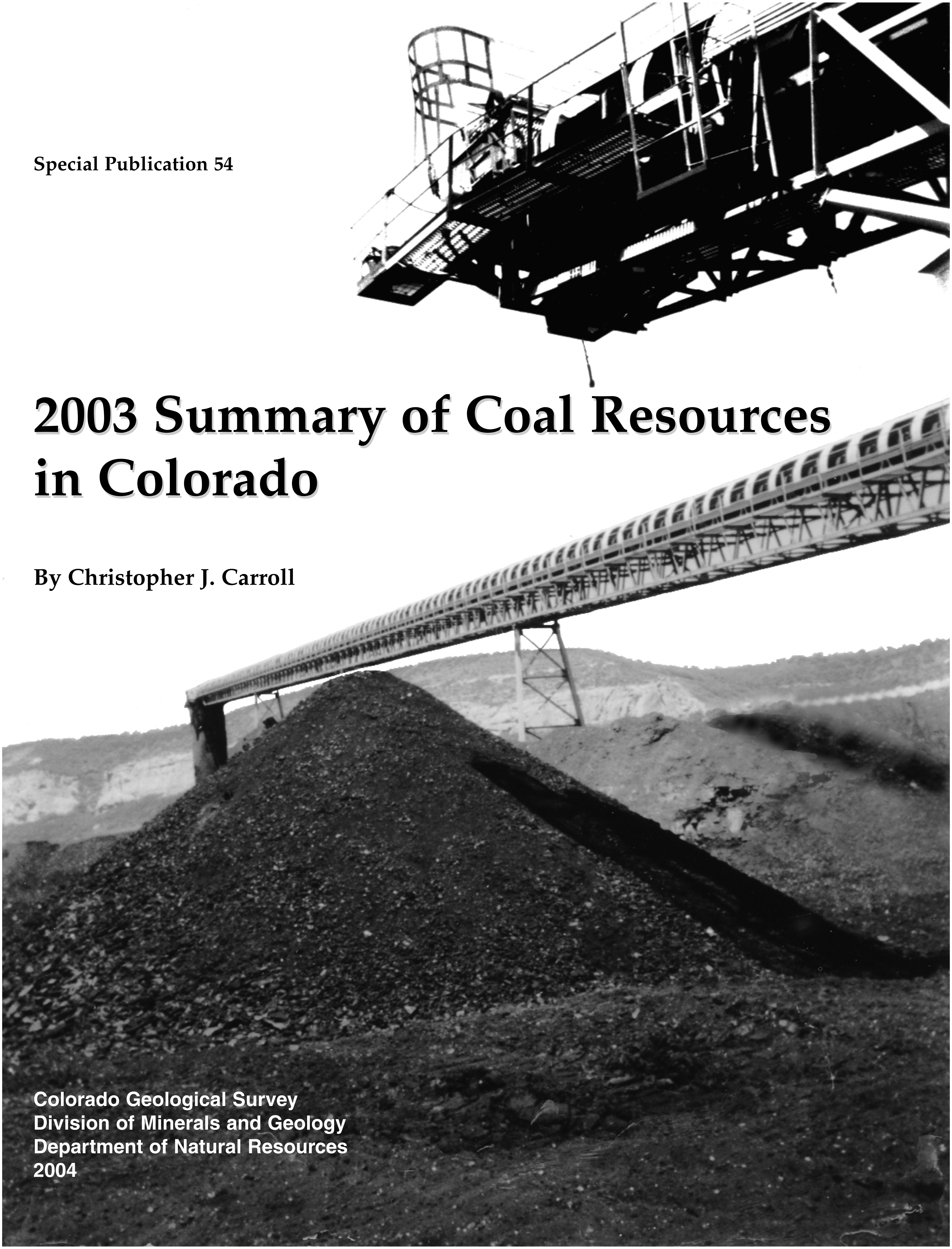
Special Publication 54

2003 Summary of Coal Resources in Colorado

By Christopher J. Carroll



Colorado Geological Survey
Division of Minerals and Geology
Department of Natural Resources
2004

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2003 Summary of Coal Resources in Colorado

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COLORADO
DEPARTMENT OF NATURAL RESOURCES

Bill Owens, Governor,
State of Colorado

Russell George, Executive Director,
Department of Natural Resources

COLORADO DIVISION OF MINERALS & GEOLOGY
RECLAMATION•MINING SAFETY•SCIENCE

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COLORADO GEOLOGICAL SURVEY

Colorado Geological Survey
Denver, Colorado / 2004

https://doi.org/10.58783/cgs.sp54.hppp3354

FOREWORD

The Colorado Department of Natural Resources is pleased to publish Colorado Geological Survey Special Publication 54, *2003 Summary of Coal Resources in Colorado.* This publication describes the coal resources and production, coal physical and chemical properties, and the general geology of each coal producing region. Chris Carroll, Coal Geologist of the Mineral and Mineral Fuel Resources Section of the Colorado Geological Survey, gathered this information in 2003. The geological information on Colorado coal deposits is valuable to resource developers, government planners, and interested citizens.

Funding for this project came from the Colorado Department of Natural Resources Severance Tax Operational Fund. Severance taxes are derived from the production of gas, oil, coal, and minerals.

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ACKNOWLEDGMENTS

This publication was made possible by the work of previous coal geologists from the Colorado Geological Survey (CGS). With respect to their efforts, the current author appreciates their contributions. A.L. Hornbaker and R.D. Holt first published *1972 Summary of Coal Resources in Colorado* in 1973. Much of that pioneering publication included a format and original coal quality data that has been used in subsequent publications. The Summary was updated for the years 1975 (Hornbaker, Holt, and Murray, 1976), 1979 (Murray, 1980), 1981 (Ladwig, 1983), 1990 (Tremain and others, 1991) and 1995 (Tremain and others, 1996). This updated publication draws from these works.

The internal manuscript was reviewed by Janet E. Schultz and J.A. Cappa of the CGS. Peer review manuscript was reviewed by S.B. Roberts of the USGS. Cheryl Brchan and Chris Redman completed the figures and publication design.

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INTRODUCTION

Due to its great wealth of coal, the United States is considered the world leader for coal production. Colorado has some of the cleanest burning coal in the U.S. In terms of coal quality, Colorado ranks in the top five "compliance coal" producing states in the nation (*Keystone Coal Industry Manual, 2003*). More than 434 bil tons (all references to tons in this report refer to short tons) of in-place coal resources are estimated in Colorado to a maximum depth of 6,000 ft (Speltz, 1976). According to the Department of Energy's Energy Information Agency (EIA) this resource represents 11 percent of the nation's coal, and is the fourth largest state coal resource in the country. To a mineable depth of 3,000 ft, Colorado's remaining identified coal resources are nearly 129 bil tons (Averitt, 1975). In terms of identified bituminous coal resources, Colorado ranks second nationally behind Illinois, but is first in low-sulfur bituminous coal.

Coal is the largest available source of energy in Colorado. It underlies nearly 30,000 sq mi, or 28.4 percent of the state (Fig. 1). Colorado lies in the Rocky Mountain Coal Province with coal occurring in Upper Cretaceous to Eocene age sedimentary formations (Fig. 2). The state's eight named coal-bearing regions and 28 coal fields are located throughout western and central Colorado. Coal is currently produced from the Green River, Uinta, San Juan River, and Raton Mesa coal regions. The most important coal regions in terms of total in-place resources and production of environmentally compliant coal are the Green River and Uinta coal regions in northwestern Colorado.

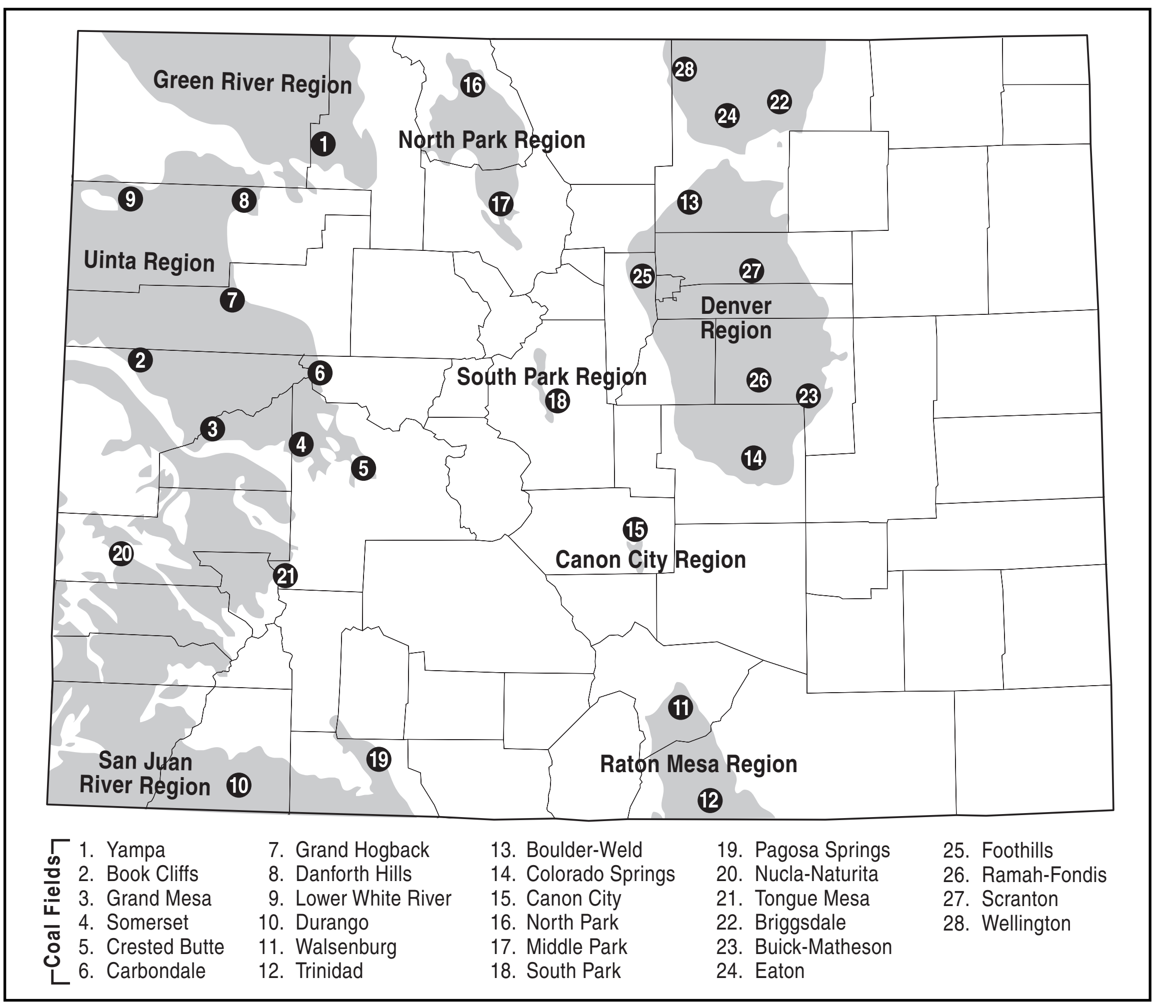

Figure 1. Coal-bearing regions (shaded) and coal fields in Colorado.

