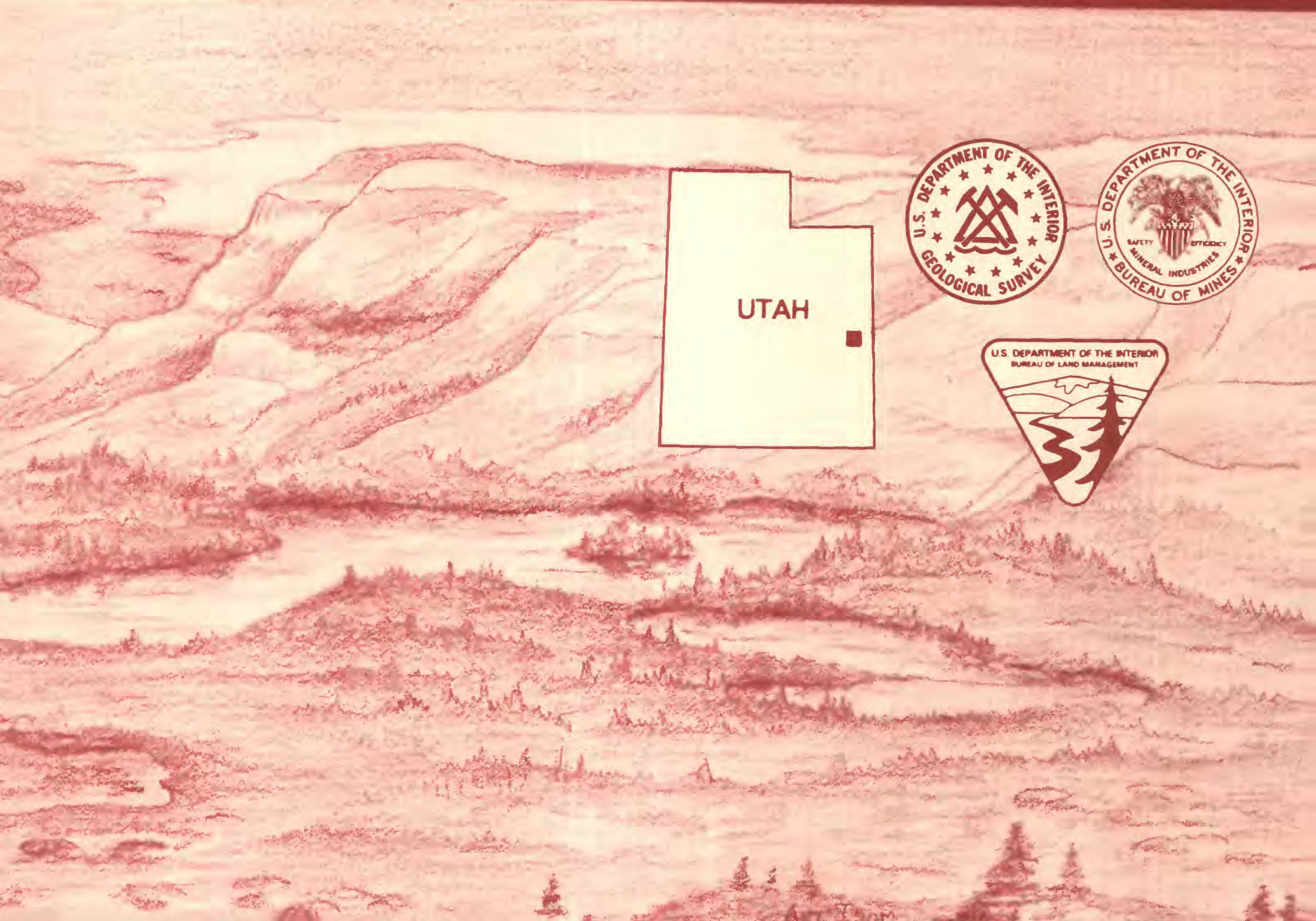
Mineral Resources of the Coal Canyon, Spruce Canyon, and Flume Canyon Wilderness Study Areas, Grand County, Utah

U.S. GEOLOGICAL SURVEY BULLETIN 1753–A



Chapter A

Mineral Resources of the Coal Canyon, Spruce Canyon, and Flume Canyon Wilderness Study Areas, Grand County, Utah

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U.S. Bureau of Mines

U.S. GEOLOGICAL SURVEY BULLETIN 1753

MINERAL RESOURCES OF WILDERNESS STUDY AREAS:
CENTRAL GREEN RIVER REGION, UTAH

DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, JR., Secretary

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STUDIES RELATED TO WILDERNESS

Bureau of Land Management Wilderness Study Areas

The Federal Land Policy and Management Act (Public Law 94–579, October 21, 1976) requires the U.S. Geological Survey and the U.S. Bureau of Mines to conduct mineral surveys on certain areas to determine the mineral values, if any, that may be present. Results must be made available to the public and be submitted to the President and the Congress. This report presents the results of a mineral survey of the Coal Canyon (UT–060–100C), Spruce Canyon (UT–060–100D), and Flume Canyon (UT–060–100B) Wilderness Study Areas, Grand County, Utah.

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[Plate is in pocket]

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Mineral Resources of the Coal Canyon, Spruce Canyon, and Flume Canyon Wilderness Study Areas, Grand County, Utah

By Robert P. Dickerson, Jerry D. Gaccetta, *and* Dolores M. Kulik
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Abstract

The Coal Canyon (UT–060–100C), Spruce Canyon (UT–060–100D), and Flume Canyon (UT–060–100B) Wilderness Study Areas are in the Book Cliffs in Grand County, eastern Utah. Demonstrated coal reserves totaling 22,060,800 short tons, and demonstrated subeconomic coal resources totaling 39,180,000 short tons are in the Coal Canyon Wilderness Study Area. Also, inferred subeconomic coal resources totaling 143,954,000 short tons are within the Coal Canyon Wilderness Study Area. No known deposits of industrial minerals are in any of the wilderness study areas. All three of the wilderness study areas have a high resource potential for undiscovered deposits of coal and for undiscovered oil and gas. There is a moderate resource potential for tar sand in the northwestern parts of the Spruce Canyon and Flume Canyon Wilderness Study Areas, and a low potential for tar sand in the rest of the wilderness study areas. All three wilderness study areas have a low potential for resources of oil shale, gilsonite, uranium and other metals, and geothermal energy.

SUMMARY

Character and Setting

The Coal Canyon (UT–060–100C; 20,774 acres), Spruce Canyon (UT–060–100D; 14,736 acres), and Flume Canyon (UT–060–100B; 16,495 acres) Wilderness Study Areas are in the Book and Roan Cliffs in Grand County, Utah, approximately 12 mi (miles) west of the Colorado state line (fig. 1). The wilderness study areas are about 50 mi west of Grand Junction, Colo., and 40 mi north of Moab, Utah, and are contiguous. The Book and Roan Cliffs mark the transition between the canyon-lands country to the south and the Uinta Basin to the north. The wilderness study areas consist of a series of deep, stair-step-sided canyons and high ridges eroded into the flat-lying sedimentary rocks of the Book Cliffs. Sagebrush, juniper, pinyon, and cottonwood trees abound at lower elevations of the wilderness study areas, and pine, fir, and aspen forests are present higher up. Access to the wilderness study areas is by several public and private dirt roads that exit to the north from Interstate Highway 70 and extend up the valleys of Westwater Creek, Cottonwood Wash, Nash Wash, and Sego Canyon.

The strata making up the Book and Roan Cliffs within the three wilderness study areas dip gently to the north and consist of, in ascending order, the Cretaceous Mancos Shale, Blackhawk Formation, Castlegate Sandstone, Buck Tongue of the Mancos Shale, Sego Sandstone, and Neslen, Farrer, and Tuscher Formations (all except the Mancos are units of the Mesaverde Group), and the Paleocene and Eocene Wasatch and Green River Formations. Several very gentle northwest-trending folds are in the region of the wilderness study areas, as well as a few normal faults of modest displacement. Episodic deposition in changing environments has characterized the geologic history of the Book Cliffs and has led to the accumulation of a variety of energy resources in the vicinity of the wilderness study areas.

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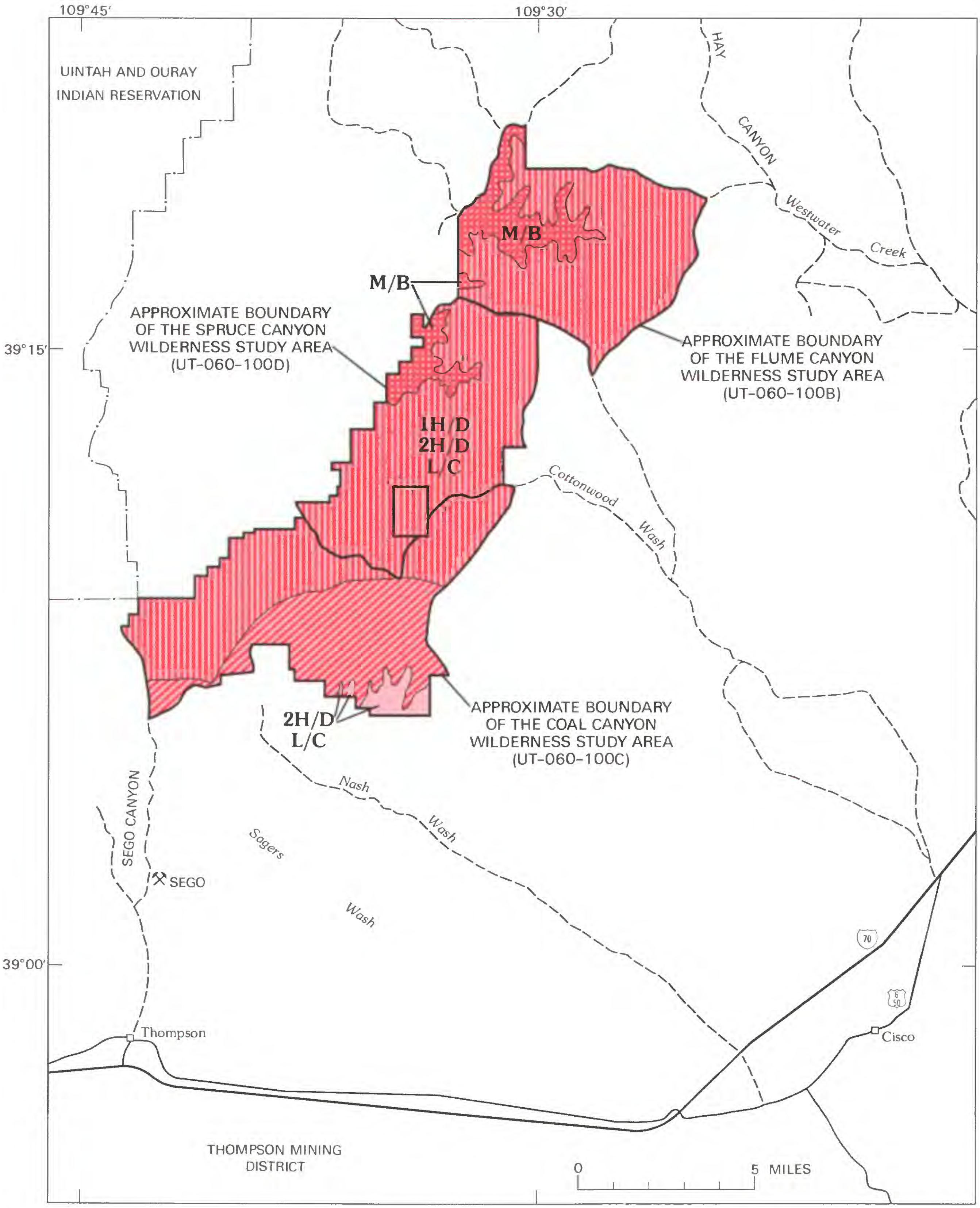

Figure 1 (above and facing page). Summary map showing coal reserves and resources, and mineral resource potential of the Coal Canyon, Spruce Canyon, and Flume Canyon Wilderness Study Areas, Grand County, Utah.

