

Since the late 1800's, this important region has produced more than 91.5 million short (83 million metric) tons of coal, which constitutes nearly 15 percent of the total for all of Colorado, from nearly 300 mines. Currently, the Uinta region is second only to the Green River region in annual production, and first in the State in the production of both underground-mined coal and coking coal.

Book Cliffs field contains a number of high-quality coal beds in the Mount Garfield Formation of the Mesaverde Group. These are mostly high-volatile C bituminous in rank, with some high-volatile B. Hornbaker and others (1976) have estimated total in-place resources in this field (in the 1,287 km' area considered) at approximately 7.2 billion short (6.5 billion metric) tons to a depth of 1,830 m.

Carbondale field, located at the eastern edge of the region, in Garfield and Pitkin Counties, produces high-quality coking coal from the Mesaverde Group. In the Coal Basin area, Pitkin County, in the southern part of the field, some of the coals have been metamorphosed to high-volatile A and medium-volatile bituminous; and, locally, to semianthracite and anthracite. Original in-place coal resources to a depth of 1,830 m in the 265 km' area considered have been estimated at more than 5.2 billion short (4.7 billion metric) tons.

Crested Butte field is located at the southeastern tip of the Uinta region, in Gunnison County, near the Crested Butte ski resort. Much of the field lies at elevations above 3,000 m. Coal-bearing Mesaverde strata in this area have been folded, faulted, and intruded by igneous rocks. The coals here range from high-volatile C bituminous to anthracite; some are of good coking quality. Coal beds in the field vary from about 0.6 to 4 m in thickness. Original in-place coal resources, to a depth of 1,830 m in the 386 km^2 area surveyed, are estimated at some 1.56 billion short (1.41 billion metric) tons (Hornbaker and others, 1976).

Danforth Hills field, which extends from Axial south to Meeker, is situated at the northeast limit of the Uinta region, in Rio Blanco and southern Moffat counties. This field is separated from the Yampa field, Green River region, to the north by Axial basin, a topographic low in which the coal-bearing Mesaverde Group, which crops out in hills both to the north and south, has been stripped away. Both subdivisions of the Mesaverde Group here (the Iles and Williams Fork formations) contain numerous good-quality bituminous coal beds, chiefly high-volatile C in rank. Some of these beds exceed 6 m in thickness. Original in-place coal resources to a depth of 1,830 m in the approximately 644 km^2 area for which the estimate was made, total more than 10.5 billion short (9.5 billion metric) tons (Hornbaker and others, 1976).

Grand Hogback field is located along the east rim of the Piceance Creek basin, the edge of which is sharply upturned to form the prominent Grand Hogback monocline. This feature extends south of Meeker for some 64 km to Rifle, then makes an abrupt bend to the southeast, through the old mining town of New Castle, where the hogback is cut through by the Colorado River, then to Glenwood Springs, where the structure again trends south, making the eastern edge of the Uinta region (fig. 1). Coal-bearing Mesaverde sediments crop out along the length of the Grand Hogback, with 40-degree to nearly vertical dips, where coal has been mined for many years. The Mesaverde coals in the northern part of the Grand Hogback field are mainly high-volatile C bituminous; these grade southward toward Glenwood Springs, in Garfield County, to high-volatile B bituminous. The major part of the coal mined from this field has come from the "Fairfield" and "South Canon" coal "groups" or "zones" in the lower part of the Williams Fork Formation. The "Black Diamond" coal group, in the upper part of the Iles Formation, also has been mined in this area, as has the "Keystone" coal group, in the upper part of the Williams Fork. The numerous coal beds in this sequence range from approximately 1 m to more than 5 m in thickness. Original in-place resources to a depth of 1,830 m in the 257 km' area considered is estimated at more than three billion short (2.7 billion metric) tons.

Grand Mesa field, situated on the south flank of the prominent Grand Mesa, a very large flat-topped feature over 3,000 m in eleva-

tion that is capped by Tertiary volcanic flows, lies primarily in Delta County. The northwestern part of the field, on the west flank of Grand Mesa and south of the Colorado River, is located in Mesa COunty (fig. 1). The Mesaverde coals in this field, as in the Book Cliffs field, are in the Mt. Garfield Formation. The coal beds in Grand Mesa field range from high-volatile C bituminous to subbituminous A and are typically 1.2-4.3 m thick. Original in-place resources, to a depth of 1,830 m in the 850 km^2 area for which the estimate was made, probably exceed 8.6 billion short (7.8 billion metric) tons (Hornbaker and others, 1976).

Lower White River field covers a large area that includes the western Piceance Creek basin and much of the Douglas Creek arch, westward to the Utah State line (fig. 1). Most of the field lies in Rio Blanco County; a small part, a few kilometers north of the giant Rangely oil field (the largest field in Colorado), is located in southern Moffat County. Coals in Lower White River field occur in both the Williams Fork and Iles formations. Most of the mining to date has taken place in the Rangely area, in the Mesaverde rimrock that defines the flanks of the large, breached Rangely anticline. Coal beds here vary from about 2.4 to 3.7 m or more in thickness and are high-volatile C bituminous in rank. In the 1,496 km^2 area surveyed, 11.76 billion short (10.67 billion metric) tons of in-place coal resources have been estimated to a depth of 1,830 m.

Somerset field is located in the valley cut by the North Fork of the Gunnison River and its tributaries, in Delta and Gunnison Counties. The coals in this area occur in the Bowie and Paonia Members of the Williams Fork Formation, are high-volatile B and C bituminous in rank, and range up to 7.6-9.1 m in thickness. In the eastern part of the field, near the settlement of Somerset, coking coal of relatively good quality is produced at mines that include United States Steel's Somerset Mine, the largest underground mine in Colorado (present capacity, approximately one million short, 0.9 million metric, tons per year). In-place coal resources to a depth of 1,830 m in the 515 km^2 area investigated are conservatively estimated at more than 8 billion short (7.3 billion metric) tons (Hornbaker and others, 1976).

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Independence Monument, separating the two entrances of Monument Canyon in Colorado National Monument. Looking north from Grand View; Colorado River, Grand Valley, and Book Cliffs in distance. Roan Cliffs are white cliffs at extreme distance on right skyline. Floor of canyon is Proterozoic metamorphic rocks; overlying strata are upper Triassic. Slopes at foot of cliffs are red Chinle Formation; cliffs are Wingate Sandstone (107 m); thin protective caprock on top of cliffs is lower sandstone of the resistant Kayenta Formation. Top of monument is nearly 137 m above canyon floor. Infrared photograph by S. W. Lohman, U.S. Geological Survey.