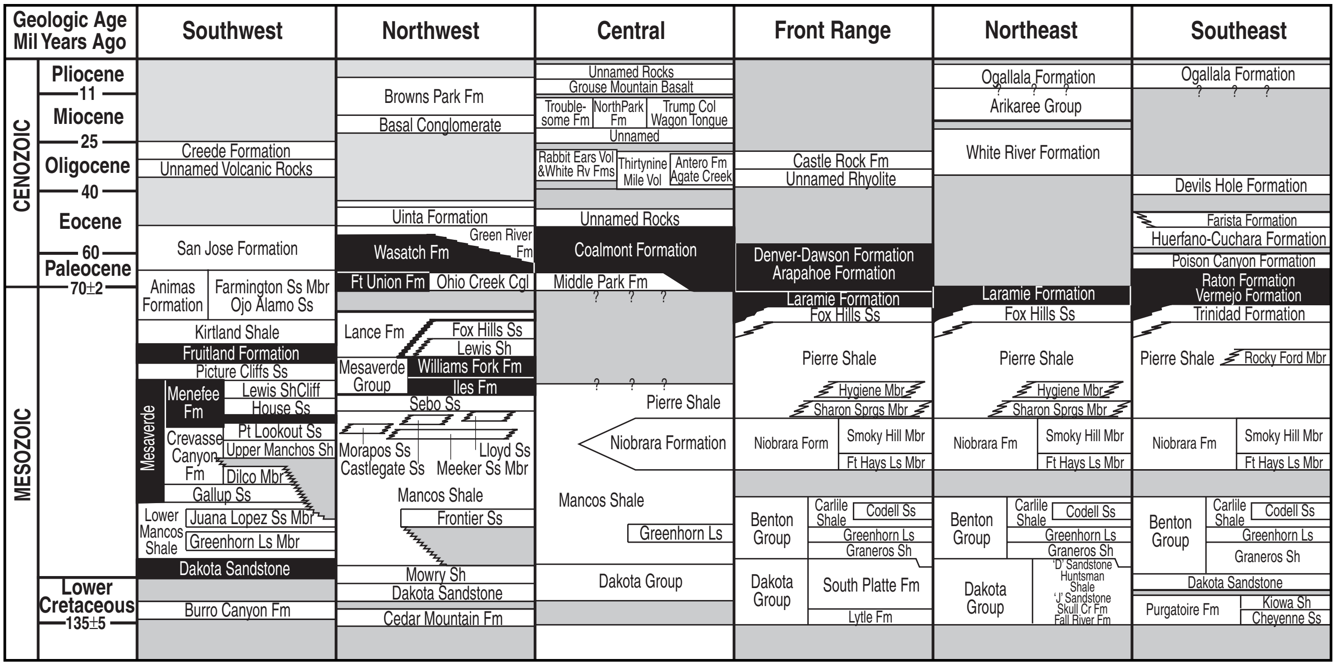

Figure 2. Colorado stratigraphic correlation chart for the coal-bearing parts (shown in black) of the Mesozoic and Cenozoic. Modified from Pearl and Murray, 1974; and Tremain and others, 1996.

COAL PRODUCTION

Since 1864, approximately 1,736 mines and prospect pits have produced more than 1.15 bil tons of coal in Colorado (Carroll, 2003). Coal was originally excavated for individual home use, but was expanded to light industrial uses near Golden and Boulder during the Gold Rush in the 1860s and 1870s. Industrial uses for both brick and steel-making at the turn of the 20th Century marked a significant increase in coal production and the refractory clays associated with the coal beds from the Boulder-Weld Coal Field, as well as the Trinidad and Walsenburg coal fields. Coal production from the Western Slope began in the 20th Century when railroads were constructed through the mountains. After setting a record for annual coal production of 12.66 mil tons in 1918 (Colorado State Inspectors Report, 1918), Colorado's coal production began to decrease, declining somewhat during the Great Depression (Fig. 3). A slight increase in the state's coal production occurred during World War II, but mine output again declined markedly after 1945, a trend that continued until 1963. Much of this decrease was due to increased use of natural gas for heating and the replacement of coal-burning trains with diesel-powered locomotives. Annual coal production fluctuated between 3 mil and 6 mil tons until 1973, when production again increased.

Colorado's annual coal production increased dramatically during the 1980s and 1990s due to rising electricity usage. Over the last 30 years the state's annual coal production rose from 5.3 mil tons in 1971 to a record 35.2 mil tons in 2002 (Colorado Division of Minerals and Geology estimate for 2002). The state record for annual coal production has now been surpassed in five of the last six years. In 2002, coal was produced from just 12 coal mines (seven underground and five surface mines), with a 5 percent increase in annual production over the previous year. Nationally, Colorado ranks eighth in coal production, just behind Indiana and ahead of Illinois.

This statewide increase in coal production is the result of several factors: large, modern surface mining equipment; longwall machines operating in 8- to 11-ft thick Cretaceous coal seams; and an increasing demand for environmentally clean power plant fuel. An available system of rail transportation through the Colorado mountains has also assisted the economics of the rural industry. Much of the asymptotic increase in coal production is a

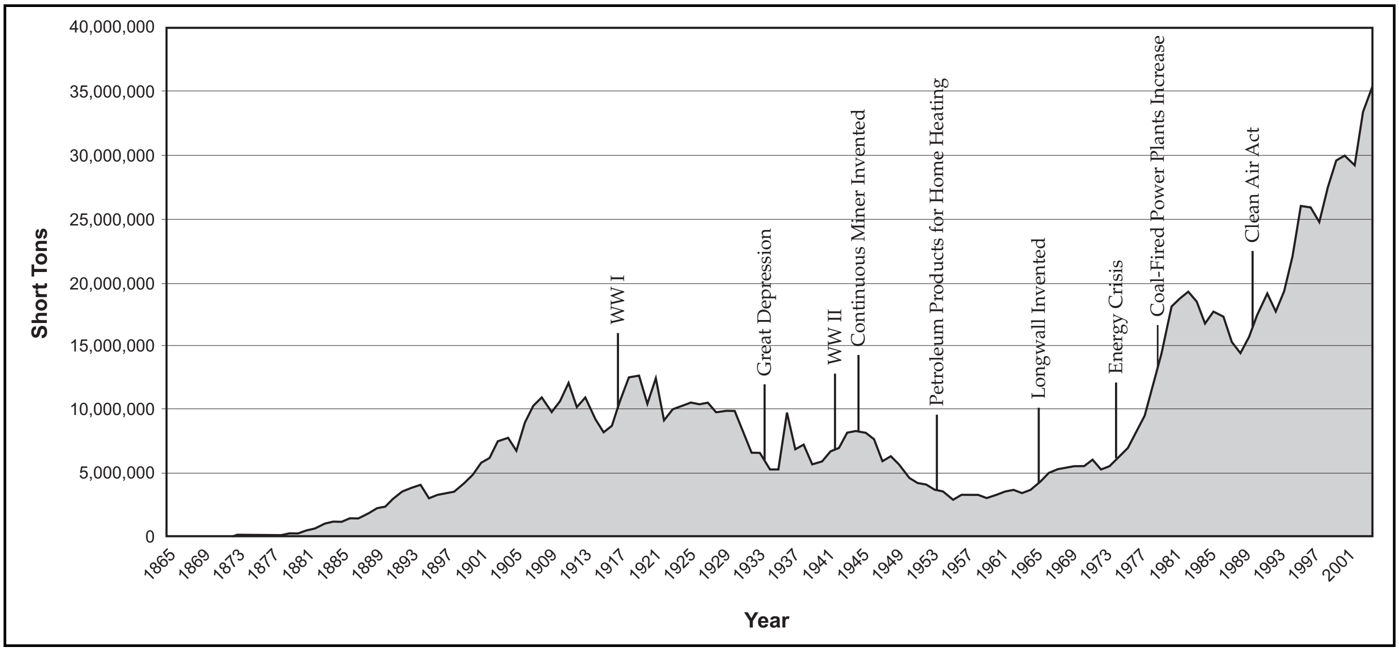

Figure 3. Historic coal production in Colorado, 1864–2002. Source: *State Inspectors Reports*, CDMG.

response to the implementation of the Federal Clean Air Act of 1990 (U.S. EPA, 2003). Part of the act calls for lowering air emissions for Hazardous Airborne Pollutants (HAP) at power plants in the U.S. For the last 13 years the demand for low sulfur steam coal has increased across the nation. The coal mined in Colorado today is a high-grade bituminous steam coal product with low sulfur and ash contents—generally called "clean air compliant" (Carroll and Widmann, 2000; EPA, 2003) coal (Table 1). This product is considered good steam coal since it can be blended with higher sulfur coals for air quality compliance purposes.

Colorado mines employed 1,853 miners as of December 2002—a 3 percent increase over the previous year. The price of coal peaked in late 2001 and has remained high at $17.50/ton average at the mines. The value of coal produced in 2002 is estimated at $616 mil (Carroll, 2003).

More than 54 percent of the coal produced in Colorado in 2001 was exported to other states and foreign countries, primarily as steam coal (EIA, 2003). Approximately 18 mil tons of coal were shipped out of state that year; Kentucky, Utah, Illinois, Texas, Missouri, and Tennessee are the largest consumers.

Gunnison, Routt, and Moffat counties were the three leading coal producing counties in 2002. Tables 2 and 3 show 2002 production data by county and coal-bearing region, respectively. Gunnison County also leads the state in miners employed with 556 miners as of December 2002 (Carroll, 2002).

Historically coal has been produced since 1864. Most of the early mining was on the Eastern Slope in the Boulder-Weld Coal Field and the Trinidad-Walsenburg coal fields. Today coal mining exists mostly in northwest Colorado. Table 4 displays cumulative (1864–2002) production data by county and coal region. Over 1.15 bil tons of coal have been mined historically. The Uinta Coal Region is the leading coal producing region with more than 368 mil tons produced; but Routt County is the leading coal producing county with more than 238 mil tons extracted since 1864.

COAL RESOURCES

According to the EIA, Colorado ranks eighth in the total U.S. demonstrated reserve base (drb) of coal (16.8 bil tons). The drb includes coal beds (except lignite) that occur at depths above 1,000 ft, or deeper coals that are currently being mined to

Table 1. Arithmetic mean of proximate and ultimate analyses for six Colorado coal regions.

	Denver Region	Green River Region	North Park Region	Raton Mesa Region	San Juan River Region	Uinta Region
Moisture (%)	28.9	9.7	16.3	3.9	2.9	2.8
Volatile Matter (%)	27.5	36.4	32.1	33.5	31.0	31.6
Fixed Carbon (%)	33.1	46.8	39.4	46.6	53.6	58.6
Ash (%)	11.2	9.0	12.4	16.1	12.7	6.8
Hydrogen (%)	6.3	5.5	5.2	5.1	5.1	5.3
Carbon (%)	45.0	63.2	53.1	65.1	71.3	75.3
Nitrogen (%)	1.0	1.5	0.9	1.3	1.4	1.8
Oxygen (%)	36.7	20.2	27.8	11.7	8.0	10.8
Sulfur (%)	0.3	0.6	0.5	0.7	0.8	0.6

2,000 ft. Bituminous coal and anthracite must be at least 28 in. thick and subbituminous coal and lignite 60 in. or more in thickness to be included. Recent demonstrated reserve studies in both the Somerset Coal Field (Eakins and others, 1998) and the Yampa Coal Field (Carroll and Morgan, 2000) suggest that an additional 6 bil tons of coal reserves are available in those areas. Only 4.8 bil tons, or 28 percent, are surface-mineable in the Yampa Coal Field. The Colorado Geological Survey (CGS) estimates that more than 80 percent of the state's total reserve will be underground mineable. A small part of Colorado's bituminous coal reserve base is of coking or metallurgical grade (Goolsby and others, 1979); however, the U.S. market at this time is very stagnant.

The U.S. Geological Survey (USGS) defines coal resources (Wood and others, 1983) based on the known extent of coal near data points (boreholes or outcrop measurements). “Measured” coal is determined to be within 0.25 mi radius of a data point. “Indicated” coal is that resource between 0.25 and 0.75 mi of the data point. Together these two resource categories represent “identified” coal resources. Beyond 0.75 mi and up to 3 mi away are resources classified as “hypothetical” coal resources. Of the 434 bil tons of identified and hypothetical coal resources remaining in Colorado to a depth of 6,000 ft, 128.95 bil tons(30 percent) are identified resources less than 3,000 ft deep (Speltz, 1976).

About 60 percent of the coal in-place can be recovered using current underground mining technology. Thick, multiple coal beds typical of many parts of Colorado may defy efficient recovery by even the most advanced mining methods. In some instances, recovery of naturally occurring coalbed methane, or in situ combustion of deeply buried or steeply dipping coal beds, may be the only way to recover the energy contained in much of the state's coal resources (Murray and others, 1977).

The USGS defines potentially surface mineable coal as coal less than 200 ft deep (Wood and others, 1983). According to Speltz (1976), 75 percent of Colorado's potentially surface-mineable coal is located in the Denver Coal Region. The San Juan River Coal Region (Nucla-Durango-Cortez area) has 16 percent and the Green River Coal Region (Oak Creek-Craig-Axial area) has 5 percent. The CGS indicates that approximately 3.4 bil tons of lignite, in beds at least 2.5 ft thick above a depth of 2,000 ft, may exist in the central part of the Denver Coal Region (Eakins and Ellis, 1987). In terms of potential renewed mining, the Denver Coal Region is limited due to urban growth in the Denver, Boulder, and Colorado Springs metropolitan areas.