EXPLANATION OF MINERAL RESOURCE POTENTIAL

	Area of demonstrated and inferred reserves and resources
1H/D	Geologic terrane having high mineral resource potential for coal, with certainty level D
2H/D	Geologic terrane having high mineral resource potential for oil and gas, with certainty level D—Includes entire area of all three wilderness study areas
M/B	Geologic terrane having moderate mineral resource potential for tar sand, with certainty level B
L/C	Geologic terrane having low mineral resource potential for oil shale, gilsonite, uranium, other metals, and geothermal energy (includes entire area of all three wilderness study areas) and of tar sand, with certainty level C
	Levels of certainty
B	Available information only suggests level of mineral resource potential
C	Available information gives a good indication of level of mineral resource potential
D	Available information clearly defines level of mineral resource potential
⚒	Coal mine
-------	Unpaved road

Identified Resources

An estimated 2.65 million short tons of coal was produced prior to 1955 from the Sego mining district adjacent to the Coal Canyon Wilderness Study Area. More than 2 million barrels of oil and 216 MCF (million cubic feet) of gas have been produced from petroleum fields in and near all three wilderness study areas since the late 1950's. No mines or mining claims exist within the study areas, but 76 percent of the Coal Canyon, 89 percent of the Spruce Canyon, and 53 percent of the Flume Canyon Wilderness Study Areas have been leased for oil and gas exploration.

Significant deposits of oil shale, tar sand, and gilsonite are known in the Green River Formation near the wilderness study areas. Except for one reported occurrence of tar sand in the extreme northern part of the Flume Canyon Wilderness Study Area, no such deposits are known within the study areas. Modest deposits of uranium are in the Wasatch Formation near the wilderness study areas as well, but none are known within them. No known economically extractable deposits of industrial rocks and minerals are within the wilderness study areas.

Coal is present in several zones in the Neslen Formation within the Coal Canyon Wilderness Study Area. Demonstrated coal reserves totaling 22,060,800 short tons underlie 2.54 mi^2 (square miles) of the wilderness study area (fig. 1), and demonstrated subeconomic coal resources totaling 39,180,000 short tons underlie 3.86 mi^2 of the wilderness study area. Inferred subeconomic coal resources totaling 143,954,000 short tons underlie 15.52 mi^2 of the Coal Canyon Wilderness Study Area.

Mineral Resource Potential

Geochemical surveys conducted within and near the study areas revealed a few single-element anomalies of gold, silver, and uranium in samples, and one iron oxide nodule from outside of the Flume Canyon Wilderness Study Area contained anomalous values of silver, zinc, copper, arsenic, antimony, cadmium, molybdenum, strontium, and uranium. None of the anomalies in samples from within the study-area boundaries is considered significant. Geophysical surveys conducted in the Book Cliffs region revealed numerous magnetic and gravity anomalies. The magnetic anomalies are largely a result of different lithologies of the crystalline rocks of the Precambrian basement. High and low gravity anomalies appear to be the result of different lithologies of the Precambrian basement as well as structural features involving the Precambrian rocks, such as subsurface thrust faults, beneath the wilderness study areas. Some gravity lows are known to be associated with salt structures in the Paradox basin just south of the wilderness study areas, and other gravity lows are hypothesized to result from evaporites, either above or below thrust-faulted Precambrian rocks. Aerial gamma-ray surveys indicate that the wilderness study areas have overall low concentrations of radioactivity; however, a potassium anomaly was detected on the western side of the Coal Canyon Wilderness Study Area.

Subsurface data from oil and gas exploration holes have revealed coal in the Neslen Formation throughout the region of the wilderness study areas. The Flume Canyon, Spruce Canyon, and the northern part of the Coal Canyon Wilderness Study Areas are all assigned a high resource potential for coal. Oil and gas have been produced from three fields partly or wholly within the study areas and from many fields around them. All three study areas are therefore assigned a high resource potential for oil and gas.

Large deposits of oil shale exist in the Mahogany bed of the Green River Formation north of the wilderness study areas. The oil shale of the Mahogany Bed thins to a few inches at the northern edge of the Flume Canyon Wilderness Study Area. Hence, the three study areas are assigned a low resource potential for oil shale.

Large deposits of tar sand exist at P.R. Springs northeast of the Flume Canyon Wilderness Study Area. These deposits thin in the direction of the study areas, and only a few tar sands a few inches to 14 ft (feet) thick were observed in the northernmost corner of the Flume Canyon Wilderness Study Area. The northwestern parts of the Spruce Canyon and Flume Canyon Wilderness Study Areas are assigned a moderate potential for resources of tar sand, and the rest of the wilderness study areas are assigned a low potential.

Gilsonite (a black, shiny mineraloid composed of solid asphalt) occurs as thick veins within northwest-trending faults and fractures more than 30 mi north and northeast of the wilderness study areas. The few faults within the study areas trend east-west, and none of the faults contained any gilsonite. The study areas all have a low resource potential for gilsonite.

A few modest deposits of uranium occur in carbonaceous fluvial sandstone beds in the Wasatch Formation 8–12 mi northwest of the wilderness study areas. Carbonaceous fluvial sandstone beds were not observed in the Wasatch Formation within the study areas, and the few modest anomalies in samples detected during the geochemical survey were not of this type. The study areas are assigned a low mineral resource potential for uranium.

The Book Cliffs are not known to host metal deposits, and the geochemical data do not indicate that copper and other metal deposits that occur on the Colorado Plateau exist in the wilderness study areas. The study areas, therefore, have a low mineral resource potential for metal deposits.

The Book Cliffs are not a favorable environment for geothermal energy resources, and the potential for geothermal resources is considered low.

INTRODUCTION

At the request of the U.S. Bureau of Land Management (BLM), the U.S. Geological Survey (USGS) and the U.S. Bureau of Mines (USBM) studied the Coal Canyon (UT–060–100C), Spruce Canyon (UT–060–100D), and Flume Canyon (UT–060–100B) Wilderness Study Areas. These wilderness study areas are contiguous and are in the Book and Roan Cliffs from Thompson, Utah, east to Westwater Creek canyon. In this report the areas studied are referred to as "wilderness study areas" or "study areas."

Access and Setting

The study areas are about 50 mi west of Grand Junction, Colo., and about 40 mi north of Moab, Utah (fig. 2). They are bounded on the west by Sego Canyon, on the east by Westwater Creek, on the north by the top of the Roan Cliffs, and on the south in part by the base of the Book Cliffs along the northwestern edge of the Grand Valley. Access to the study area is by several maintained dirt ranch roads and BLM access roads that exit Interstate Highway 70 to the north and extend up Westwater Creek, Cottonwood Wash, Nash Wash, and Sego Canyon. Several of these roads cross private land and permission to travel on them must be obtained from the land owner. The road in Sego Canyon is closed at the top of the Roan Cliffs at the Uintah and Ouray Indian Reservation boundary. The road along Westwater Creek reaches the top of the Roan Cliffs from Hay Canyon where it connects with a road along the northern boundary of the Flume Canyon Wilderness Study Area.

The Book and Roan Cliffs mark the transition between the Canyon Lands part of the Colorado Plateau to the south and the Uinta Basin part of the Colorado Plateau to the north. The canyons of the study areas are cut into interbedded sandstone and mudstone and are stair-step-sided, differing from the steep-sided canyons and slickrock country to the south. Elevations range from 5,800 ft at the base of the Book Cliffs at Calf Canyon to 8,885 ft at the top of the Roan Cliffs near Westwater Point. A diverse variety of vegetation abounds in the study area, consisting of sagebrush, piñon pine, juniper, and cottonwood trees in the lower elevations, scrub oak and mountain mahogany in the canyons, and aspen, spruce, pine, and fir trees at higher elevations. Traditional human activities within the wilderness study areas include livestock grazing, hunting, and oil and gas exploration.

This report presents an evaluation of the mineral endowment (identified resources and mineral resource potential) of the wilderness study areas and is the product of several separate studies by the USBM and the USGS. Identified resources are classified according to the system of the U.S. Bureau of Mines and U.S. Geological Survey (1980), which is shown in the appendix of this report. Identified resources were studied by the USBM. Mineral resource potential is the likelihood of occurrence of undiscovered metals and nonmetals, industrial rocks and minerals, and undiscovered energy sources (coal, oil, gas, oil shale, tar sand, and geothermal sources). It is classified according to the system of Goudarzi (1984) and is shown in the appendix of this report. The potential for undiscovered resources was studied by the USGS.

Investigations by the U.S. Bureau of Mines

USBM personnel reviewed sources of minerals information including published and unpublished literature, USBM files, and mining-claim and oil and gas lease records at the BLM state office in Salt Lake City. Discussions on the mineral resources of the study areas were held with Terry McParland, district geologist, BLM Moab District Office.

Field work, completed in 24 employee-days, consisted of traverses made looking for outcrops of oil shale (none were found, although minor amounts of oil-shale float were found in a wash) and sampling and measuring coal outcrops. Five samples of coal were analyzed for quality by Core Laboratories, Aurora, Colo. Traverses were also made with a scintillometer, but no anomalous radiation was detected.

Investigations by the U.S. Geological Survey

A geologic map (pl. 1) of the Coal Canyon, Spruce Canyon, and Flume Canyon Wilderness Study Areas was prepared from published mapping by Gualtieri (1988) and field checked by R.P. Dickerson in May 1988. Foot and vehicle traverses of the study areas were conducted to determine the presence of oil shale, tar sands, oil seeps, additional coal beds, and uranium anomalies.

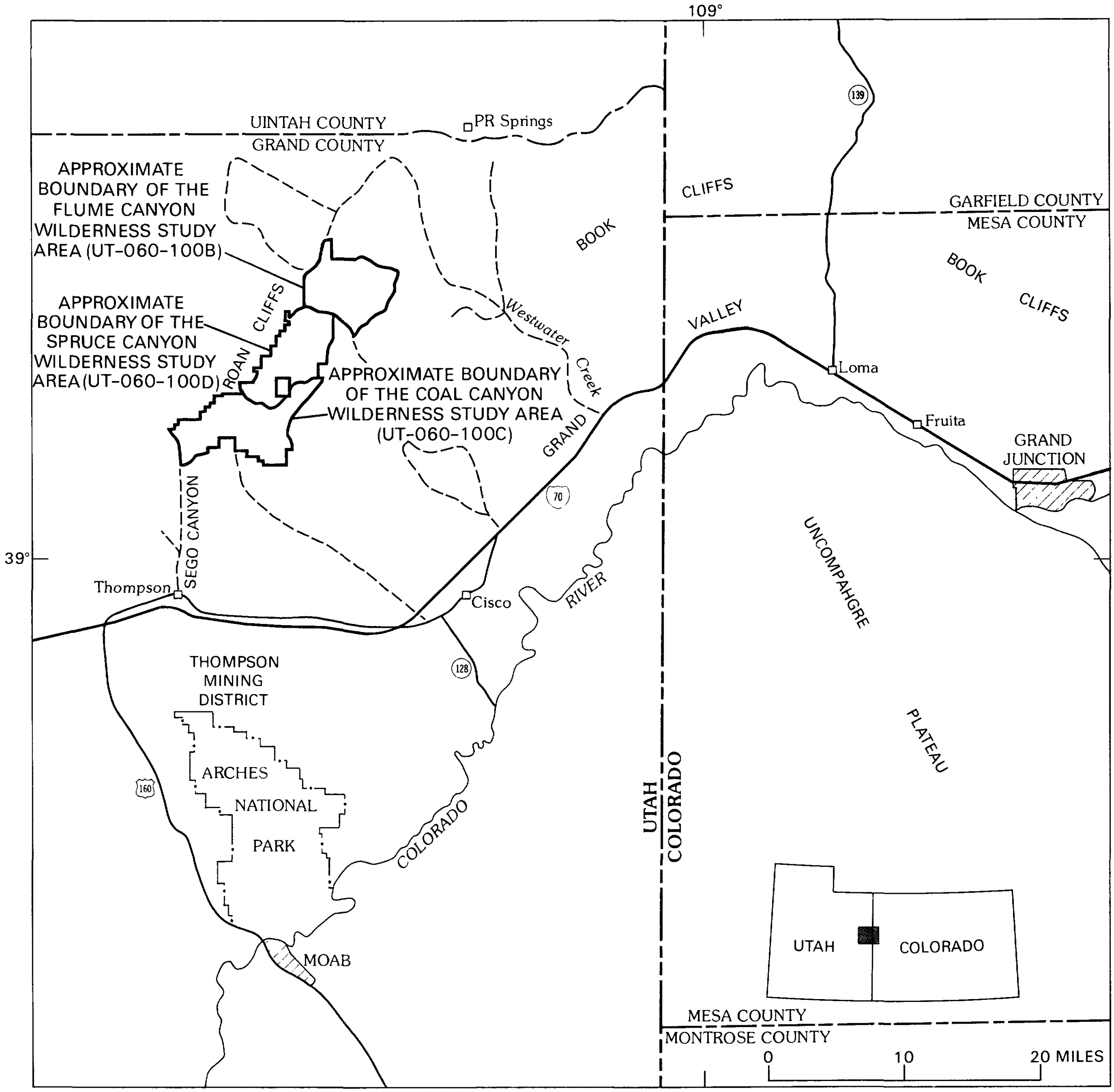

Figure 2. Index map showing the location of the Coal Canyon, Spruce Canyon, and Flume Canyon Wilderness Study Areas, Utah. Dashed lines are unpaved roads.

Sampling for a stream-sediment geochemical survey was conducted in May 1988; geochemical data were collected and interpreted by J.D. Gaccetta for this report. A gravity survey of the region of the study areas was made in the summers of 1986 and 1988 by D.M. Kulik. A magnetic anomaly map of the region was prepared by D.M. Kulik from data that had previously been gathered by the U.S. Department of Energy. Gravity and aeromagnetic data were interpreted by D.M. Kulik for this report. Airborne radiometric data from the U.S. Department of Energy for the region of the study areas were interpreted for this report by J.S. Duval.

Table 1. Summary of oil and gas production data for fields near the Coal Canyon, Spruce Canyon, and Flume Canyon Wilderness Study Areas, Utah

[bbl, barrel (oil); MCF, thousand cubic feet (gas); SI, shut in; ?, data on productive horizons not available; production data from the Utah Department of Natural Resources, Division of Oil, Gas, and Mining]

Field name	Producing horizon	1988 production	Cumulative production	Wells active in 1988
Fields within 5 miles of the wilderness study areas				
Book Cliffs----	Dakota-----	0	408,863 MCF	2
Diamond Ridge--	Dakota, Morrison.	0	261,455 MCF	SI
Lefthand Canyon	Dakota-----	0	59 MCF, 20,003 bbl.	SI
Pear Park------	Dakota-----	0	139,219 MCF	1
Peterson Spring	?	4,013 MCF	92,524 MCF	1
Segundo Canyon-	Dakota-----	44,978 MCF	1,557,649 MCF, 704 bbl.	2
Westwater------	Castlegate, Dakota, Morrison, Entrada.	416,193 MCF, 349 bbl.	28,588,974 MCF, 608,303 bbl.	37
9-17S23E-------	?	1,678 MCF	49,918 MCF	1
15-17S23E------	?	5,992 MCF	129,097 MCF	1
Fields between 5 and 10 miles of the wilderness study areas				
Bryson Canyon--	Castlegate-	746,068 MCF, 230 bbl.	13,756,097 MCF, 2,815 bbl.	40
Bushy----------	?	499 bbl	2,391 MCF, 32,545 bbl.	2
Fence Canyon---	Dakota, Morrison.	139,623 MCF	6,850,200 MCF, 1,448 bbl.	8
Horse Point----	Dakota-----	26,082 MCF	2,128,400 MCF	2
Ice Canyon-----	Dakota, Morrison.	23,543 MCF	629,543 MCF	1
Mancos Flat----	?	348 bbl	14,412 bbl	1
Middle Canyon--	Dakota-----	13,190 MCF	133,616 MCF	1
Mood Ridge-----	Dakota-----	34,324 MCF	1,570,609 MCF	1
5-16S22E-------	?	0	6,590 MCF	1
9-16S22E-------	?	0	213,726 MCF	1
2-16S23E-------	?	27,988 MCF	169,747 MCF	1

[1]Greater Cisco field includes Agate, Bull Canyon, Cisco Dome, Cisco Springs, Cisco Springs North, Cisco Townsite, Danish Wash, Eagle Monument, Gravel Pile, Harley Dome, Sage, and Seiber Nose fields, which are 2-15 mi from the wilderness study areas.

Table 1. Summary of oil and gas production data for fields near the Coal Canyon, Spruce Canyon, and Flume Canyon Wilderness Study Areas, Utah—Continued

Field name	Producing horizon	1988 production	Cumulative production	Wells active in 1988
Fields between 10 and 15 miles of the wilderness study areas				
Bar-X----------	Dakota, Morrison.	816,286 MCF, 16 bbl.	26,609,787 MCF, 1,024 bbl.	34
East Canyon----	Dakota, Morrison.	384,870 MCF, 160 bbl.	9,203,258 MCF, 4,304 bbl.	17
Greater Cisco[1]	Dakota, Morrison.	322,567 MCF, 49,746 bbl.	16,435,058 MCF, 1,293,290 bbl.	289
San Arroyo-----	Mancos, Dakota, Morrison, Entrada.	3,039,058 MCF, 1,725 bbl.	102,521,616 MCF, 148,209 bbl.	106
Stateline------	Dakota, Morrison, Entrada.	342,196 MCF, 233 bbl.	4,786,946 MCF, 8,276 bbl.	20
27-17S25E------	?	0	13,673 MCF	1

APPRAISAL OF IDENTIFIED RESOURCES

By Terry J. Kreidler
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Robert P. Dickerson
U.S. Geological Survey

Mining Activity

No mining has taken place in the three wilderness study areas; the nearest mining was at Sego, in Sego Canyon, about 5 mi south of the Coal Canyon Wilderness Study Area. Although coal was discovered here in 1879, the first mine was not opened until 1900. Production was sporadic for the first few years, but from 1914 to 1930 mining was at its peak, and production was at a rate of 100,000 tons per year. Production decreased until 1954 when the last mine ceased operations. Total coal production from the mines at Sego is estimated at 2.65 million short tons (Doelling, 1972a).

Several blocks of claims, as close as 1.5 mi from the southern boundary of the Coal Canyon Wilderness Study Area, have been staked over Mancos Shale outcrops in the flat land between Interstate 70 and the Book Cliffs (Kreidler, 1989). The claims were probably staked for uranium and bear no relationship to the study areas. No information was available on the claims staked near the Flume Canyon Wilderness Study Area.

Oil and Gas Activity

Oil and gas were discovered in the Book Cliffs area in the late 1950's; since then, fields within 15 mi of the study areas have produced about 216 MCF of gas and more than 2 million barrels of oil. Three of the fields are wholly or partly within the study areas (Lefthand Canyon field in the Coal Canyon Wilderness Study Area, Book Cliffs field in the Spruce Canyon Wilderness Study Area, and Diamond Ridge field in the Flume Canyon Wilderness Study Area). Production data for the fields in the Book Cliffs area are summarized on table 1. The main producing horizons are the Cretaceous Castlegate Sandstone, the Dakota Sandstone, the Burro Canyon Formation, and the Jurassic Morrison Formation and Entrada Sandstone. Currently (1988) there are 569 producing wells within 15 mi of the study areas. (Data supplied by the Utah Department of Natural Resources, Division of Oil, Gas, and Mining.)

The abundance of hydrocarbons in the region has resulted in extensive oil and gas leasing in and near the study areas (Kreidler, 1989). About 76 percent of the Coal Canyon Wilderness Study Area, 89 percent of the Spruce Canyon Wilderness Study Area, and 53 percent of the Flume Canyon Wilderness Study Area are currently under lease. (Lease data are from the BLM as of May 1988). As of March 1989, private industry had not been actively exploring for oil and gas in or near the study areas (Eric Jones, BLM, written commun., March 1989).

Commodity Appraisal

Oil Shale and Tar Sand

The Mahogany oil-shale bed was mapped by Gualtieri (1988) in the Spruce Canyon Wilderness Study Area along Diamond Ridge and in the Flume Canyon Wilderness Study Area around Westwater Point. In this part of the Uinta Basin, the oil shale is less than 3 ft thick and covered by talus; no outcrops of oil shale were found within the study area. According to Cashion (1967), a minimum thickness for commercial development is about 15 ft with a yield of at least 15 gallons of oil per ton. Although the grade of the oil shale in the vicinity of the study areas is not known, a thickness of less than 3 ft is below the minimum required for development.

A few feet to 50 ft below the Mahogany bed, lenticular oil-impregnated sandstone and siltstone beds of the P.R. Springs deposit occur in the Douglas Creek Member of the Green River Formation. Five samples from the vicinity of the Flume Canyon Wilderness Study Area were analyzed by Byrd (1970). The samples came from beds ranging from 3 to 14 ft thick and averaged 8.4 gallons of oil per ton (samples from the main part of the P.R. Springs deposit northeast of the study areas (fig. 1) contained as much as 29 gallons of oil per ton). At present, no method is known to economically extract the oil from tar sands of this low grade. Any deposits in the vicinity of the study areas are not likely to be developed in the foreseeable future.

Uranium

Small uranium deposits have been found in the Wasatch Formation throughout Utah and Wyoming, several in the Book Cliffs and the Uinta Basin. In Showerbath Canyon, 8 mi west of the Coal Canyon Wilderness Study Area, the U.S. Defense Minerals Exploration Administration estimated a uranium resource of about 5 tons containing less than 0.5 percent U_3O_8 in the lower part of the Wasatch Formation (McDonnell, 1988). The uranium is associated with carbonized wood fragments. Outcrops of the Wasatch Formation in the study areas were examined for evidence of carbonized wood and anomalous radioactivity; neither were found. No uranium resources are known to be present in the study areas.

Coal

Coal beds of the Neslen Formation crop out within and adjacent to the southern boundary of the Coal Canyon Wilderness Study Area and dip to the north and northwest 1–2° beneath it. Because this is a terrain of high ridges separating deep canyons, these coal beds may be overlain by as little as 5–10 ft of overburden or as much as 3,700 ft of overburden under the highest points in the northern part of the study area. The coal in these beds is described as low sulfur, medium to high ash, and bituminous (table 2), and is sometimes referred to as "western type" coal (Fisher, 1936). Although no coal has been mined in the study areas, more than 2 million tons were mined at Sego.