Table 2. Colorado 2002 coal production, miners employed, and number of mines listed by county.

County	Production	No. of Employees	No. of Mines (Surface / Underground)
Delta	5,396,329	209	0/1
Garfield	327,199	22	0/1
Gunnison	9,769,096	556	0/2
La Plata	328,730	56	0/1
Las Animas	154,824	10	1/0
Moffat	7,386,511	376	2/0
Montrose	386,366	23	1/0
Rio Blanco	2,088,876	169	0/1
Routt	9,365,777	432	1/1
Total	**35,203,708**	**1,853**	**5/7**

Table 3. Colorado 2002 coal production listed by coal region.

Coal Region	Production (tons)	Number of Miners	Number of Mines(Surface/ Underground)	Mine Names
Green River	11,403,876	552	2/1	Foidel Creek, Seneca II/Yoast, Trapper
Raton Mesa	154,824	10	1/0	Lorencito Canyon
San Juan River	715,096	79	1/1	King Coal, New Horizon
Uinta	22,929,912	1,212	1/5	Colowyo, McClane Canyon, Deserado, Bowie No. 2, Sanborn Creek, West Elk
Totals	**35,203,708**	**1,853**	**5/7**	

Table 4. Cumulative Coal Production (tons) by county and coal regions from 1864 through 2002. Source: Colorado Division of Mines and Geology mine inspector's annual reports.

Coal Region	County	County Production	Coal Region Total Produced	Production Ranking
Canon City*	Fremont	48,004,745	48,004,745	5
Denver*	Adams	37,112		
	Arapahoe	36,259		
	Boulder	43,321,306		
	Douglas	27,367		
	Elbert	108,948		
	El Paso	15,251,246		
	Jefferson	6,697,939		
	Larimer	54,284		
	Weld	68,660,774	134,195,235	4
Green River	Moffat (part)	77,006,830		
	Routt	237,248,974	314,255,804	2
North Park*	Jackson	7,067,310	7,067,310	7
Raton Mesa	Huerfano	75,690,588		
	Las Animas	186,571,615	262,262,203	3
San Juan River	Archuleta	1,391,713		
	Dolores	62,631		
	La Plata	10,603,699		
	Montezuma	174,515		
	Montrose	6,466,617		
	Ouray	14,216		
	San Miguel	27,197	18,740,588	6
South Park*	Park	724,658	724,658	8
Uinta	Delta	40,132,397		
	Garfield	8,837,971		
	Gunnison	143,588,174		
	Mesa	18,785,850		
	Moffat (part)	104,983,718		
	Pitkin	29,548,497		
	Rio Blanco	24,966,379	370,842,986	1
Totals			**1,156,093,529**	

* Coal region not currently mined.

COAL OWNERSHIP

The U.S. Bureau of Land Management (BLM) is the agency charged with managing Federal mineral leases in Colorado. According to information on their Web site *(http://www.co.blm.gov/energy/Energydevelopment.htm),* the federal government owns 48 percent of the mineral rights, and 36 percent of the surface lands in Colorado. Nearly 8.8 mil acres of these federal lands are within coal regions. Actively leased acreage is much less. Energy companies pay a royalty to the federal government equivalent to about 12.5 percent of the value of the minerals extracted (oil, gas, and surface coal mines) and eight percent for underground coal extraction from federal lands. County governments receive millions of dollars annually from mineral royalties on federal mineral production and severance taxes. In 2001, nearly $63 million in federal royalties were collected—half of which was shared with local governments (Cappa, 2002).

The BLM further estimates that 6.4 bil tons(or more than 10 percent of the original federal coal) are minab1e by surface methods. Recoverable coal reserves in Colorado held under federal lease are estimated to be 1.65 bil tons, with 273 mil tons suitable for surface mining. Federal coal leases provide over 80 percent of the total coal produced in the state. Statewide, ten coal mines on federal leases produced 21 mil tons of low sulfur coal in 2000. The BLM estimates that approximately 70 percent of federal coal extracted is consumed in Colorado for electricity generation. Colorado ranks second in the nation in federal coal revenues.

GENERAL COAL CHARACTERISTICS

COAL ANALYSES

For more than 25 years the CGS and the USGS have conducted cooperative projects to sample and analyze coal from most of the producing coal mines in Colorado, plus coals likely to be mined in the future. The USGS conducted trace element and other geochemical analyses while the U.S. Bureau of Mines conducted the proximate, ultimate, and related tests.

In the 1970s the CGS (Khalsa and Ladwig, 1981) in cooperation with the USGS collected coal samples for chemical and proximate and ultimate analyses from around the state. A range of analyses for each coal region is summarized in Table 5. These were published by both groups, and also are available on the Internet through the USGS (1994) COALQUAL (CD-ROM) Web site at *http://energy.er.usgs.gov/products/databases/CoalQual/index.htm.* None of the Colorado coal samples contain significant quantities of HAPs for trace elements such as arsenic, mercury, selenium, strontium, thorium, and uranium (Kolker and Finkelman, 1997; Bragg and others, 1998). In fact, most contain smaller amounts of these elements than do coals from other regions of the U.S. Of all the coal producing states, Colorado has the lowest average mercury concentrations for in-place coal resources.

RANK

Colorado coals range in rank from lignite to anthracite. More than 70 percent of the state's coal resources are bituminous, approximately 24 percent subbituminous, 5 percent lignite, and less than 1 percent anthracite. In general terms, the older the coal, the higher the rank; however, geologic factors such as high geothermal gradient and deep burial have increased the rank of even the youngest coals. In particular, the Crested Butte and Carbondale coal fields (Fig. 1) consist of Cretaceous coals exposed to low-grade metamorphism near Tertiary igneous intrusions. The coal rank in the field has been increased to anthracite and high-volatile bituminous. For the most part, coals in Colorado are low slacking. Many also are nonagglomerating, although resources of coking coal are found in parts of the Uinta, San Juan River, and Raton Mesa coal regions (Goolsby and others, 1979).

COAL QUALITY

For consistent comparisons, all values reported are “as-received” unless otherwise noted.

Moisture/Volatile Matter/Fixed Carbon — Moisture, volatile matter, and fixed carbon contents of Colorado coals vary considerably from region to region (refer to Table 1). Moisture contents generally are in the 1 to 23 percent range (as-received).

Table 5. Range of analyses of Colorado coals. From *2003 Keystone Coal Industry Manual* (Carroll, 2003). FSI = Free Swelling Index; HAP = Hazardous Airborne Pollutants; Hg = Mercury.

REGION Field Formation (Coal Bed)	Moisture (%)	Volatile Matter (%)	Ash (%)	Sulfur (%)	Heating Value (Btu/lb)	Ash Fusion Temperature (°F)	FSI	HAP (Hg) (mg/kg)
CANON CITY (and field)								
Vermejo Fm. (7 beds)	5.4–11.9	31.4–42.9	4.6–14.8	0.3–1.7	10,400–11,390	2,030–2,720	0	0.18
DENVER								
Boulder–Weld								
Laramie Fm. (beds 1–7)	13.7–29.1	27.3–43.6	3.5–12.7	0.2–0.9	8,250–10,810	1,990–2,470	0	——
Colorado Springs								
Laramie Fm. (beds A, B, C)	19.0–26.2	31.4–45.1	5.6–20.8	0.3–0.7	8,440–9,280	2,150–2,470	0	——
Southeast and South–Central								
Denver Fm. (Bijou, Kiowa,Comanche)	26.4–39.6	19.3–42.7	9.8–44.6	0.2–0.6	3,636–6,803	2,480–2,530	0	——
Laramie Fm.	33.1–35.0	30.8–44.2	7.8–15.7	0.4–1.1	6,150–7,340	2,140–2,400	0	——
GREEN RIVER								
Yampa								
Fort Union Fm. (Seymour)	20.7–23.0	——	3.9–7.8	0.2–0.4	8,250–8,710	——	0	——
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	<0.02
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	<0.02
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	——
RATON MESA								
Trinidad								
Raton Fm. (11 beds)	1.8–4.5	34.4–40.3	5.3–16.4	0.4–1.1	10,169–13,871	2,055–2,800	0–8.5	0.03
Vermejo Fm. (14 beds)	1.6–7.5	32.2–39.1	7.7–21.8	0.5–1.0	11,430–13,510	2,290–2,910	0–6.5	——
Walsenburg								
Raton Fm.	2.5–4.2	——	5.3–13.5	0.4–1.0	12,660–13,340	2,230–2,730	0	——
Vermejo Fm.	5.3–10.2	36.4–38.0	7.2–14.4	0.4–1.3	11,050–12,880	2,210–2,840	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	0.08
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	0.1
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	——
NORTH PARK (and field)								
Coalmont District								
Coalmont Fm. (Riach; beds 1–4; (Monahan)	14.5–20.2	29.3–37.3	5.5–13.1	0.6–1.0	6,520–9,570	2,060–2,570	0	——
McCallum Anticline District								
Coalmont Fm. (Hill, Winscom, Sudduth)	12.0–16.1	27.4–37.3	2.1–19.2	0.2–0.3	8,580–11,280	2,040–2,680	0	——
SOUTH PARK (and field)								
Laramie Fm. (3 beds)	6.3–15.5	——	1.3–6.4	0.47–0.53	9,780	2,700	——	——
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	0.04
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 Canyon., Goff, Fairfield gps.)	8.9–15.5	——	2.2–9.6	0.3–1.4	10,140–11,790	2,210–2,910	——	0.03
Illes 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	0.04
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	0.03

However, some of the subbituminous coals and lignites in the Denver Coal Region contain as much as 38 percent moisture (Hornbaker and Holt, 1973). Overall, Colorado coals average about 12 percent moisture content. Statewide, volatile matter contents vary from 6.9 percent (anthracite in the Crested Butte Coal Field) to about 45 percent—with most coals being in the 31 to 40 percent range. Fixed carbon contents typically vary between 39 and 69 percent.

Ash — Colorado coal is moderate to moderately low ash. Ash content (as-received) varies considerably even within the same coal zone due to different depositional environments. The range is typically from 2 to 20 percent—averaging about 6 percent. Locally, however, ash contents may reach 25 percent to 30 percent or more (as-received sampling) depending on the amount of parting collected.

Sulfur — Colorado coal is generally regarded as a low-sulfur product. Sulfur content (as-received) varies from 0.2 to 2.2 percent. More than 99 percent of produced Colorado coal contains less than 1.0 percent sulfur. More than half of the coal resources in the state contain less than 0.7 percent sulfur. The bulk of the coal being mined in Colorado at present contains between 0.2 and 0.5 percent sulfur. On the other hand, much of the metallurgical-grade coal in Colorado contains 0.5 to 1.0 percent sulfur—still low in comparison with many eastern coals. Work by the USGS and the CGS (Boreck and others, 1977) indicates that organic sulfur usually predominates, followed by pyritic sulfur and sulfate. For example, a typical coal in the Yampa Coal Field may have the following forms of sulfur: organic (0.49 percent), pyritic (0.03 percent), sulfate (0.03 percent), and total sulfur (0.55 percent). Abnormally high pyrite content can be reduced by conventional coal preparation techniques to 0.5 percent total sulfur, or less. Colorado steam coals typically contain between 0.2 and 0.5 pounds sulfur per mil Btu—well within the definition of low-sulfur coals (<0.6 pounds sulfur per mil Btu, U.S. EPA Clean Air Act Amendment, 1990).

Heating Values — The subbituminous and bituminous steam coal produced in Colorado ranges from about 9,900 to 13,100 Btu/lb. Current supplies of Colorado coal sales average 11,370 Btu/lb (EIA, 2002). On a dry, ash-free basis, most Colorado coals vary between 13,300 and 14,500 Btu/lb, and average about 14,000 Btu/lb (moist, mineral-matter free basis).