Coal deposits in the Book Cliffs west of Green River are in the Blackhawk Formation in an environment of extensive backshore delta-plain swamps behind wave-dominated delta fronts. These coal beds tend to be fewer in number, thicker, and laterally more persistent than coal beds in the Neslen Formation. Coal in the Book Cliffs east of the Green River (as in the study areas) occurs in the stratigraphically higher Neslen Formation, and formed along an alluvial coastal plain where rivers constantly shifted their courses, building deposits seaward across successive swamps. These coal beds are more numerous but thinner, contain more partings, and are not as laterally persistent as coal beds in the slightly older Blackhawk Formation to the west (Balsley, 1982; Willis, 1986; Franczyk, 1989). The coal zones in the Neslen Formation commonly consist of more than one coal bed, and individual coal beds may pinch out or swell, bifurcate, or coalesce with other coal beds (fig. 3). The individual coal beds are constituted variously of coal, bony coal, and bone (a nonquantitative term for impure coal that contains much clay or other fine detrital matter). Coal beds of the Neslen Formation range in thickness from 0.1 to 5.0 ft in the Coal Canyon Wilderness Study Area. The Carbonera coal zone has not been exploited in Utah, but regionally it thickens to the east towards Colorado where it has been mined. Resources calculated for the Carbonera zone are based on measured thicknesses of coal that do exist but may have been incorrectly attributed to the Carbonera zone by R.P. Dickerson. The Chesterfield coal zone of the Neslen Formation is defined as the coal zone directly above the Thompson Canyon Sandstone bed (fig. 3) or its equivalent, the Sulfur Canyon Sandstone bed. This coal zone is fairly persistent and has been traced eastward to the Colorado state line. The Chesterfield coal zone has been the most productive coal zone in the Sego mining district, and in several places contains coal beds 4 ft or more thick in the area between Thompson and Nash Canyons. The Ballard coal zone lies just below the Thompson Canyon Sandstone bed (fig. 3). The Ballard coal zone contains the most persistent single coal bed. This bed is also thickest between Thompson and Nash Canyons, where it is commonly 4–5 ft thick. The Palisade coal zone on the other hand, contains several different coal beds that pinch and swell (Fisher, 1936; Doelling, 1972b). In this report the category "other" (table 4) is for

Table 2. Analytical data for typical coals from east-central Utah and coal outcrop samples from the Coal Canyon Wilderness Study Area, Utah

[Btu/lb, British thermal unit per pound; AR, as received; MMF, mineral matter free (as-received values calculated using Parr formula in Wood and others, 1983, p. 28); MAF, moisture ash free; —, not determined; Na, not available. Samples 1, 3, and 5 are from the Chesterfield zone; samples 2 and 4 are from the Ballard zone; SCF, average analysis for Sego coal field (from Doelling, 1972a); BCF, average analysis for Book Cliffs coal field (from Doelling, 1972b); SM, Sunnyside mine (analysis by the Sunnyside mine laboratory); 81827, Chesterfield zone (Fisher, 1936); A15503, Chesterfield zone (Fisher, 1936); 17577, Ballard zone (Fisher, 1936); 3856, Ballard zone (Fisher, 1936); 17578, Palisade zone (Fisher, 1936)]

Sample			Proximate analysis (percent)				Ultimate analysis (percent)					Heat value (Btu/lb)		
No.	Length (ft)	Reporting basis	Moisture	Ash	Volatile matter	Fixed carbon	Carbon	Hydrogen	Nitrogen	Sulfur	Oxygen	AR	MAF	MMF
1	6.8	As received	6.50	6.68	35.57	51.25	64.08	3.89	1.42	0.41	17.02	10,496	---	11,318
		Dry--------	.00	7.15	38.04	54.81	68.54	4.13	1.52	.44	18.19	11,226	12,090	---
2	3.2	As received	6.62	22.39	31.47	39.52	50.84	3.46	1.29	.48	14.92	8,641	---	11,405
		Dry--------	.00	23.98	33.70	42.32	54.44	3.71	1.38	.51	15.98	9,254	12,173	---
3	4.3	As received	4.13	10.33	33.46	52.08	64.02	3.87	1.43	.52	15.70	10,684	---	12,035
		Dry--------	.00	10.78	34.90	54.32	66.78	4.04	1.49	.54	16.37	11,144	12,419	---
4	4.75	As received	4.46	16.29	32.57	46.68	58.08	3.74	1.39	.64	15.40	9,784	---	11,885
		Dry--------	.00	17.05	34.09	48.86	60.79	3.91	1.46	.67	16.12	10,240	12,345	---
5	4.7	As received	15.93	6.25	31.29	46.53	55.89	3.16	1.30	.39	17.08	9,168	---	9,833
		Dry--------	.00	7.44	37.22	55.34	66.48	3.76	1.55	.46	20.31	10,905	11,781	---
SCF	NA	As received	9.1	11.1	34.7	46.8	NA	NA	NA	.60	NA	10,940	NA	12,442
BCF	NA	As received	4.8	6.7	39.4	49.1	NA	NA	NA	.85	NA	12,760	NA	13,792
SM	NA	As received	7.01	6.10	37.25	49.64	NA	NA	NA	.57	NA	12,988	---	13,920
		Dry--------	.00	6.56	40.05	53.39	NA	NA	NA	.61	NA	13,967	14,949	---
81827	NA	As received	2.3	11.0	37.6	48.4	69.2	5.6	1.5	.7	12.3	12,220	14,150	---
A15503	NA	As received	3.1	13.4	38.0	45.5	65.7	4.9	1.5	1.0	13.5	11,620	13,920	---
17577	NA	As received	5.3	10.6	37.8	46.3	67.3	5.5	1.5	.7	14.4	11,950	14,210	---
3856	NA	As received	4.1	19.5	32.6	43.8	60.5	4.9	1.4	.6	13.2	10,850	14,210	---
17578	NA	As received	5.1	10.7	38.3	45.9	---	---	---	.6	---	12,020	14,280	---

SOURCES OF DATA

1,2,5, from Chesterfield coal zone.
2,4, from Ballard coal zone.
SCF, average analysis for Sego coal field (from Doelling, 1972a).
BCF, average analysis for Book Cliffs coal field (from Doelling, 1972b).
SM, from fresh coal stockpile at Sunnyside mine (analysis by the Sunnyside mine laboratory).
81827, Chesterfield coal zone (Fisher, 1936).
A15503, Chesterfield coal zone (Fisher, 1936).
17577, Ballard coal zone (Fisher, 1936).
3856, Ballard coal zone (Fisher, 1936).
17578, Palisade coal zone (Fisher, 1936).

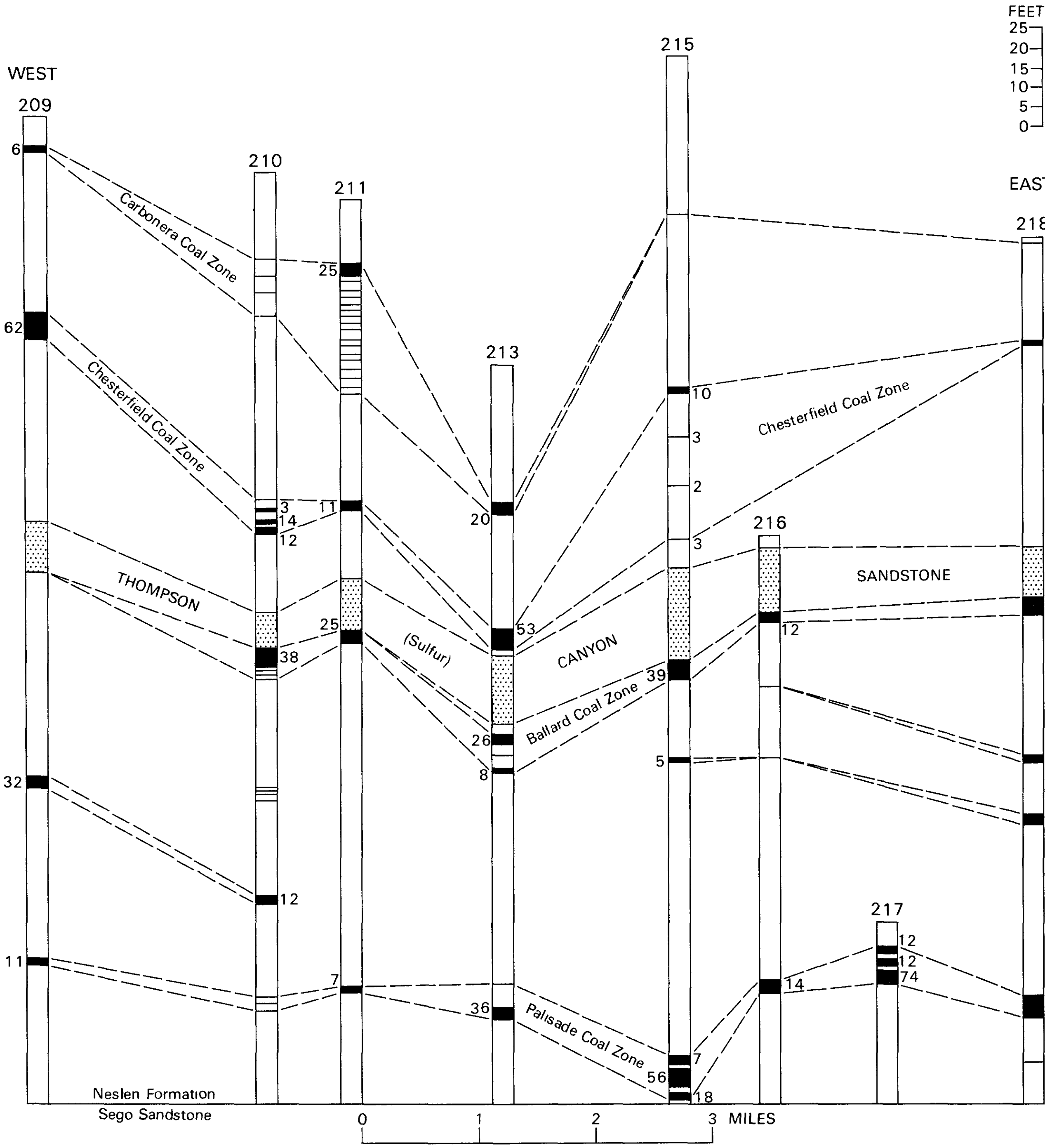

Figure 3. Measured sections of the coal-bearing part of the Neslen Formation in and near the Coal Canyon Wilderness Study Area, Utah. Datum is the base of the Neslen Formation and top of the Sego Sandstone. The numbers next to the coal beds indicate measured thicknesses in inches. Modified from Fisher (1936). Locations of sections are shown on figure 4. Numbers at tops of columns indicate measured sections from Fisher (1936). Solid black, coal; line pattern, bone coal or carbonaceous shale; dot pattern, sandstone marker bed.

individual coal beds that do not appear to be part of the named coal zones but meet the requirements of Wood and others (1983) to be considered as resources of coal (fig. 3).

Analytical data for oxidized outcrop coal samples taken by USBM personnel are shown in table 2. The apparent rank of the oxidized coal samples taken by the USBM from the Coal Canyon Wilderness Study Area is high volatile C bituminous (one sample ranks subbituminous B), which matches closely with the average for the Sego coal field. The samples are low in sulfur and have medium to high ash content.

Resource Estimates

Coal resources for this report were determined using procedures outlined by Wood and others (1983). Data on which the resource calculations are based are from Fisher (1936) and Albee (1979). Regions in the study areas within 0.25 mi (measured), 0.25 to 0.75 mi (indicated), and 0.75 to 3 mi (inferred) of a measured section or cored drill hole were delineated and areas determined using a planimeter (fig. 4). Regions greater than 3 mi from a measured section or cored drill hole are classified as areas of hypothetical resources and are not utilized in determining coal resources. Hypothetical coal resources are discussed in the section on "Mineral and Energy Resources." For simplicity, all coal, bony coal, and bone were treated as coal in determining the thickness of coal beds because not all measured sections differentiated between these types. Therefore, some of the coal resources estimated may be too high in ash content to be economically exploited. All coal beds 14 in. (inches) thick or greater (less partings) were added together to determine the thickness of coal resources in each zone. A square mile 1 ft thick was assumed to contain 1,152,000 short tons of coal.

The USGS (Wood and others, 1983) classifies bituminous coal in beds greater than 28 in. thick with less than 1,000 ft of overburden as reserves, and bituminous coal in beds 14–28 in. thick as subeconomic coal resources (fig. 5). Nearly all of the coal in the areas of measured and indicated resources in the wilderness study areas and vicinity have less than 1,000 ft of overburden, with the exception of coal beneath the summits of a few peaks that rise 1,100 ft above the level of the coal. For simplicity, the area beneath these summits has been included in the coal resource estimate. Coal in the areas of inferred resources in the wilderness study areas and vicinity have between 200 and 1,700 ft of overburden.

Measured, indicated, and inferred reserves and resources underlie only the Coal Canyon Wilderness Study Area. Demonstrated (total of measured plus indicated) reserves of coal totaling 22,060,800 short tons have been estimated for the Neslen Formation underlying 2.54 mi^2 of the study area. Coal reserves tabulated by coal zone are shown in table 3. Demonstrated subeconomic coal resources totalling 39,180,000 short tons have been estimated for all coal zones underlying 3.86 mi^2 of the study area (fig. 4). Coal resources tabulated by coal zone are shown in table 4. The data in table 4 include all coal classified as coal reserves as well as coal classified as subeconomic coal resources. Inferred subeconomic coal resources totalling 143,954,000 short tons have been estimated for all coal zones underlying 15.52 mi^2 of the Coal Canyon Wilderness Study Area (fig. 4, table 4). An unspecified amount of the inferred subeconomic coal resources lies at depths greater than 1,000 ft. The breakdown of areas in square miles underlain by measured, indicated, inferred, and hypothetical coal reserves and resources is given in table 5.

Economic Feasibility

The demonstrated coal reserves in the Coal Canyon Wilderness Study Area are in-place tonnages, and current mining technology does not permit 100-percent recovery. United States coal mines generally recover between 35 and 70 percent of the in-place resources; the average recovery rate is about 50 percent (Wood and others, 1983). Using the average recovery rate, current selling price, and production costs (as of 1988), a gross profitability range can be determined for the reserve base in the study area (table 6). The figures for selling price and production cost are for coal produced at the Sunnyside mine, courtesy of Kaiser Coal Co.

In an evaluation of coal resources in the Desolation Canyon Wilderness Study Area 10 mi west of the Coal Canyon Wilderness Study Area, McDonnell (1988) determined the coal to be subeconomic to marginally economic, even though the tonnage was at least three times greater and located relatively close to the processing facilities at the Sunnyside mine. Even though the coal in the Coal Canyon Wilderness Study Area is only 17 mi from a railhead, the cost of transporting the coal to a processing facility makes the deposits subeconomic. An exploration program would have to increase the reserve base by several times before development in the foreseeable future would be feasible.

Industrial Commodities

Although sand and gravel are in nearly every drainage in the study areas, the deposits are not extensive. No commercially exploitable deposits were observed, though some may be adequate for local use such as road repair or building construction. Similar deposits can be found in drainages outside the study areas, however. The Wasatch Formation sandstone contains too many impurities such as clay, silt, and iron minerals to have any value as a source for silica sand for industrial purposes.

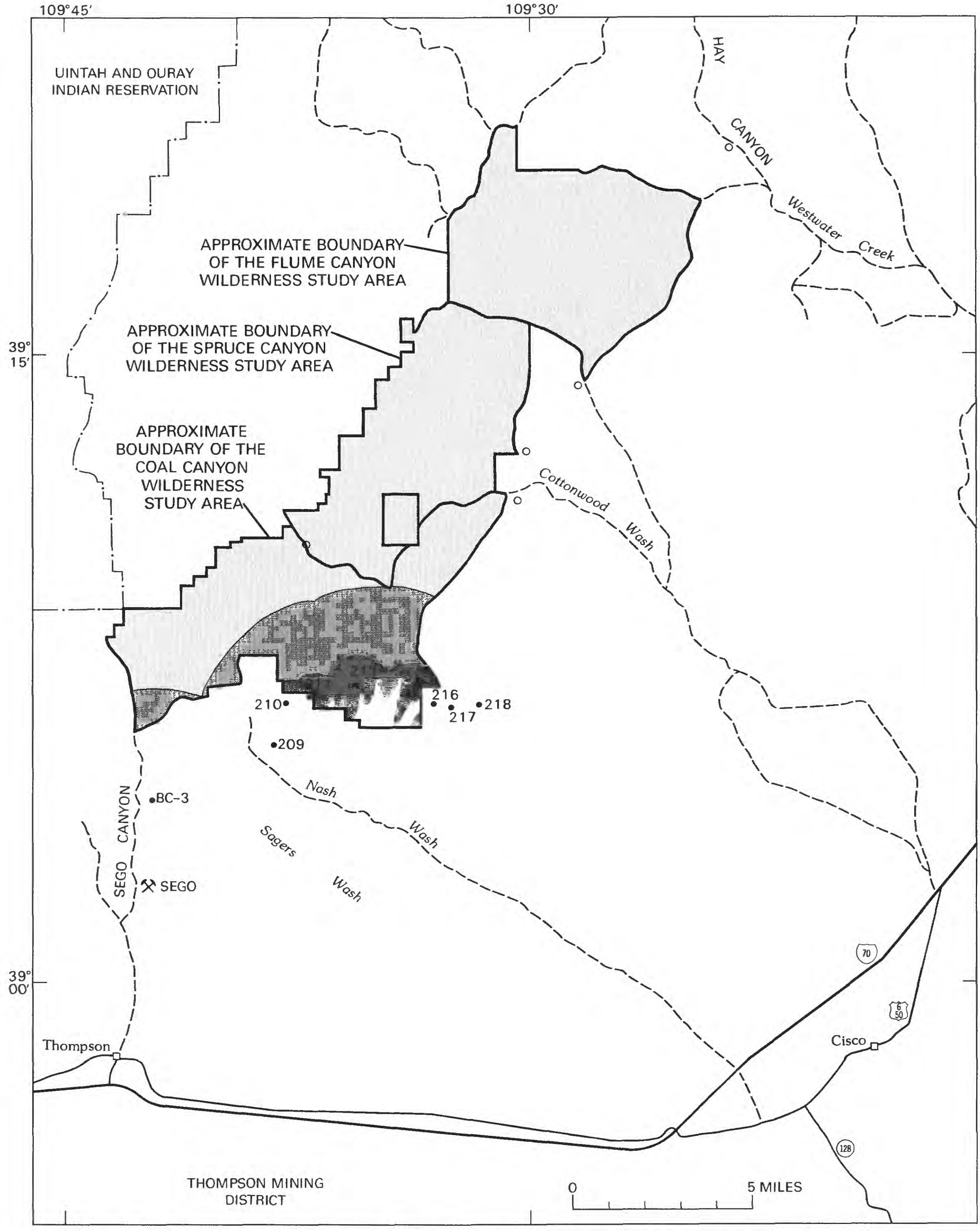

Figure 4 (above and facing page). Summary map showing coal reserves, coal resources, and mineral resource potential for undiscovered coal in the Coal Canyon, Spruce Canyon, and Flume Canyon Wilderness Study Areas, Utah.

EXPLANATION

(pattern)	Area of demonstrated coal reserves and resources
(pattern)	Area of inferred subeconomic coal resources
(pattern)	Geologic terrane having high mineral resource potential for coal resources, with certainty level D
o	Location of oil and gas exploration well where coal was detected at the stratigraphic level of the Neslen Formation
•210	Location of measured section of the Neslen Formation—Sections 209–218 are shown on figure 3
------	Unpaved road

ASSESSMENT OF POTENTIAL FOR UNDISCOVERED RESOURCES

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Geology

Geologic Setting

The Coal Canyon, Spruce Canyon, and Flume Canyon Wilderness Study Areas are in the Book and Roan Cliffs in eastern Utah. The top of the Roan Cliffs marks the southern limit of the Uinta Basin to the north, and the base of the Book Cliffs marks the northern edge of the Grand Valley to the south. The Cretaceous and Tertiary (see geologic time chart in appendix) sedimentary rocks of the Book and Roan Cliffs crop out throughout the study areas and dip gently to the northwest into the Uinta Basin.

Upper Cretaceous sedimentary rocks of the study areas include (oldest to youngest) the marine Mancos Shale, the marginal marine Blackhawk Formation and Castlegate Sandstone, the marine Buck Tongue of the Mancos Shale, the marginal marine Sego Sandstone, and the nonmarine Neslen, Farrer, and Tuscher Formations (Fisher and others, 1960; Gualtieri, 1988; Webster, 1980). As many as four different coal seams in the Neslen Formation crop out within or adjacent to the study areas and dip to the northwest beneath them. These coal seams are laterally persistent enough to be detected at depth in drill holes within and outside of the study areas.

Tertiary sedimentary rocks of the study areas include the fluvial Wasatch Formation and the lacustrine Green River Formation. There are minor occurrences of uranium in carbonaceous fluvial sandstone in the Wasatch Formation northwest of the study areas. Within the Green River Formation there are persistent oil-shale beds that thicken to the north towards the center of the Uinta Basin. One such oil-shale bed, the Mahogany bed, crops out adjacent to and partly within the Flume Canyon Wilderness Study Area, although actual oil shale is less than 3 ft thick at this point. Tar sands are also found within the Green River Formation in the vicinity of P.R. Springs north and northeast of the study areas (fig. 1), though some thin tar sands do crop out adjacent to the Flume Canyon Wilderness Study Area boundary. These tar sands commonly thicken towards the edge of the basin and may seep oil (Cashion, 1967). In the Roan Cliffs northeast of the study areas there are gilsonite-bearing veins. The relationship of these hydrocarbon occurrences is not currently understood, but the lacustrine beds of the Green River Formation are believed to be the source.

Beneath the Upper Cretaceous rocks of the study areas lie, in order of increasing age, the Upper Cretaceous Dakota Sandstone, the Lower Cretaceous Cedar Mountain Formation, the Upper Jurassic Morrison Formation, Summerville(?) Formation, and Entrada Sandstone, the Lower Jurassic Glen Canyon Group, and the Upper Triassic Chinle Formation. In some parts of the study areas the Chinle Formation lies nonconformably on Precambrian crystalline rocks, whereas in other parts, a thin interval of Moenkopi Formation is between the Chinle and the Precambrian basement. Deposits of oil and gas have been found within and near the study areas in the Dakota Sandstone, Cedar Mountain Formation, Morrison Formation, and Entrada Sandstone. These older rocks crop out a few miles south of the study areas in the Grand Valley, where the Morrison Formation also is a host rock for uranium deposits.