Specific Gravity — Colorado coals range from 1.28 for bituminous coal from the Farmers Mine in the Somerset Coal Field in Delta County to 1.468 for anthracite from the Yampa Coal Field (Routt County). Average specific gravity for cleaned bituminous coal in Colorado is 1.332; for subbituminous coal, 1.291. The specific gravity of coal varies considerably with rank and ash content. For unbroken coal in the ground, the following values are representative (Averitt, 1975):

Anthracite and semianthracite coal — specific gravity (sp gr) 1.47 (2,000 ton/acre-foot)

Bituminous coal — sp gr 1.32 (1,800 tons/acre-foot)

Subbituminous coal — sp gr 1.30 (1,770 tons/acre-foot)

Lignite — sp gr 1.29 (1,750 tons/acre-foot)

Carbonizing Properties — Many Colorado coals are nonagglomerating and may be carbonized in fluidized systems. Chars produced at relatively low temperatures (450 to 700º F) contain about 8.5 to 14.4 percent residual volatile matter and are easily ignited. Char heating values on a moisture-free basis vary from 14,600 to 14,960 Btu/lb and are suitable for boiler fuel. Lump chars can be produced from most Colorado coals, but are relatively weak. Some of the lump chars might constitute suitable substitutes for coke breeze in special uses.

Coking Coal — The coking coal market has all but disappeared in Colorado in the last 15 years. However, significant reserves of marginal and premium grade coking coal occur in the Carbondale, Crested Butte, and Somerset coal fields, Uinta Coal Region; in the Trinidad Coal Field, Raton Mesa Coal Region; and in the Durango Coal Field, San Juan River Coal Region (Fig. 1). The CGS completed an evaluation of coking coals showing that the original in-place identified coking coal reserves in the state total more than 4.2 bil tons (Goolsby and others, 1979). According to the authors, the Uinta Coal Region contains an estimated 0.5 bil tons of coking-coal reserves—ranging from premium grade medium-volatile bituminous to marginal grade high-volatile bituminous. The Raton Mesa Coal Region contains about 2.0 bil tons of marginal grade high-volatile A and B bituminous; and the San Juan River Coal Region contains about 1.7 bil tons of premium grade high-volatile A bituminous to latent grade high-volatile B bituminous coking coal reserves.

The Raton Mesa Coal Region coking coals are generally of lower quality than coals from the other two regions, but they are the most accessible. The San Juan River Coal Region is the least well-known of the three. It produces a medium quality bituminous coal. The thinness of the coal beds and the lack of rail transportation in southwestern Colorado have hindered development of coking coal in this region.

The Somerset Coal Field of the Uinta Coal Region has produced the most desirable coke-oven feedstock in Colorado. Depth of overburden and the abnormally gassy nature of the coals have tended to retard development of the resource in this area.

A significant percentage of the bituminous coking coal reserves of Colorado lie beneath more than 1,000 ft of overburden. In western Colorado, for example, virtually all of the major underground coal mines are mining beneath cover ranging from 1,000 to 2,000 ft thick. The portals of most of these mines are located in the sides of steep-walled valleys, and drift or slope mining techniques are used to produce the coal. Because of the rugged topography in these areas, overburden rapidly increases as mining progresses, often attaining 1,000 ft thick within relatively short distances from the portal. West Elk Mine in Somerset routinely mines under steep terrain with overburden ranging from 1,400 ft to 2,300 ft.

Trace Element Chemistry — Future coal mining in the U.S. will need to meet new environmental requirements for emissions standards at power plants. Among these new requirements are tough laws aimed at reducing the amount of trace elements allowed in the atmosphere. Mercury is the primary element of concern. Colorado boasts some of the lowest concentrations for mercury in coal in the nation (Kolker and Finkelman, 1997; Bragg and others, 1998). CGS geologists collected 54 samples at active coal mines in Colorado between 2000–2002. Sample analyses show that mercury averages 0.026 ppm concentration. In terms of environmental concern, this very low concentration, along with low sulfur and high Btu coals, makes Colorado an attractive area for future coal mining. Preliminary analysis shows that the Williams Fork coals in the northern Uinta Coal Region and the Fruitland Formation coals in the San Juan River Coal Region have the lowest concentrations for mercury in the state.

GENERAL GEOLOGY OF THE COLORADO COAL REGIONS AND COAL FIELDS

Colorado coal ranges in age from Lower Cretaceous to Eocene. The higher rank bituminous coals, and the largest reserves, are generally found in the Cretaceous age Dakota and Mesaverde groups (Fig. 2) in western Colorado, specifically in the region from Moffat County south to the New Mexico state line. Cretaceous coals, which are related to alternating transgressions and regressions of the Western Interior seaway, are generally of higher rank and better quality than the nonmarine Tertiary-age coals deposited in the more restricted Laramide age structural basins (Averitt, 1975; Robinson-Roberts and Kirschbaum, 1995).

The oldest coal beds in Colorado occur in the Dakota Sandstone in the southwestern part of the state (northern San Juan Coal Region, Durango to Nucla-Naturita Coal Field areas). Successively younger coals were laid down as the Upper Cretaceous seaway retreated northeastward across the state.

Subbituminous coals occur in the Cretaceous age Lance, Laramie, and Vermejo Formations; in the Paleocene Fort Union and Raton Formations; and in the Paleocene-Eocene Wasatch and Coalmont Formations. The youngest coals, generally of lower rank (subbituminous A to lignite), are found in Tertiary rocks in the Green River, North Park, Raton Mesa, and Denver coal regions. Eocene coals in the Coalmont Formation of North Park may be the very youngest coal beds found in the state. Lignite is found in the Paleocene-age Denver Formation in the Denver Coal Region and the

Table 6. Colorado coal mine statistics, 2002. Mine type abbreviations: U—underground mine, S—surface mine.

Mine Name	County	Coal Region	Coal Field	Operator	2002 Coal Production (tons)	Geologic Formation	Producing Bed Names	Bed Thickness (ft)	Btu/lb Avg.	Mine Type	Mining Method
Bowie No. 2	Delta	Uinta	Somerset	Bowie Resources Ltd.	5,396,329	Mesaverde	D	9–12	11,800	U	Longwall, continuous
McClane Canyon	Garfield	Uinta	Book Cliffs	Lodestar	327,199	Mesaverde	Cameo B	4.4–9.4	11,250	U	Continuous
West Elk	Gunnison	Uinta	Somerset	Arch (ACI) Mountain Coal Co.	6,560,421	Mesaverde	B	14	11,650	U	Longwall, continuous
Sanborn Creek	Gunnison	Uinta	Somerset	Oxbow Mining Inc.	3,208,675	Mesaverde	B, C	18, 6.0–8.0	12,375	U	Longwall, continuous
King Coal	La Plata	San Juan River	Durango	National King Coal, LLC	328,730	Upper Menefee	Upper Bed	4.3–6	12,500	U	Continuous
Lorencito Canyon	Las Animas	Raton Mesa	Trinidad	Addington Bros.	154,824	Raton	Na, M	1.5–4	13,000	S	Contour
Colowyo	Moffat	Uinta	Danforth Hills	Colowyo Coal Co. (Kennecott)	5,348,412	Williams Fork–Fairfield Coal Group	A–F, X,Y	8 beds–5.4–10.7	10,453	S	Dragline, Shovels, Dozers
Trapper	Moffat	Green River	Yampa	Trapper Mining, Inc.	2,038,099	Williams Fork–Upper Coal Group	H, I, L, Q, R	6, 5, 4, 13, 4	9,850	S	Dragline, Shovels, Hyd. Excav.
New Horizon	Montrose	San Juan River	Nucla–Naturita	Western Fuels Assn.	386,366	Dakota	1,2	0.75–1.25, 4.0–6.5	10,800	S	Shovels, dozers
Deserado	Rio Blanco	Uinta	Lower White River	Blue Mountain Energy, Inc.	2,088,876	Williams Fork	B Seam	7.0–16.0	10,000	U	Longwall, continuous
Twentymile (Foidel Creek)	Routt	Green River	Yampa	Twentymile Coal Co. (RAG American Coal)	7,573,438	Williams Fork–Middle Coal Group	Wadge	7.0–11.0	11,250	U	Longwall, continuous
Seneca II–W,Yoast	Routt	Green River	Yampa	Peabody Western Coal Co.	1,792,339	Williams Fork–Middle Coal Group	Wadge, Wolf Cr., Sage Cr.	8.9–14.2, 15–20.4, 3.4–5.4	11,908–12,581	S	Dragline, loaders

Riach bed in North Park, and the Wasatch Formation in the Green River Coal Region near the Wyoming border.

The San Juan River, Uinta, Green River, Raton Mesa, and Denver coal regions are located principally within Laramide age structural basins. The interior parts of these basins are relatively free from structural complications and the coal beds usually are not highly folded, faulted, or otherwise disturbed. Some of the margins of these structural basins, however, are moderately to severely folded and faulted. In places, Tertiary igneous activity has metamorphosed the coal to anthracite, or even coke. The Uinta Coal Region (which includes the Piceance Creek Basin) and the Green River Coal Region (which includes the Sand Wash Basin) each contain significant coal resources to depths exceeding 10,000 ft. These two basins are the deepest structural basins in the state. The Canon City, North Park, and South Park coal regions occur in smaller, more structurally complex Laramide basins.

The coal-bearing regions and coal fields of Colorado are discussed below, region by region, in alphabetical order. Stratigraphic columns for most of the currently producing coal fields display the relative vertical distribution of the major coal-bearing intervals (or zones) together with the names of the coal beds. Unlike coals in many eastern states, the coal beds in Colorado have been only tentatively correlated; thus, care should be used in assigning coal quality characterizations to a specifically named coal bed. A summary of actively producing coal mines is shown in Table 6.

Colorado coals are variable in both chemical and physical character, as well as thickness and areal extent. Although recent coalbed methane studies (Wray, 2000; Carroll and Tremain-Ambrose, 1999) have found some coals that extend up to 30 mi, correlation of individual coals from basin to basin, or from region to region, is rarely possible. For these and other reasons, many workers prefer to delineate coal-bearing sequences, or zones, when mapping coal beds. The stratigraphic columns included herein are preliminary attempts at coal bed correlation and should be used with care.

CANON CITY COAL REGION

The Canon City Coal Region (or field) (Fig. 1) of Fremont County, lies within the Laramide-age Canon City Basin—a downfaulted, synclinal, structural embayment located at the southwest extremity of the Denver structural basin. The Canon City embayment is bounded on the north by the Front Range uplift, on the southwest by the Wet Mountains Uplift, and on the south by the Apishapa Uplift, which separates the Canon City and Denver basins from the Raton Basin to the south. Geologically, the Canon City Basin is more analogous to the Raton Basin than to the Denver Basin. The geologic structure in the Canon City Coal Region is asymmetric, with gentle dips on the east and moderately steep dips on the west. Some faulting occurs along the east flank of the Wet Mountains uplift. This is the smallest of Colorado's coal regions, covering an area of only about 50 sq mi.

The coals in the Canon City Coal Region occur in the lower part of the Vermejo Formation (Upper Cretaceous). Seven main coal beds in the area have been mined commercially (Fig. 4), and between eight and ten beds are present in the area. Canon City coals typically are high-volatile C bituminous in rank (10,400–11,800 Btu/lb), relatively low in sulfur content (0.4–0.9 percent), non-weathering, non-agglomerating, and non-coking (Carroll and Bauer, 2002; Boreck and Murray, 1979).