Structure

The structure of the Book and Roan Cliffs area consists of gently inclined beds dipping to the northwest towards the center of the Uinta Basin. Superimposed upon this broad incline are several subordinate gentle folds whose axes are oriented to the northwest. These subordinate folds are the cause of the sinuous outcrop pattern of the Book Cliffs (Gualtieri, 1988). The subordinate folds in places contain accumulations of oil and gas, although much of the hydrocarbon production in the Book Cliffs area is also associated with stratigraphic traps not controlled by these structures. The Westwater anticline is just north of Westwater Creek, the northeastern boundary of the Flume Canyon Wilderness Study Area, and produces oil and gas from the Westwater gas field (Schuh, 1961) (pl. 1). The Cottonwood Wash anticline is along Cottonwood Wash just southeast of the Spruce Canyon Wilderness Study Area and produces oil and gas from the Cisco Springs North gas field. The Cisco

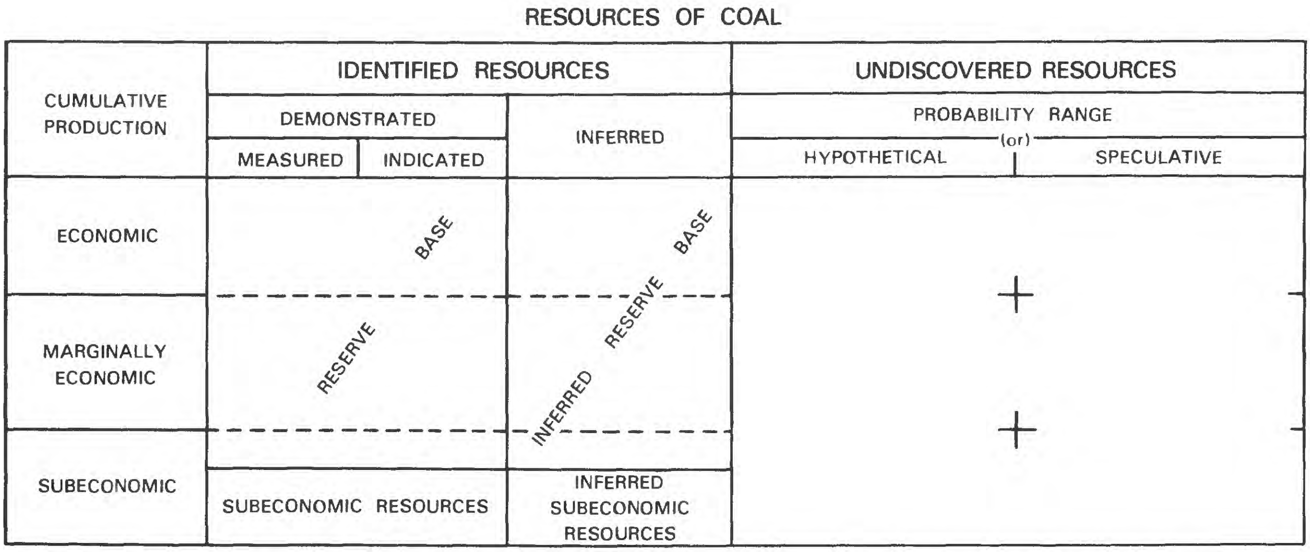


Figure 5. Format and classification of coal resources by reserve and inferred reserve bases and subeconomic and inferred subeconomic resource categories.

Table 3. Distribution of coal reserves by coal zone and reliability of estimate, Coal Canyon Wilderness Study Area, Utah

[Values in short tons]

Coal zone	Measured	Indicated	Demonstrated (Total)
Carbonera---	0	0	0
Chesterfield	990,720	7,096,320	8,087,040
Ballard-----	472,320	3,133,440	3,605,760
Palisade----	1,324,800	9,043,200	10,368,000
Total-----	2,787,840	19,272,960	22,060,800

Dome Oilfield on Nash Wash just south of the Coal Canyon Wilderness Study Area produces oil and gas, but the Bear Canyon nose (a plunging anticline) near Bear Canyon in the Coal Canyon Wilderness Study Area does not (Quigley, 1961). The Diamond Canyon syncline, the Horse Canyon syncline, and the Sager syncline are all gentle northwest-trending folds within the study areas. Very few faults are in the study areas, but those are high-angle normal faults that resulted from the relaxation of tectonic stress (Gualtieri, 1988).

Geologic History

The geologic history of the Book Cliffs area is primarily periodic deposition of sediments in changing environments that directly affected the accumulation of the mineral wealth found today. During the Late Jurassic and Early Cretaceous, deposition was dominated by fluvial systems on a plain of low relief. These systems deposited sediments that became the channel sandstone of the Morrison Formation, which would later act as host for uranium deposits. Stratigraphically controlled oil and gas deposits occur in fluvial sandstone of the Morrison and Cedar Mountain Formations, and in fluvial and marginal marine sandstone of the Dakota Sandstone. The Late Cretaceous sea transgressed into the area, depositing thousands of feet of organic-rich mud that became the Mancos Shale. As the Cretaceous sea retreated, coal-forming swamps and deltas predominated. The coal within the study areas formed along an alluvial coastal plain where smaller rivers constantly shifted their courses to build deposits oceanward across successive swamps (Neslen Formation). Coal fields west of the study areas were formed on extensive backshore delta-plain swamps behind wave-dominated delta fronts, and these coal beds tend to be fewer in number but thicker and more extensive (Blackhawk Formation) than those to the east (Willis, 1986; Franczyk, 1989). The Cretaceous Period closed with fluvial systems once again depositing sediments producing the hundreds of feet of sandstone, siltstone, and mudstone of the Farrer and Tuscher Formations, from source areas to the west and southwest.

The Uinta Basin formed during the Laramide orogeny. Thick lacustrine sequences were deposited in the center of the basin while interfingering marginal lacustrine and fluvial sequences were deposited along the margins of the basin. The fluvial rocks are part of the Wasatch Formation, and the lacustrine sequences are included in the Green River Formation. Uranium is known to occur in carbonaceous channel sandstone within the lower part of the Wasatch Formation. The source of this uranium is believed to be reworked

Table 4. Distribution of coal resources by coal zone and reliability of estimate, Coal Canyon Wilderness Study Area, Utah

[This tabulation of coal resources includes coal classified as coal reserves as well as coal classified as subeconomic coal resources. Values are in short tons. NA, not applicable]

Coal zone	Measured	Indicated	Demonstrated subeconomic (Total)	Inferred subeconomic
Carbonera---	910,080	6,336,000	7,246,080	24,019,200
Chesterfield	990,720	7,303,680	8,594,400	32,129,280
Ballard-----	1,382,400	9,538,560	10,920,960	44,524,800
Palisade----	1,624,320	10,794,240	12,418,560	41,230,080
Other-------	NA	NA	NA	2,050,560
Total-----	4,907,520	33,972,480	39,180,000	143,954,000

Table 5. Total area underlain by coal in the Coal Canyon, Spruce Canyon, and Flume Canyon Wilderness Study Areas, Utah

[Values in square miles]

Measured resources (Coal Canyon)----------	0.45
Indicated resources (Coal Canyon)---------	3.41
Demonstrated resources (Coal Canyon)------	3.86
Demonstrated reserves (Coal Canyon)-------	2.54
Inferred resources (Coal Canyon)----------	15.52
Hypothetical (Coal Canyon)----------------	14.33
Hypothetical (Flume Canyon)---------------	25.77
Hypothetical (Spruce Canyon)--------------	23.03
Total---------------------------------	82.51

volcanic ash originating from volcanic centers to the west. The thick lacustrine sequences contain oil-shale deposits that thicken towards the basin center. These oil shales are a probable source for many of the hydrocarbon deposits found in the Uinta Basin, including the gilsonite veins and tar-sand deposits along the southern margin of the basin (Cashion, 1967). Late Tertiary uplift on the Colorado Plateau caused gentle folding, minor faulting, uplift, and erosion of the Book Cliffs area. In places faults and open fractures became filled with the solid hydrocarbon gilsonite.

Description of Rock Units

Upper Cretaceous main body of the Mancos Shale (unit Km, *pl. 1).*—The main body of the Mancos Shale is a medium- to dark-gray shale containing abundant selenite plates throughout. Some lenses of calcareous sandstone or marlstone occur in the main body of the formation, whereas the uppermost part is sandy or silty. The main body of the formation is 3,400–3,800 ft thick and is conformably overlain by the Blackhawk Formation and the Castlegate Sandstone (undivided) in the western part of the study areas, and by the Castlegate Sandstone in the eastern part of the study areas. Typically, the Mancos Shale forms the gray, flat floor of the Grand Valley at the base of the Book Cliffs.

Upper Cretaceous Buck Tongue of the Mancos Shale, Castlegate Sandstone, and Blackhawk Formation (undivided) (unit Kbb, *pl. 1).*—For this study, these three units were mapped together. The Blackhawk Formation has a maximum thickness of 50 ft and pinches out in the western part of the study areas. The Castlegate Sandstone thins to the east from about 100 ft thick in the western part of the study areas to 70 ft in the eastern part. The overlying Mancos Shale thickens from 200 ft in the western part of the study areas to more than 400 ft in the eastern part. The Blackhawk Formation and Castlegate Sandstone in the study areas are both composed of the brown to light-gray, fine- to medium-grained sandstone and sparse beds of gray siltstone. The sandstone is mostly trough bedded in the western part of the study areas and mostly flat bedded and ripple laminated in the eastern part of the study areas. Typically this sandstone erodes to form a cuesta near the base of the Book Cliffs. The Buck Tongue is medium- to dark-gray shale, silty to sandy in part, containing abundant plates of selenite. It conformably overlies the Castlegate Sandstone, the contact being placed at the top of the cuesta-forming sandstone. This slope-forming unit is commonly obscured by talus and rockfall debris from overlying sandstone.

Upper Cretaceous Farrer Formation, Neslen Formation, and Sego Sandstone (undivided) (unit Kfns, *pl. 1).*—The Sego Sandstone is a light-gray to light-brown, fine-grained, flat-to-trough cross laminated sandstone containing sparse gray sandy and silty shale beds. This unit ranges from 150 to 200 ft in thickness and commonly crops out as a small cliff. The contact with the underlying Buck Tongue is conformable and gradational. The Neslen Formation contains about equal proportions of

Table 6. Estimated gross profitability of coal reserve base in the Coal Canyon Wilderness Study Area, Utah

[Selling price ($32.50 per ton) and production costs ($27.00 per ton) as of April 1989 (Jeff Vigil, Kaiser Coal Co., oral commun.). Recoverable coal tonnage equals 0.5 times in-place coal tonnage from table 4]

Coal zone	Recoverable coal (short tons)	In millions of U.S. dollars		
		Selling price	Production cost	Gross profitability
Chesterfield:				
Measured-----	495,000	16.1	13.4	2.7
Indicated----	3,548,160	115.3	95.8	19.5
Ballard:				
Measured-----	236,160	7.7	6.4	1.3
Indicated----	1,566,720	50.9	42.3	8.6
Palisade:				
Measured-----	662,400	21.5	17.9	3.6
Indicated----	4,521,600	147.0	122.1	24.9

sandstone and shale, and as many as four major coal seams with several minor coal seams and carbonaceous partings. The sandstone is brown to light brown to light gray, very fine to medium grained, and flat to trough cross laminated. The shale is medium to dark gray, in places light greenish gray, and variably carbonaceous or silty. The coal ranges in thickness from a few inches to 6 ft, and ranges from clean, blocky, bituminous coal to bone coal to very carbonaceous shale. The Neslen Formation ranges from 200 to 500 ft in thickness and commonly crops out as steep slopes with small cliffs of sandstone. The Neslen Formation conformably overlies the Sego Sandstone, and the contact is commonly distinct. The Farrer Formation consists mostly of brown to gray, medium-grained, thin- to thick-bedded, commonly crossbedded sandstones. Greenish-gray, silty, and locally carbonaceous shale beds occur in the lower part. Thickness ranges from 400 to 800 ft. Contact with the underlying Neslen Formation is conformable and gradational; the contact is placed where predominantly greenish-gray shales grade downward into predominantly carbonaceous shales. The Farrer Formation commonly weathers to form sandstone cliffs broken by short slopes of shale.

Upper Cretaceous Tuscher Formation (unit Kt, *pl. 1).*—This formation comprises brown to gray, fine- to medium-grained, thick to crossbedded sandstone and olive to greenish-gray silty shale. Thickness ranges from 300 to 600 ft in the study areas. The Tuscher Formation conformably overlies the Farrer Formation; the contact is placed at the base of a thick succession of sandstone beds. Like the Farrer Formation, this unit commonly forms a series of stair-step cliffs broken by slopes of shale.