This region has produced a total of 48 mil tons of coal—ranking fifth in the state. Historically, more than 175 mines have operated in this region (Carroll and Bauer, 2002; Boreck and Murray, 1979). In 2000, the last underground mine in the region closed, ending 122 years of continuous coal

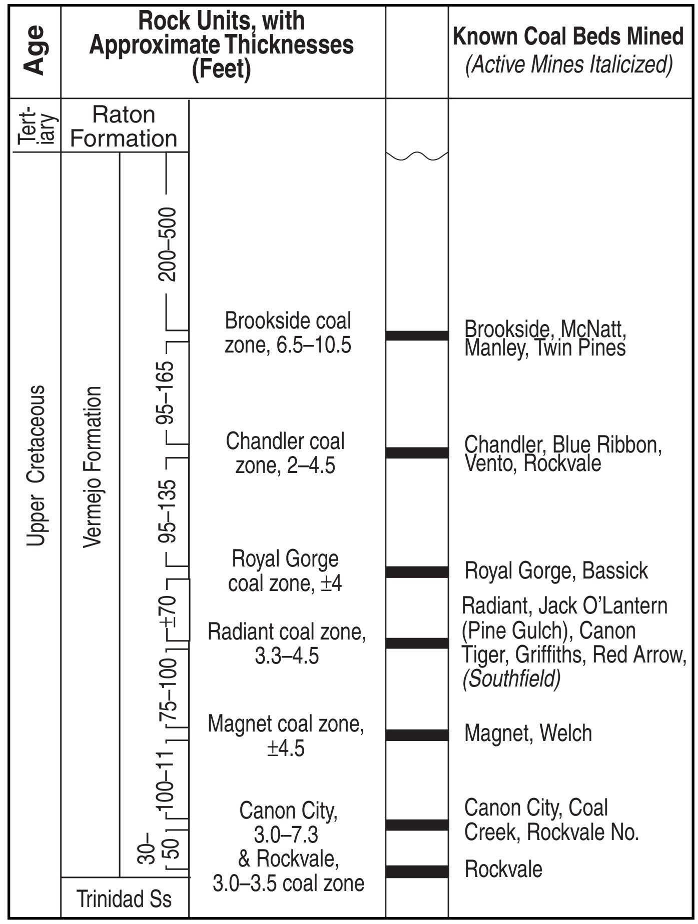

Figure 4. Stratigraphic column, coal-bearing Vermejo Formation, Canon City Coal Field, Canon City Coal Region (no vertical scale). Ss = Sandstone.

production. In recent years, a nearby steam-electric power plant and a cement plant used the coal mined in the Canon City Coal Region. Of the estimated original in-place coal resource of 295 mil tons(Landis, 1959), about 248 mil tons remain in the region with overburden less than 1,000 ft.

DENVER COAL REGION

The Denver Coal Region (Fig. 1) encompasses an area of some 7,500 sq mi east of the Front Range. This region consists of two separate coal-bearing sub-basins: the Cheyenne sub-basin from Wyoming to Mead, Colorado in the north; and the Denver sub-basin from Firestone to Colorado Springs. These basins are separated by a structural high, the Greeley arch, from which the coal-bearing sequences have been eroded (Kirkham and Ladwig, 1979). The extent of the Upper Cretaceous Laramie Formation coal-bearing interval defines the sub-basins. The coal region lies within the larger Laramide Denver structural basin. This region contains large resources of subbituminous coal and lignite within 3,000 ft of the surface.

There are six coal fields in the Denver sub-basin: Boulder-Weld, Foothills, Colorado Springs, Ramah-Fondis, Buick-Matheson, and Scranton. There are three small coal fields in the Cheyenne sub-basin: Wellington, Eaton, and Briggsdale. Cretaceous Laramie Formation coal was mined in all of these fields with the exception of Scranton and Ramah-Fondis, which mined Tertiary Denver Formation coal only. The lower part of the Cretaceous Laramie Formation in both sub-basins contains coal that ranges from subbituminous to lignite in rank. Since 1864 the Denver Coal Region has produced nearly 135 mil tons of coal, or 12.1 percent of the statewide total, from approximately 385 primarily underground mines (Carroll and Bauer, 2002). The Denver Coal Region is the only coal region in Colorado in which shaft mining dominated over drift or slope mining. Shaft depths ranged from about 250 to 500 ft.

Foothills Coal Field — Coal mining in Colorado began in this field near Golden. Laramie Formation coals are exposed in hogbacks and road cuts along the foothills of the Front Range from Colorado Springs to Boulder. The Laramie coal beds are almost vertical in the Foothills Coal Field, but their dips decrease rapidly eastward to 5º or less. Laramie coal beds occur in a 50- to 275-ft thick zone in the lower part of the formation. These coals were deposited on a delta plain in poorly-drained swamps. More than 6.6 mil tons of coal were mined in the Foothills Coal Field between 1874 and 1950, when the largest and last mine, the Leyden Mine, was shut down. Public Service Company of Colorado later used this mine for natural gas storage until 2002.

Boulder-Weld Coal Field — The very first coal mine in Colorado was developed in 1863 near Marshall (Carroll and Bauer, 2002). Later, thicker and more continuous coal seams were developed near Louisville and Lafayette. This field was developed between 1885 and 1977 because of its close proximity both to the railroads and to Denver. The Boulder-Weld area produced more coal than any other field in the Denver Basin. Shaft-mining dominated in this area. Laramie Formation coals are lenticular and generally thicker and more continuous in the Denver Basin than in the Cheyenne Basin. The coals are typically 5 to 10 ft thick and, locally, 20 ft thick in the former, but only 3 to 7 ft thick in the latter. In approximately 1,850 sq mi of the Denver Coal Region, Laramie coal beds are within 200 ft of the surface (Kirkham, 1978), but surface mining is restricted due to urban development. Another 2,000-plus sq mi contain Laramie coal beds from 500 to 1,500 ft in depth; these coals may be candidates for in situ gasification or coalbed methane production. The last mine was the Keenesburg Mine, a surface operation owned by Coors Brewing Company, which closed in 1988. The higher rank coals, which average 8,500 to 10,000 Btu/lb (as-received), occur along the west side of the Denver Basin in the Foothills and Boulder-Weld coal fields. These coals range in ash content from 3.5–12.7 percent and sulfur 0.2–0.9 percent (Lowrie, 1966). The Boulder-Weld Coal Field was famous for the prototype development of the first continuous miner (1943) in the U.S. (Lowrie, 1966)

Buick-Matheson and Ramah-Fondis Coal Fields — These small fields mined shallow coal beds of the Laramie Formation southeast of Denver. Usually lower rank in quality, these fields were mined on a smaller scale than Boulder-Weld Coal Field. Laramie coal beds vary significantly in rank in the Denver Coal Region, from subbituminous B to lignite A. Lower rank Laramie coals, ranging from 5,000 to 7,300 Btu/lb (as-received) are typical of the eastern flank of the Denver Coal Region. The lower rank coals also average higher ash (7.8–15.7 percent) and sulfur content (0.4–1.1 percent) (Kirkham, 1978). Coal quality also varies by thickness and stratigraphic position, with the best quality beds near the base of the Laramie Formation.

Wellington, Eaton, and Briggsdale Coal Fields — Three small coal fields also mined the Laramie Formation coals in the Greeley sub-basin. A total of 66,000 tons of coal were mined between 1897 and 1946. Laramie Formation coal beds were between 3- and 6-ft thick in the Greeley sub-basin, but less continuous in stratigraphic extent.

Scranton Coal Field — The only mines in the Denver Basin to produce Tertiary coal was the Scranton Coal Mine. It produced 38,000 tons

(Carroll and Bauer, 2002). The Denver Formation (Late Cretaceous to Paleocene in age) occurs only in the Denver sub-basin and contains multiple beds of lignite in the central part of the sub-basin. Thick lignite beds of early Paleocene age occur in the upper 300 to 500 ft of the Denver Formation. The lignite beds were deposited in two separate areas (northern and southern) in an alluvial plain east of the Front Range piedmont. The northern lignite area contains individual beds that are typically 10 to 30 ft thick, with a maximum observed thickness of 55 ft. The southern lignite area contains generally thinner beds, averaging 5 to 10 ft, with a maximum thickness of about 30 ft. Most of the known lignite beds occur in the central and eastern parts of the Denver Basin and are potentially surface-mineable, beneath less than 200 ft of cover. To the west, in the deeper parts of the basin, the Denver Formation lignites pinch out.

Denver Formation lignites exhibit the following properties, based on as-received analyses: heating value, 4,000 to 7,000 Btu/lb; ash content, 8 to 30 percent; moisture content, 22 to 40 percent; and sulfur content, 0.2 to 0.6 percent. Variations in quality are primarily a function of the number and thickness of partings, chiefly kaolinite, within a given bed. These kaolinite-rich partings, which may comprise 5 to 30 percent of the total thickness of a bed, are high in alumina content and offer the potential for dual-resource (lignite and alumina) recovery.

Colorado Springs Coal Field — This major historic coal field was the southern-most coal field in the Denver Basin. More than 16 mil tons of coal were mined from three coal beds in the basal Laramie Formation near Colorado Springs. Of these, the largest mine was the Pikeview Mine in northern Colorado Springs, which produced 8 mil tons of coal until 1955.

Approximately 15 mil tons of all the production in the region (11 percent of the Denver Basin) came from the Colorado Springs Coal Field in Douglas, El Paso, and Elbert counties (Brand and Eakins, 1980). The last mine near Colorado Springs was the Bacon Strip Mine which produced 42,000 tons and closed in 1981 (Carroll and Bauer, 2002). Coal resources in the Denver Coal Region are approximately 38 bil tons of subbituminous coal in the Laramie Formation, and 34 bil tons of lignite in the Denver Formation, all with less than 3,000 ft of overburden (Eakins and Ellis, 1987).

GREEN RIVER COAL REGION

The southeast arm of the Greater Green River Coal Region is located in Moffat and Routt counties of northwest Colorado (Fig. 1). The larger part of this important coal region covers most of southwestern Wyoming (Averitt, 1972). The Colorado part of this region is comprised of the Sand Wash structural basin of Laramide age, with the north flank of the Axial Basin Uplift, bounding the basin to the south. The perimeter of the Green River Coal Region is defined (except where faulted) by the base of the Upper Cretaceous Mesaverde Group. The lower part of the Mesaverde is the Iles Formation; the upper part is the Williams Fork Formation. Both formations contain significant coal resources (Fig. 2).

Yampa Coal Field — 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. The Yampa Coal Field is the only named field in the Colorado part of the Green River Coal Region. The south flank of the field consists of gently northward-dipping sediments that are locally folded, faulted, and intruded (especially in the southeast part near Twentymile Park and Oak Creek). The intrusive rocks have upgraded some of the coals to anthracite in some rare locations (Bass and others, 1955).

Nearly all of the coal mined in the Green River Coal Region is from the Iles and Williams Fork (Fig. 5) formations of the Mesaverde Group. Younger coal-bearing rocks (Lance, Fort Union, and Wasatch Formations) are exposed in the northern part of the Yampa Coal Field. A major part of the region contains multiple coal beds in several formations below a depth of 3,000 ft. In the central part of the Sand Wash Basin, coals are present to depths in excess of 10,000 ft.

The Mesaverde coals in the Green River Coal Region are principally high-volatile C bituminous in rank at the outcrop and vary in thickness from approximately 3 to 20 ft. The younger Lance Formation coals, which have been mined locally in the past, are subbituminous B or C in rank and range up to 10 ft in thickness. The overlying Fort

Union coals are as thick as 20–50 ft, as shown by geophysical logs of oil wells drilled in the Sand Wash Basin. Where sampled near the surface, these coals are subbituminous B or C in rank.

Very little is known about the Wasatch Formation coals in the Colorado part of the region, although they have been mined in limited quantities at several ranches on both sides of the Colorado-Wyoming state line. Like the older Fort Union and Lance coals, those in the Wasatch Formation probably are subbituminous in rank, range from a few feet to twenty feet or more in thickness, and may be surface-mineable in parts of the region.

Historically, the Green River Coal Region has produced a total of approximately 314 mil tons of coal through 2002 (26.1 percent of the state total) from 194 mines. Routt County recently became the first Colorado county to surpass 200 mil tons of cumulative coal produced. During 2002, more than 10.9 mil tons of coal were produced in the Yampa Coal Field, accounting for 34 percent of the coal produced in the state that year. Production from this region in 2002 was from one underground mine and three surface mines. RAG American Foidel Creek mine has been the largest coal producer in Colorado since 1994 (Carroll and Widmann, 2000). The Foidel Creek longwall mines the 10-ft thick Wadge seam of the Middle Coal Group of the Williams Fork Formation. This same seam is mined at the Seneca Coal Company's Yoast and Seneca II-W surface mines 10 mi west of Foidel Creek. Trapper Mine, near Craig, Colorado, surface mines the Upper Coal Group of the Williams Fork Formation.

The CGS recently estimated 11.1 bil tons of available coal in the Williams Fork Formation for the Yampa Coal Field (Carroll and others, in press). Available coal is the amount of coal that is actually mineable after discounting surface and technological restrictions to mining are considered. In-place coal resource estimates in the Colorado part of the Green River Coal Region exceed 300 bil tons above a depth of 6,000 ft (Kaiser and others, 1994). Speltz (1976) estimates that nearly 1 bil tons of potentially surface-mineable coal exist in this part of the region. Much of the coal being mined in the Green River Coal Region is burned in electric generating plants at Craig and Hayden. The balance is shipped primarily to Denver, Colorado Springs, and Mexico.

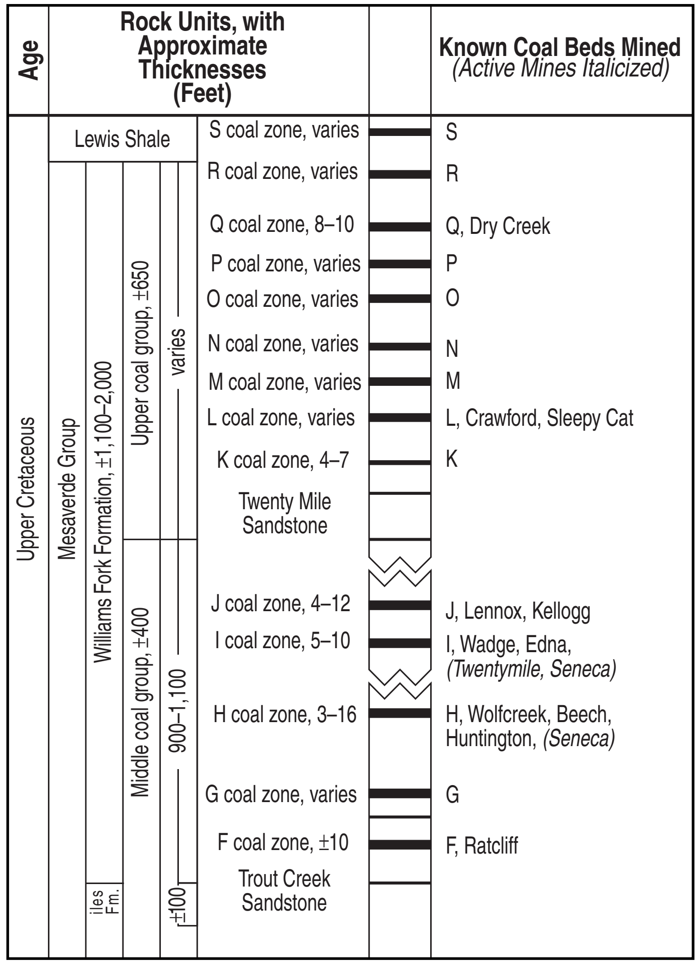

Figure 5. Stratigraphic column, coal-bearing Williams Fork Formation, Mesaverde Group, Green River Region (no vertical scale). Fm = Formation.

NORTH PARK COAL REGION

The North Park Coal Region of Grand and Jackson counties (Fig. 1) lies in a 7,000 to 9,000 ft high intermontane structural basin in north-central Colorado. The North Park Basin or Syncline of Laramide age, is bounded by the Medicine Bow-Front Range Uplift to the east, the Park Range Uplift to the west, the Independence Mountain thrust fault to the north (near the Wyoming state line), and the Williams River-Vasquez Mountains to the south. The North Park Coal Region is comprised of two topographic basins, North Park and Middle Park, separated by the east-west-trending Rabbit Ears Range, a middle to late Tertiary volcanic field. Each basin contains a coal field: North Park Coal Field in North Park (Jackson County) and Middle Park Coal Field in Middle Park (Grand County).

All of the coals found in the North Park Coal Region occur in the Middle Park and Coalmont Formations of late Paleocene and early Eocene age (Hendricks, 1978). The Coalmont Formation contains up to 12,000 ft of terrigenous clastics; carbonaceous shales and coals deposited in an alluvial basin that rapidly subsided as the Rocky Mountains arose during Laramide time. The Middle Park Formation has a maximum thickness of 600 ft (Hail, 1968) in the southeastern part of North Park, and pinches out beneath the Coalmont Formation in the center of North Park. Coals were formed in flood basins and swamps between the meandering streams. The Coalmont Formation unconformably overlies the marine Pierre Shale of Upper Cretaceous age in the northern part of the basin. The Middle Park Formation only occurs in the southern part of the basin. The North Park Coal Region has produced more than 10 mil tons of coal from 35 mines since the early 1900s. The last mine to operate in the region, the Marr surface mine on the east flank of McCallum Anticline, ceased production in 1993 (Carroll and Bauer, 2002). Two of the coal beds (Sudduth and Riach coal beds) in the Coalmont Formation locally exceed 50 ft in thickness (Roberts and Rossi, 2000).

North Park Coal Field — This coal field is the only part of the North Park Coal Region ever mined. Coal was produced in the Coalmont District and the McCallum Anticline District. The coal beds mined in the region were: (1) highly-folded-with bed dips at McCallum Anticline exceeding 45°; (2) generally faulted; (3) very thick (50 to 60 ft); and (4) lenticular. North Park coals generally are subbituminous A to B in rank (Hendricks, 1978); Most of the coal mined in the 1970s from McCallum Anticline was subbituminous A (see Table 5). Heat values in the North Park Coal Field ranges from 6,520–9,570 Btu/lb in the Coalmont Formation Riach beds (Hatch and others, 1979) and 8,580–11,280 Btu/lb in the Sudduth beds of the McCallum District.

Middle Park Coal Field — The Middle Park Coal Field has never produced commercial amounts of coal; however, coal beds reported in lower Tertiary Middle Park Formation probably correlate to the Coalmont Formation (in part) in North Park (Hendricks, 1978; Roberts and Rossi, 2000). A minor amount of coal exists within this 250 to 300 sq mi southern extension of North Park Basin (C. Martin, personal communication, 2003).

RATON MESA COAL REGION

The Raton Basin is a geologic basin on the east side of the Rocky Mountains in both Colorado and New Mexico. The Colorado part of the Raton Mesa Coal Region (Fig. 1) extends northward from the Colorado-New Mexico state line to just north of the town of Walsenburg, and from the prominent Sangre de Cristo and Culebra mountain ranges eastward to Interstate Highway I-25 and the town of Trinidad. This region lies within the Laramide Raton Basin, an asymmetric syncline with a south-plunging axis near the west flank of the basin. Formation dips are gentle on the east flank, but are sharply up-turned to over-turned on the west flank, which is marked by the faulted east edge of the Sangre de Cristo Uplift. Tertiary age igneous rocks that form the Spanish Peaks and rise to elevations exceeding 12,000 ft intrude the central part of the basin. These mountains are associated with several dikes, sills, and laccoliths. The coals in this region have been upgraded, even coked in some areas, by abnormally high heat flow.

The base of the Upper Cretaceous Vermejo Formation (Fig. 5), the oldest coal-bearing sequence in the basin, defines the perimeter of the Raton Mesa Coal Region. Immediately above the Vermejo is the coal-bearing Raton Formation of Upper Cretaceous-Paleocene age (Fig. 6). The multiple, lenticular coal beds in both of these sequences generally are less than 10 ft thick.

Coals of both formations in the southern part of the region in Las Animas County generally are of coking quality, whereas those in the northern part, Huerfano County, typically are non-coking.

The Colorado part of the Raton Mesa Coal Region has produced a total of over 262 mil tons of coal from approximately 376 mines; this represents 23 percent of all the coal produced in Colorado. Prior to 1997, this region had produced more coal than any other region in the state. As of 2003, the Raton Mesa Coal Region ranks third to the Green River and Uinta Coal Regions in cumulative coal production (Carroll and Bauer, 2002). Despite the large volume of coal that has been removed from the Raton Mesa Coal Region, more than 98 percent of the estimated in-place resource of 13.2 bil tons remains.

The coal mines are located along the escarpment at the eastern edge of the basin and along the drainage of the eastward-flowing Purgatoire River, which dissects the area west of Trinidad. Four mines located along the river have produced 41 mil tons of coal from the Raton Formation. The easternmost mine in the river valley produced coal from the Vermejo Formation. One mine, the Lorencito Canyon Mine, operated briefly between October 2001 and May 2002, and produced 168,000 tons of 13,000 Btu coal. The southern part of the basin contains significant amounts of coalbed methane (Danilchik and others, 1979).

Trinidad Coal Field — Coal mines in Las Animas County's Trinidad Coal Field (Fig. 1) have produced considerable amounts of coal since the late 1800s, much of it coking quality. As of 1995, more than 185 mil tons(16 percent of the state total) came from about 150 mines, most of them underground. Table 5 summarizes the coal analyses from this field. Trinidad coal ranges from 10,170–13,870 Btu/lb for the Raton Formation, to 11,430–13,510 Btu/lb for the Vermejo Formation.

Walsenburg Coal Field — This coal field, located in Huerfano County (Fig. 1), has produced approximately 75.7 mil tons of coal (mostly non-coking), which is nearly 7 percent of the cumulative production of Colorado. Most of this coal came from the lower part of the Vermejo Formation. The Raton Formation in Walsenburg ranges in heat value from 12,660–13,340 Btu/lb, while the Vermejo Formation is 11,050–12,880 Btu/lb (Table 5).

SAN JUAN RIVER COAL REGION

The San Juan River Coal Region of Colorado and New Mexico (Fig. 1) covers part of southwest and west-central Colorado as far north as the Grand Valley/Grand Junction area. This region includes the San Juan structural basin of Colorado and New Mexico, the Red Mesa-Mesaverde platform, the Cortez saddle, and the eastern Paradox Basin. The region also includes parts of the Gunnison and Uncompahgre uplifts.

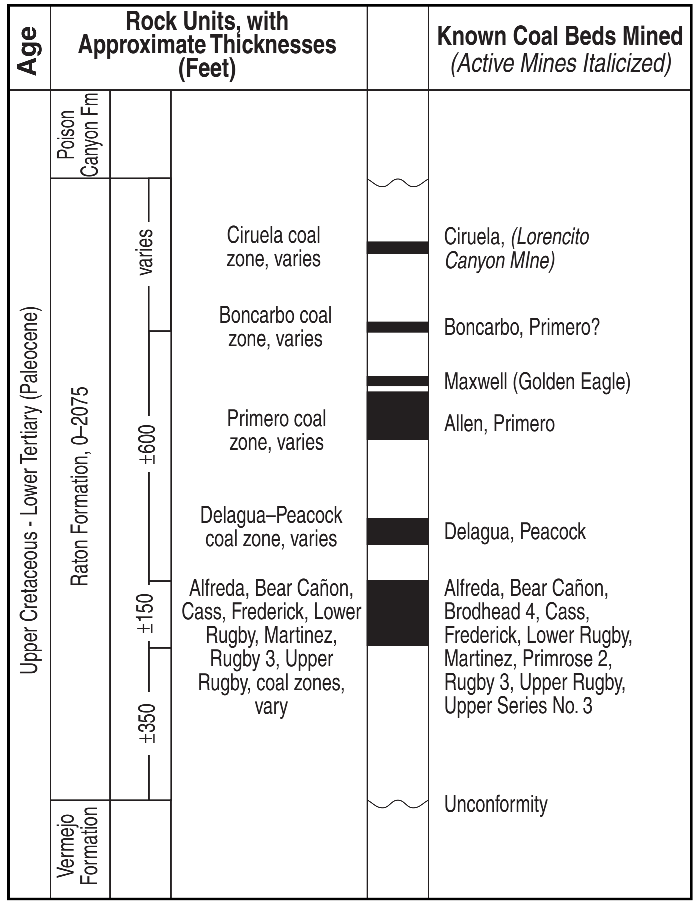

Figure 6. Stratigraphic column, coal-bearing rocks, Raton Formation, Raton Mesa Coal Region (no vertical scale). Fm = Formation, ~ = Unconformity.

Since the late 1800s, the San Juan River Coal Region has produced more than 18 mil tons of coal from nearly 200 mines, representing 1.9 percent of the total production for Colorado. In 2002, the region produced 670,588 tons of bituminous coal from one underground and one surface mine—representing less than 2 percent of the state's production for that year.

Approximately 17 mil tons of coal were produced from La Plata and Montrose counties, the largest producing coal counties in southwestern Colorado, since 1882 (Carroll and Bauer, 2002). This represents 92 percent of the historic total for the San Juan River Coal Region. Production during 2002 from the King Coal underground mine in La Plata County was 328,730 tons, the highest annual output in its 69 year history. King Coal supplies coal to cement manufacturing plants in New Mexico, Arizona and Mexico. Production from the

New Horizon surface mine near Nucla, Montrose County was 386,366 tons for the same year. King Coal produces from the Menefee Formation and New Horizon produces from the Dakota Group (Carroll and Widmann, 2000). New Horizon supplies the Tri-State Energy Nucla power station, which uses a circulating, fluidized bed combustion system to capture sulfur dioxide emissions from the high-sulfur Dakota coals.