Early Tertiary (Eocene and Paleocene) Wasatch Formation (unit Tw, *pl. 1)*.—The Wasatch Formation consists of a thick sequence of interbedded sandstones, siltstones, and shales, with sandstones predominating in the lower half and shales predominating in the upper half of the formation. Though not subdivided on plate 1, a thick sandstone sequence at the top of the Wasatch Formation that intertongues with the overlying Green River Formation is called the Renegade Tongue of the Wasatch. At the base of the formation are dark-brown conglomerate and conglomeratic sandstone beds containing pebbles of black chert and varicolored quartzite. The sandstone is light brown to gray, fine to medium grained, and irregularly bedded, and the shale is silty, red to green, and variegated. The Wasatch Formation is as much as 1,300 ft thick in the western part of the study areas but thins to as little as 400 ft 12 mi northeast of the study areas. The contact with the underlying Tuscher Formation is unconformable and is placed at the base of the conglomerate.

Tertiary (Eocene) Green River Formation (unit Tg, *pl. 1)*.—For this report the Green River Formation was not subdivided, though other workers (Cashion, 1967; Gualtieri, 1988) subdivided it into the lower Douglas Creek Member and the upper Parachute Creek Member, with the Mahogany bed marking the base of the Parachute Creek Member. Within and near the study areas the Green River Formation consists of sandstone, siltstone, shale, limestone, marlstone, and oil shale. The sandstone is brown and gray, fine to medium grained, thin to thick bedded, and partly cross-laminated to ripple mark bearing. The siltstone and shale are gray to green. The limestone and marlstone are brown to gray, oolitic, ostracodal, and algal. A few thin, dark-bluish-gray-weathering beds of oil shale occur in the Green River Formation at the edges of the Uinta Basin; these thicken and become more numerous to the north towards the basin center. An important marker bed, and the only oil-shale bed to crop out within the study area, is the Mahogany bed. The Mahogany bed is less than 3 ft thick in the mapped area and consists of blue-gray shale. Oil shale in the Green River Formation commonly occurs as kerogen-bearing marlstone. A kerogen-bearing marlstone 1–2 in. thick was observed within the boundaries of the Flume Canyon Wilderness Study Area. Only the lower 1,300 ft of the Green River Formation is preserved in the study areas. Contact with the underlying Wasatch Formation is conformable, and on a regional scale the two formations intertongue; within the study areas the contact is placed at the top of the red shale and uppermost fluvial sandstone of the Wasatch Formation.

Quaternary (Pleistocene) pediment deposits (unit Qp, *pl. 1)*.—This unit consists of unconsolidated to partly consolidated silt, sand, and gravel veneer on pediment surfaces. A conglomeratic sandstone is commonly present at the base of such deposits.

Quaternary (Holocene and Pleistocene) alluvium (unit Qa, *pl. 1)*.—This unit is the unconsolidated clay, silt, sand, and gravel that occurs on the floors of washes, some canyons, and flood plains. In places it may be as much as 30 ft thick.

Geochemistry

Methods

In May of 1988 a reconnaissance geochemical survey was conducted in and near the Coal Canyon, Spruce Canyon, and Flume Canyon Wilderness Study Areas. In and around the study areas 113 stream-sediment and heavy-mineral panned-concentrate samples as well as 54 rock samples were collected and analyzed.

Stream-sediment samples represent a composite of rock and soil exposed in the drainage basin upstream from the sample site. Chemical analysis of stream sediments may provide information that could identify drainage basins containing uncommonly high concentrations of elements possibly related to mineralized rock. Chemical analysis of heavy-mineral concentrate derived from stream sediment permits the determination of elements not generally detected in bulk stream-sediment samples. Some of these elements may provide information about the high-density, resistant minerals associated with certain ore-forming processes. Mineral identification was performed optically on heavy-mineral concentrates as a reference to the mineral assemblages present in the area.

Unaltered rock samples were collected to provide information on geochemical background values. Altered rock and coal samples were collected to determine elemental suites associated with the coal beds and altered rock.

Stream-sediment and rock samples were analyzed for 35 elements, and heavy-mineral separates were analyzed for 37 elements using a semiquantitative emission spectrographic method (Grimes and Marranzino, 1968). In addition, stream-sediment and rock samples were analyzed for arsenic, antimony, bismuth, cadmium, and zinc by inductive coupled plasma-atomic emission spectrography (Crock and others, 1987), gold by atomic absorption (Thompson and others, 1968), and uranium and thorium by delayed neutron (Millard, 1976).

Results

The geochemistry of the various sample media reflect localized anomalous concentrations of gold, silver, zinc, arsenic, antimony, strontium, uranium, thorium, barium, cadmium, molybdenum, and titanium. Mineralogic inspection of heavy-mineral-concentrate samples revealed abundant anatase and barite, both of which appear to be authigenic. The barite acts as a cementing agent in some of the formations and is common throughout much of the study areas. Analytical data from stream-sediment and rock samples revealed no significant anomalous values, with one exception. A rock sample (an iron oxide nodule) collected outside the boundary of the Flume Canyon Wilderness Study Area contained anomalous values of silver, zinc, arsenic, antimony, cadmium, molybdenum, strontium, and uranium. Heavy-mineral-concentrate sample anomalies are generally single-element anomalies of strontium, barium, thorium, or zinc. Concentrate samples taken from Right Hand Canyon of Nash Wash and Coal Canyon, both in the Coal Canyon Wilderness Study Area, show anomalous values of gold and silver. Two rock samples from within the study areas show 6–10 times background amounts of uranium, and two stream-sediment samples show 2–3 times background amounts of uranium. Several rock (including the iron nodule) and stream-sediment samples from south of the study-area boundaries also contain anomalous amounts of uranium, but there are no clusters of anomalous samples that would indicate a source region.

Iron oxide nodules commonly precipitate from low-temperature, saturated ground water passing through unconsolidated sediments. The suite of anomalous elements in the iron oxide nodule sample from outside of the Flume Canyon Wilderness Study Area probably reflect the ground-water geochemistry in that localized area during the time the nodule was formed and do not reflect an undiscovered resource of those metals. The single-element anomalies from the heavy-mineral concentrates are not considered significant. The two heavy-mineral-concentrate samples from Right Hand and Coal Canyons that contained anomalous amounts of gold and silver are suspected to represent material derived from a paleoplacer source. A significant amount of the sediments forming the rocks exposed in the study areas were stream deposited, and some of these rocks could host small, scattered concentrations of heavier elements in a placer-gravel environment. By virtue of the isolated and widely scattered nature of the gold and silver anomalies, however, these samples are not believed to signify the presence of undiscovered deposits of gold and silver. Of the rock samples containing anomalous amounts of uranium, one is an iron oxide nodule, one is medium-gray shaly sandstone, and two are limestone. None of these lithologies are similar to the carbonaceous, fluvial sandstone of the known occurrences of uranium in the Wasatch Formation. None of the rock or stream-sediment samples of this survey that contained anomalous amounts of uranium overlapped with anomalous samples reported in NURE (National Uranium Resource Evaluation) data published for this area (Langfeldt and others, 1981). The available data would seem to indicate that there are small, isolated areas with slightly elevated amounts of uranium in different rock types, but there is no indication of undiscovered deposits of uranium of the type found in the Wasatch Formation.

Geophysics

Magnetic, gravity, and aeroradiometric studies were undertaken as part of the mineral resource evaluation of the Coal Canyon, Flume Canyon, and Spruce Canyon Wilderness Study Areas to provide information on the subsurface distribution of lithologies and the structural framework. The magnetic, gravity, and aerial gamma-ray data are largely of a reconnaissance nature and are adequate only to define regional structural features.

Methods

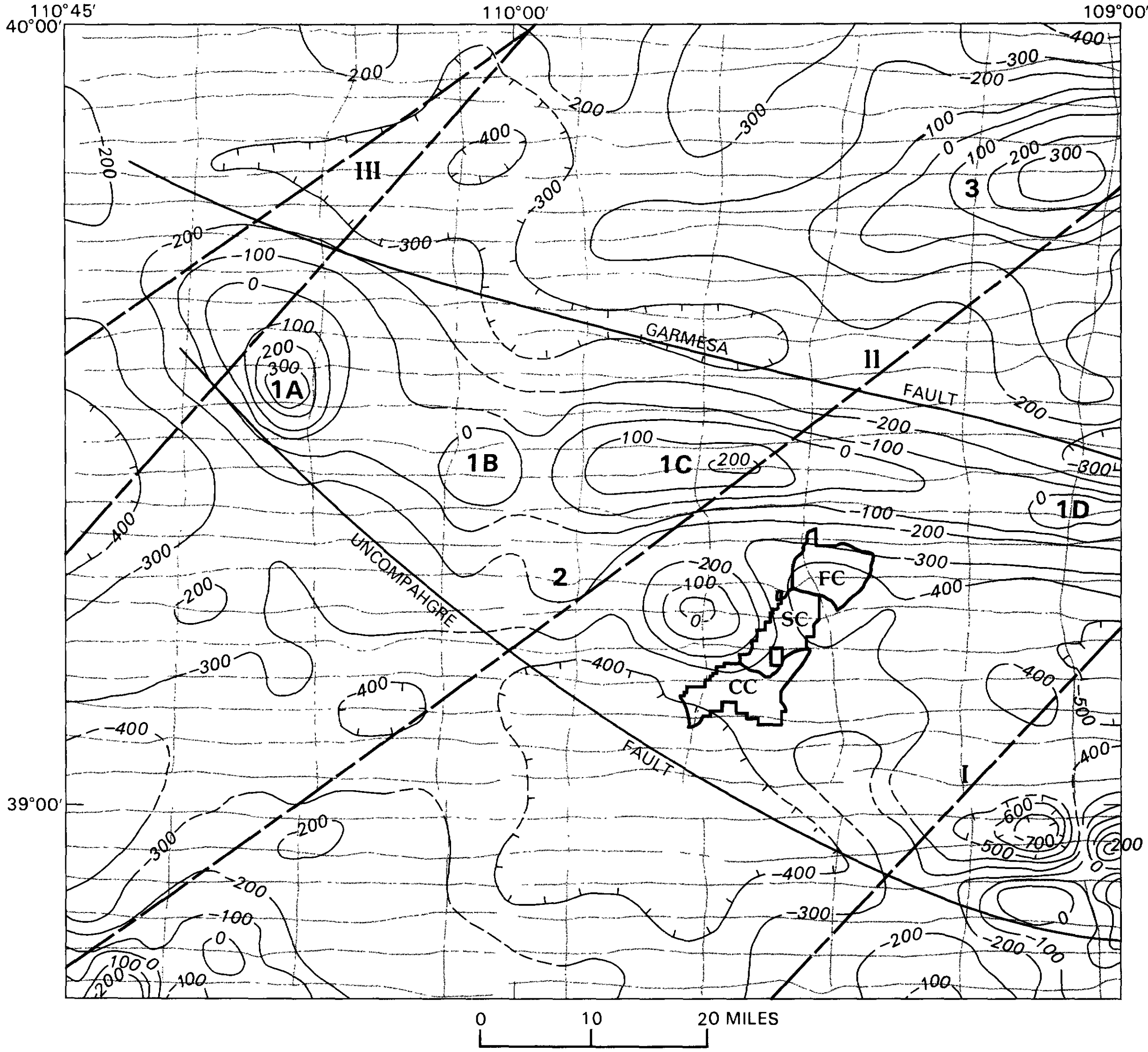
Residual intensity aeromagnetic data from four surveys were compiled to produce a composite map (fig. 6). Data south of 39° N. latitude and east of 110° W. longitude are from U.S. Department of Energy GJM–406 (1983a), north of 39° N. latitude and east of 110° W. longitude are from U.S. Department of Energy GJM–100 (1983b), north of 39° N. latitude and west of 110° W. longitude from U.S. Department of Energy GJM–414 (1983c), south of 39° N. latitude and west of 110° W. longitude from U.S. Department of Energy GJM–415 (1983d). All surveys were flown with east-west flight lines at 2- to 5-mi intervals and 400 ft mean elevation above the ground surface.