Durango Coal Field — The Durango Coal Field (Fig. 1) includes the Colorado portion of the San Juan structural basin, the Hesperus-Red Mesa-Cortez area, and the Mesa Verde area, in La Plata and Montezuma counties. Coals are found in the Dakota Sandstone (or Formation), Menefee Formation, and Fruitland Formation. The Dakota coals are relatively thin, discontinuous, and of high ash content where they outcrop as very thin beds north and northeast of Durango. To the south and west, in the subsurface, Dakota coals are thicker and have been mined to some extent at relatively shallow depths. A deeper resource exists to a depth of 8,000 ft or more in the Colorado part of the San Juan Basin. This deeper reserve contains the most prolific coal-bed methane gas field in the United States.

Coal beds in the Menefee Formation are the only coals being mined at present in the Durango Coal Field (Fig. 7). In local, structurally complex areas near Durango these coals are of coking quality. Coal quality analyses of coal beds in the Durango Coal Field are displayed in Table 5. Fruitland Formation coals are currently mined just over the state line in the New Mexico part of the San Juan Basin.

Nucla-Naturita Coal Field — The Nucla-Naturita Coal Field (Fig. 1) extends from Dolores County northward to just south of the Colorado River in Mesa County. Three mineable coal beds (Fig. 8), 3 to 5 ft thick, occur in the Dakota Group in this area (Eakins, 1986). The New Horizon Mine produced 386,000 tons in 2002. It supplies coal to the Tri-State Power Plant in Nucla.

Pagosa Springs Coal Field — This field, located in Archuleta County (Fig. 1), produced 1.4 mil tons of bituminous coal over the years. There are no mines currently active in the field. The last mine in Archuleta County, the Chimney Rock Mine, closed in 1988.

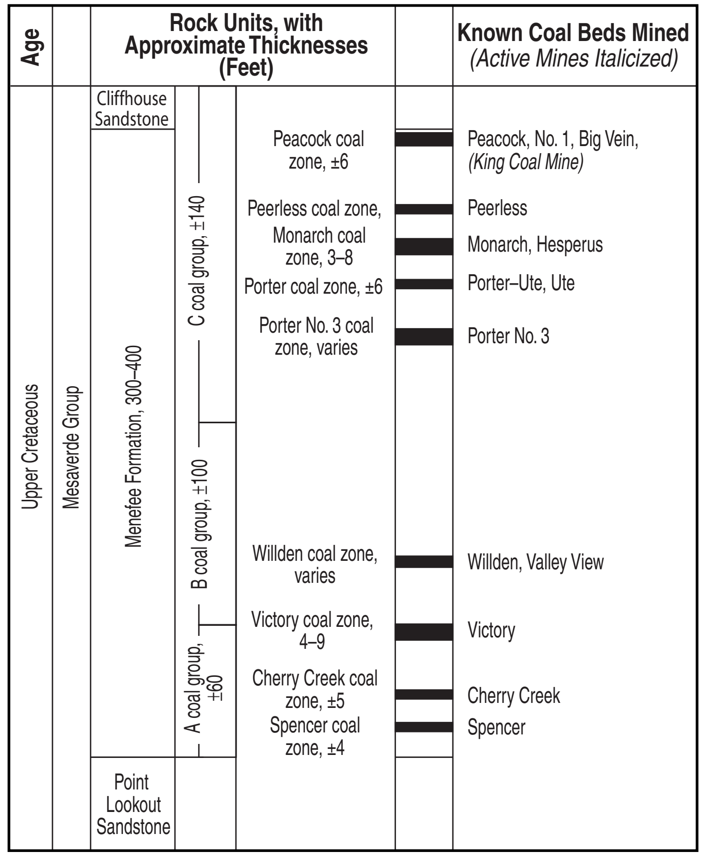

Figure 7. Stratigraphic column, coal-bearing rocks, Menefee Formation, Durango Coal Field, San Juan River Coal Region (no vertical scale).

Tongue Mesa Coal Field — The Tongue Mesa Coal Field is an isolated erosional remnant of Upper Cretaceous sediments (equivalent to at least part of the Mesaverde Group) capped by volcanic rocks of uppermost Cretaceous and lower Tertiary ages. The field is located on Cimarron Ridge, about 20 mi southeast of Montrose and eight miles east of U.S. Highway 550, straddling the Montrose County-Ouray County line.

The coals occur within a 900-ft-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 two to more than 40 ft in thickness, occur on Tongue Mesa in the lower 200 ft of the Fruitland Formation. The most persistent and the thickest coal bed, the Cimarron (or Lou Creek), and several thinner coals were mined underground intermittently from the 1890s until the 1940s. No mines are active in

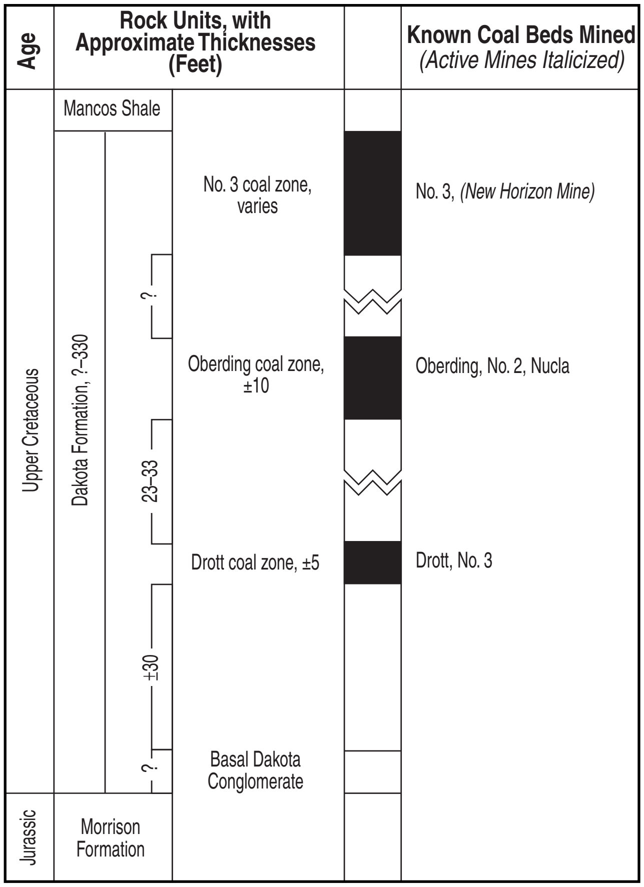

Figure 8. Stratigraphic column, coal-bearing rocks, Dakota Formation, Nucla-Naturita Coal Field, San Juan River Coal Region (no vertical scale).

this field. Tongue Mesa coals generally are subbituminous B in rank and often are considerably oxidized and boney (Table 5).

SOUTH PARK COAL REGION

The South Park Coal Region and coal field in Park County (Fig. 1), lies within a small 9,000 to 10,000 ft high intermontane structural and topographic basin of the same name. The tightly folded and faulted South Park Basin has 227 mil tons of in-place coal resources to a depth of 6,000 ft (Tremain and others, 1996).

The coal-bearing Laramie Formation of Upper Cretaceous age crops out around parts of the Michigan Syncline at the north end of the basin, and in a few other places within South Park. Near the town of Como, several Laramie coal beds— dipping as much as 45— were mined between 1870 and 1905 in 14 underground mines. Only 725,000 tons of coal was produced in the South Park Coal Region, and no mining is occurring at present. The Laramie coals near the surface in South Park probably are subbituminous A or B in rank (Table 5); however, no modern analyses are available.

UINTA COAL REGION

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

The Piceance Basin is the largest structural basin in western Colorado, covering more than 7,200 sq mi as defined by the base of the Upper Cretaceous Mesaverde Group. The basin is asymmetric in shape, with the steep flank on the east and its long axis trending northwest. This is one of the deepest basins in the Rocky Mountain Coal Region, with an estimated 25,000-plus ft of sediments at the north end of the basin in Rio Blanco County (Tremain and others, 1996).

The Elk and West Elk Mountain igneous intrusive complexes of Tertiary-age sills, laccoliths, dikes, and associated folds and faults mark the southeastern part of the region, in Gunnison and Pitkin Counties. The high geothermal heat flow characteristic of this part of the region has increased the rank of much of the coal, producing large resources of coking coal. Much of this coking coal is of premium grade, high in methane content, and commonly having less than 1,000 ft of overburden (Tremain and others, 1996).

The Uinta Coal Region produced nearly 23 mil tons of coal in 2002, or 65 percent of the state's output that year (Table 3). Since the late 1880s, this large and important region has produced more than 356 mil tons of coal from 300 mines. This represents 31.6 percent of Colorado's total, making the region the largest producer in the state. The eight coal fields that occupy the periphery of the Uinta Coal Region are briefly described here. All of these fields are, or have been, producing from the Mesaverde Group (Fig. 2). Representative ranges of analyses are given in Table 5.

Grand Mesa Coal Field — The Grand Mesa Coal Field is located primarily in Delta County (Fig. 1), on the south flank of the prominent Grand Mesa. At 10,000 ft, Grand Mesa is a very large, flat-topped feature capped by Tertiary volcanic flows. The northwestern part of the field, on the west flank of Grand Mesa and south of the Colorado River, is located in Mesa County. The Mesaverde coals in this field are in the Mount Garfield Formation, much the same as in the Book Cliffs Coal Field to the west (Fig. 9). Coals in the Grand Mesa Coal Field range from high-volatile C bituminous to subbituminous A and are typically 4 to 14 ft thick. Original in-place resources to a depth of 6,000 ft in a 530 sq mi area are estimated to exceed 8.6 bil tons. No mines currently operate in this field.

Book Cliffs Coal Field — The Book Cliffs Coal Field contains a number of high-quality coal beds in the Mount Garfield Formation of the Mesaverde Group. These are mostly high-volatile C or B bituminous in rank. Total in-place resources in the 800 sq mi area are estimated at approximately 7.2 bil tons to a depth of 6,000 ft (Speltz, 1976). The underground McClane Canyon Mine in Garfield County re-opened in 2000 and produced a record 327,199 tons of coal in 2002. McClane Canyon supplies coal to the Cameo Power Plant.

Somerset Coal Field — The Somerset Coal Field in Delta and Gunnison counties (Fig. 1) lies in a valley cut by the North Fork of the Gunnison River and its tributaries. The coals in this area occur in the lower Williams Fork Formation (Fig. 10), are high-volatile B and C bituminous, and reach up to 25 to 30 ft in thickness. The southeastern part of the field, near the town of Somerset, contains coking coal of relatively good quality. Typical coal quality from the three active mines is 11,400–12,000 Btu/lb range, 6.5–9.4 percent ash, and 0.4–0.6 percent sulfur content (Carroll and Widmann, 2000).

Three underground mines in this field produced 15.2 mil tons of coal during 2002. Sanborn Creek and West Elk mine the B-seam east of Somerset, in Gunnison County. These two mines combined for 9.7 mil tons produced in 2002. The Bowie No. 2 Mine is near Paonia, and produced more than 5 mil tons of coal from the D-seam in 2002. In-place coal resources to a depth of 6,000 ft in the 320 sq mi area investigated are conservatively estimated at more than 8 bil tons (Landis, 1959). The CGS calculated that 5.1 bil tons of coal are available for development in four seams (Lower B, B, Lower D, D) in the Somerset Coal Field (Schultz and others, 2000).

Crested Butte Coal Field — This Gunnison County Coal Field forms the southeastern tip of the Uinta Coal Region near the town of Crested Butte. Much of the field lies at elevations above 10,000 ft. Coal-bearing, Mesaverde strata in this area have been folded, faulted, and intruded by igneous rocks. The coals here range from high-volatile C

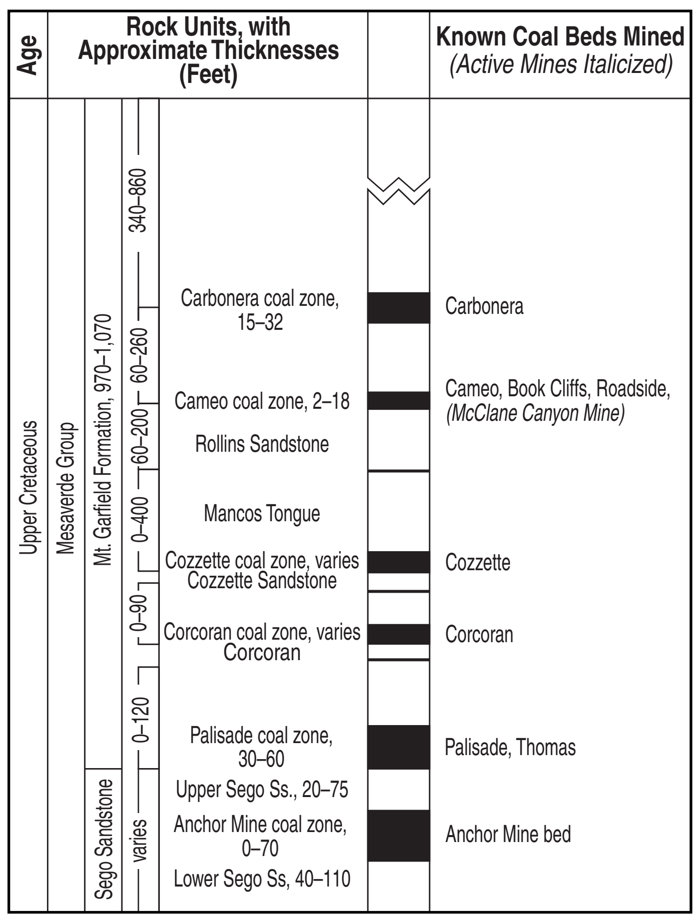

Figure 9. Stratigraphic column, coal-bearing Mesaverde Group, Book Cliffs and Grand Mesa Coal Fields, Uinta Coal Region (no vertical scale).

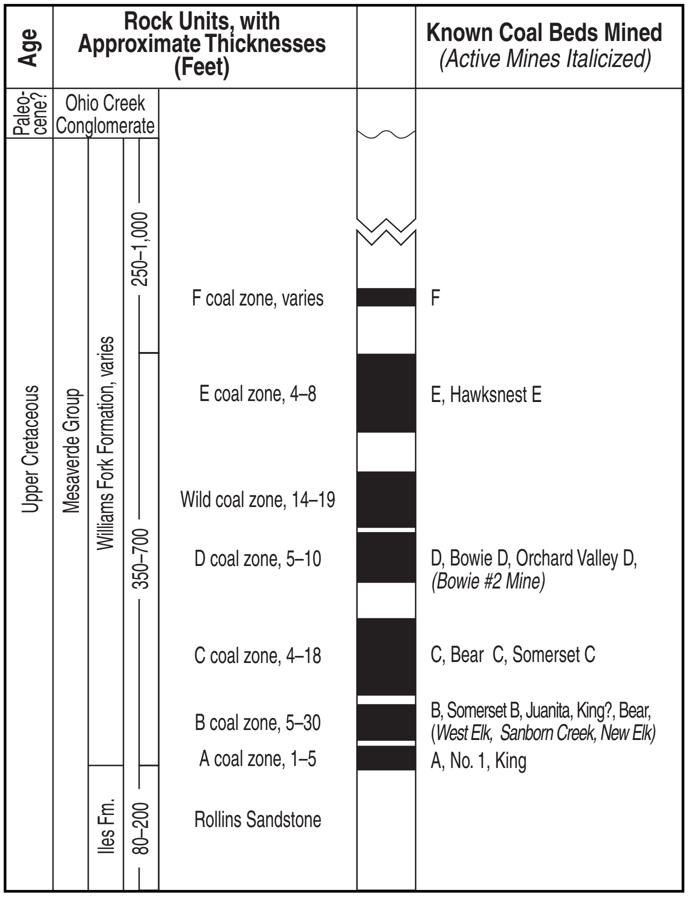

Figure 10. Stratigraphic column, coal-bearing Williams Fork Formation, Somerset Coal Field, Uinta Coal Region (no vertical scale). Fm = Formation.

bituminous to anthracite; some are of good coking quality. Coal beds vary from 2 to 14 ft in thickness. Original in-place coal resources to a depth of 1,000 ft in the 240 sq mi area surveyed are estimated at more than 1.5 bil tons. No coal has been produced in the field since 1992.

Carbondale Coal Field — Located at the eastern edge of the region in Garfield and Pitkin counties, the Carbondale Coal Field has been a source of high-quality coking coal from the Mesaverde Group. In the Coal Basin area of 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 6,000 ft in the 165 sq mi area have been estimated at more than 5.2 bil tons. No mines have operated in the field since 1990 when the last Coal Basin mine closed. These mines ranged from 11,400–14,500 Btu (as-received), with very high concentrations in methane gas.

Grand Hogback Coal Field — This coal field is located along the eastern rim of the Piceance Creek Basin, which is sharply upturned into the prominent Grand Hogback Monocline. This monocline extends southward from Meeker for some 40 mi to just north of Rifle (Collins, 1976), where the hogback makes an abrupt bend to the southeast, passes through New Castle (where it is cut by the Colorado River), then extends to Glenwood Springs where the structure again turns southward. Coal beds along the hogback were mined from 1887–1984 (Carroll and Bauer, 2002).

The Mesaverde coals in the northern part of the Grand Hogback Coal Field are mainly high-volatile C bituminous; these grade southward toward Glenwood Springs to high-volatile B bituminous. The major part of the coal mined from this field has come from the Fairfield and South Canyon 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 3 ft to more than 18 ft thick. Original in-place resources to a depth of 6,000 ft in the 160 sq mi area considered are estimated at more than 3 bil tons. No coal has been produced in this field since the Eastside Mine closed in 1995.

Danforth Hills Coal Field — This important coal field, which extends from Axial south to Meeker, forms the northeast limit of the Uinta Coal Region. The Axial Basin, a topographic low in which the coal-bearing Mesaverde Group has been stripped away, separates this field from the Yampa Coal Field in the Green River Coal Region to the north. Both subdivisions of the Mesaverde Group, the Iles and Williams Fork Formations (Fig. 11), contain numerous good-quality bituminous coal beds, chiefly high-volatile C in rank. Some of these beds exceed 20 ft in thickness. Original in-place coal resources to a depth of 6,000 ft in the approximately 400 sq mi area surveyed total more than 10.5 bil tons (Landis, 1959). Approximately 5.4 mil tons of coal were produced from this field in 2002 from the Colowyo surface mine.

Lower White River Coal Field — This coal field (Fig. 1) covers a large area including the western Piceance Creek Basin and much of the Douglas Creek Arch, westward to the Utah state line. Most of the field lies in Rio Blanco County; a small part, a few miles north of the Rangely oil field, is in southern Moffat County. Coals in the Lower White River Coal Field are in both the Williams Fork and Iles formations. Most mining is near Rangely above the Mesaverde rimrock that flanks the large, breached Rangely Anticline. Coal seams here vary from 8 to 12 ft or more in thickness. The coals are high-volatile C bituminous in rank. In the 930 sq mi area surveyed, 11.7 bil tons of in-place coal resources have been estimated to a depth of 6,000 ft. In 2002, Blue Mountain Energy's Deserado underground mine produced 2,088,876 tons of coal from the B seam. Deserado uses longwall mining methods to extract coal. The product is cleaned at a preparation facility on site, and then conveyed and transported 34 mi via electric rail to the Bonanza power plant in Utah.

COALBED METHANE POTENTIAL

This form of natural gas (methane) is extracted from coal-bearing strata. Coal beds may contain thermogenic, biogenic, or mixed gas resources. Coalbed methane (CBM) drilling is economically favorable because the resource is usually shallower than conventional natural gas and oil plays. Much of the CBM resource in Colorado is from coal beds at depths greater than 2,000 ft deep. Factors important to methane recovery include the gas content, the volume of water in the coal, the permeability, and the reservoir pressure. Colorado's thick coal beds and the shallow drilling and production depths (less than 6,000 ft) make this state an attractive target for CBM exploration (Kaiser and others, 1994).

Significant coalbed methane resources exist in southwestern, south-central, and northwestern Colorado. Colorado ranks second behind New Mexico as the largest coalbed methane producer in the nation (EIA, *Annual Report*, 2000). The two areas of Colorado with the most coalbed methane production are the San Juan Basin and the Raton Basin. The San Juan Basin in Colorado and New Mexico combined for more than 80 percent of the CBM production nationally in 2000 (Wray and Hyde, 2002). In 2000, Colorado produced a total of 410 bil cubic feet (BCF) of CBM. This accounts for 53 percent of the total gas produced in Colorado annually, and resulted in a 1.25 billion dollar industry in 2000.

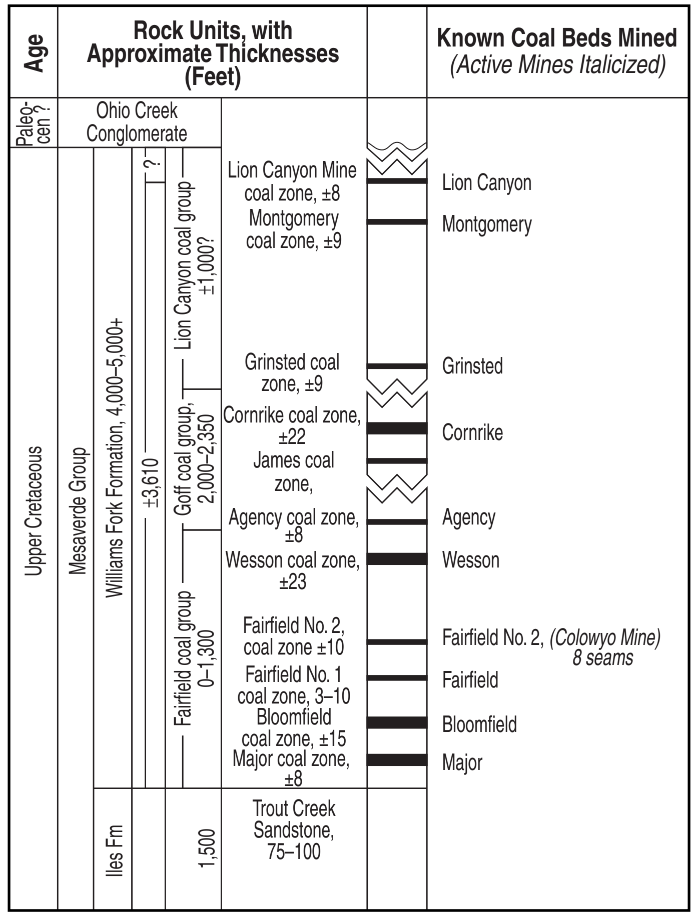

Figure 11. Stratigraphic column, coal-bearing Williams Fork Formation, Danforth Hills Coal Field, Uinta Coal Region (no vertical scale). Fm = Formation.

The San Juan Coal Basin is the largest producing coalbed methane play in the nation. The Colorado part has produced a significant amount of methane in La Plata County since 1988. In 2001, 341 BCF of CBM was produced in the county (Colorado Oil and Gas Conservation Commission [COGCC], 2002). The Raton Mesa Coal Region is the state's second leading producer of coalbed methane. In 2001, 31.6 BCF of coalbed methane was produced from Las Animas County alone (COGCC, 2002).

In terms of total proved CBM reserves through 2000, Colorado ranks number one nationally (Wray and Hyde, 2002). Future exploration targets in the state include the Sand Wash Basin (Green River Coal Region), the Denver Basin, and the Piceance Basin. The latest data from the COGCC indicates that coalbed methane production in Colorado dropped slightly from 410 BCF in 2000 to 374 BCF in 2001 (Table 7).

Coalbed methane is stored primarily within micropores of the coal matrix in an adsorbed state and secondarily in micropores and fractures as free gas or solution gas in water. The key parameters that control gas resources and producibility are thermal maturity, maceral composition, gas content, coal thickness, fracture density, in-situ stress, permeability, burial history, and hydrologic setting.

Table 7. Coalbed Methane production from seven Colorado counties in 2001 (COGCC data on Web site 2002). MCF = thousand cubic ft, BCF = billion cubic ft.

County	2001 Total CBM Produced
Archuleta	686 MCF
Garfield	73 MCF
Huerfano	7 MCF
La Plata	341 BCF
Las Animas	31 BCF
Mesa	75 MCF
Rio Blanco	320 MCF
Colorado Total	**374 BCF**

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