Gravity-anomaly data were compiled to produce a complete Bouguer gravity anomaly map (fig. 7). One hundred thirteen gravity stations were measured for this study by Kulik in and adjacent to the study areas in 1986 and 1988; additional data are from the files of the U.S. Defense Mapping Agency. Stations measured for this study were established using a Worden gravimeter W–177. The data were tied to the International Gravity Standardization Net 1971 (U.S. Defense Mapping Agency, Aerospace Center, 1974) at base station ACIC 2787–1 at Grand Junction, Colo. Station elevations were obtained from benchmarks, spot elevations, and estimates from U.S. Geological Survey topographic maps and are accurate to ±20 and ±40 ft. The error in the Bouguer anomaly is less than 2.5 mGal (milligals) for errors in elevation control. Bouguer anomaly values were computed using the 1967 gravity formula (International Association of Geodesy, 1967) and a reduction density of 2.67 grams per cubic centimeter. Mathematical formulas are given in Cordell and others (1982). Terrain corrections were made by computer for a distance of 167 kilometers from each station, using the method of Plouff (1977).

Interpretation

Anomaly configuration and trends in both magnetic and gravity data in these study areas have a variety of orientations, and in many places the anomalies change shape and orientation due to the complex geologic history of the region. East-west trends may reflect the juxtaposition of Precambrian basement rocks of different lithologies during the original development and accretion of continental crust and (or) may reflect structural offset and subsequent leveling by erosion. Northwestern trends are related to tectonic movements mainly during Pennsylvanian and Laramide deformation. Both northeast- and northwest-trending structures may have been controlled or localized by fault systems or crustal weaknesses that developed in the basement rocks prior to Pennsylvanian time. Subtle north-south trends are also present in the geophysical data and may be related to thrust-belt development to the west of the study areas during Jurassic-Tertiary deformation.

The aeromagnetic signature in the northeastern two-thirds of the aeromagnetic map (fig. 6) is characterized by two generally linear, largely east-west-trending high anomalies separated by a low anomaly of smaller magnitude. A similar pattern of alternating high and low anomalies is present on the magnetic anomaly map of the United States (Bond and Zietz, 1987) west of the Rocky Mountains and extends across northwestern Colorado, northern Utah, and southern Wyoming. The



EXPLANATION

—— -300 —— Aeromagnetic contour—Dashed between separate surveys. Hachures show closed areas of lower magnetic intensity. Contour interval 100 nanoteslas

1A Magnetic feature discussed in text

—— I —— Transverse fault zones described in text

- - - - - Flight line—Flown east-west at 2–5 mi intervals and at 400–ft mean elevation above ground surface

CC Coal Canyon Wilderness Study Area

SC Spruce Canyon Wilderness Study Area

FC Flume Canyon Wilderness Study Area

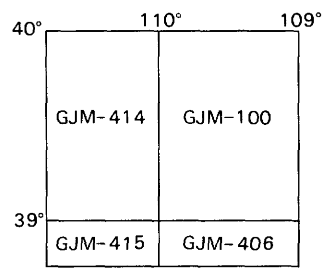
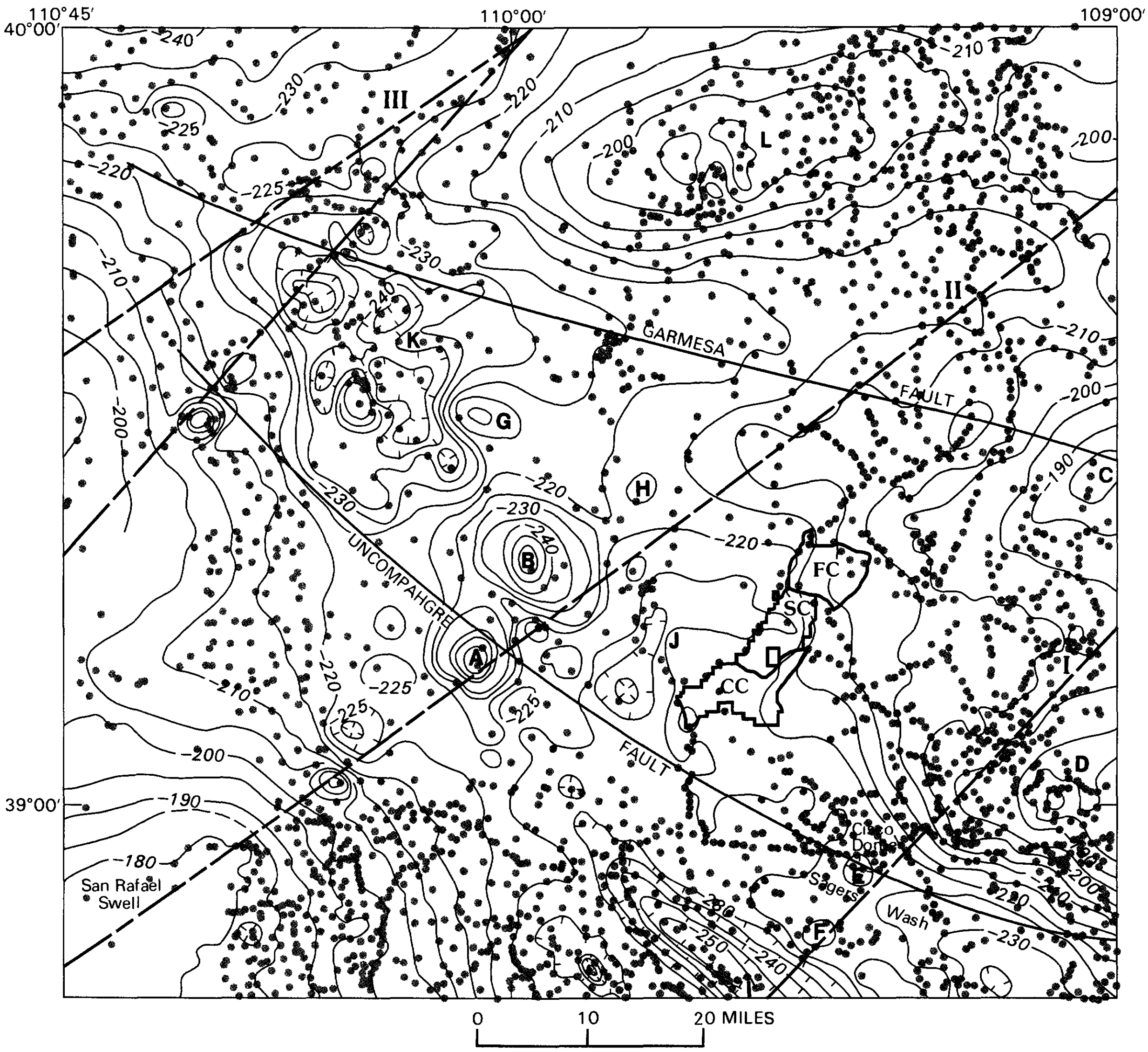


Figure 6. Residual intensity aeromagnetic anomaly and generalized geologic map of the Coal Canyon, Spruce Canyon, and Flume Canyon Wilderness Study Areas, Utah. Contours have been joined arbitrarily at survey boundaries and are shown as dashed lines in those areas. Contour interval 100 nanoteslas.

alternating pattern is probably caused by zones of different lithologies within the Precambrian basement; no correlative gravity anomalies suggest that structural offset of the basement rocks is responsible for the alternating pattern. The aeromagnetic pattern in the southwestern third of the aeromagnetic map is characterized by broader, less linear anomalies of lesser magnitude in the Paradox basin. Part of the difference in



EXPLANATION

——-200——	Gravity contour—Dashed between separate surveys. Hachures indicate closed areas of lower gravity values. Contour interval 5 milligals
A	Gravity feature discussed in text
——I——	Transverse fault zones described in text
•	Gravity station
CC	Coal Canyon Wilderness Study Area
SC	Spruce Canyon Wilderness Study Area
FC	Flume Canyon Wilderness Study Area

Figure 7. Complete Bouguer gravity anomaly and generalized geologic map of the Coal Canyon, Flume Canyon, and Spruce Canyon Wilderness Study Areas, Utah.

character between the two areas is related to structural relief on the Uncompahgre fault zone. In the southeastern corner of the map area, the Precambrian core of the Uncompahgre uplift is exposed at the surface. The uplift plunges northwestward from this point and is partly buried beneath Tertiary sedimentary rocks of the Uinta Basin. The basement rocks of the Uncompahgre uplift are highly variable in lithology, density, and effective magnetic susceptibility (Shoemaker, 1956; Joesting and Case, 1962; Case, 1966). Case (1966) stressed that most anomalies over the Uncompahgre uplift are caused by variations in density and magnetic susceptibility within the basement rocks rather than by basement relief. The short-wave-length anomalies in the southeastern corner of the map area where basement rocks crop out may be caused by such variation, but they may, in part, be due to local faulting within the upper plate of the Uncompahgre fault.

Case's (1966) cross sections (p. 1426) and gravity and magnetic models assume that the contact between the basement and sedimentary rocks of the Paradox basin dips approximately 45° to the southwest, and that offset along the Uncompahgre fault is vertical. Seismic and well data (Frahme and Vaughn, 1983) indicate that the Uncompahgre fault actually dips northeast, probably at angles less than 45°; these data require a reevaluation of Case's models. On the basis of well data, seismic-line data, and interpretation of magnetic differences, Stone (1977) identified the buried Uncompahgre fault that separates the Uncompahgre uplift (figs. 6, 7) from the Paradox basin as a major tectonic feature in the basement that has been intermittently active since Precambrian time. The steep and relatively continuous magnetic and gravity gradients along the inferred subsurface Uncompahgre fault zone also suggest that the fault zone is controlled by a fundamental boundary within the basement.

A strong gravity gradient (fig. 7) that trends northwest parallel to the Uncompahgre fault marks the transition from the Uncompahgre uplift on the northeast to the Paradox basin on the southwest. The gradient diffuses northwest of Cisco Dome where the exposed rocks in the core of the uplift plunge beneath sedimentary rocks of the Uinta Basin. The gradient here is represented by a saddle between gravity highs A and B (discussed later) (fig. 7), and extends to the northwestern corner of the map area, defining the subsurface trace of the Uncompahgre fault as inferred by Stone (1977). A high gravity anomaly is associated with the Uncompahgre uplift east and southeast of the wilderness study areas. This high gravity anomaly continues to the eastern boundary of the map area where it separates into two high anomalies, C and D. A linear composite magnetic high (1A–1D, fig. 6) is associated with the buried northwestern nose of the Uncompahgre uplift. The gradient bounding the northern flank of this magnetic anomaly extends along the northern border of the uplift defined by the Garmesa fault zone. Anomaly highs 1C and 1D coincide with the northern high-gravity anomaly (C, fig. 7) and its westward-extending nose. Less continuous high magnetic values follow the southern edge of the Uncompahgre uplift to the area of the southern gravity anomaly (D, fig. 7) and the group of short-wave-length high and low anomalies mentioned earlier. Gravity and magnetic lows occur between the high gravity anomalies (C and D), suggesting that the uplift has a composite crest here. Alternatively, the variations in magnetic and gravity values may be caused by density and susceptibility contrasts within the Precambrian core of the uplift.

Three zones of transverse faults (I, II, and III, figs. 6 and 7) that cross the Uncompahgre fault zone are suggested by the gravity and magnetic data. Zone I extends southwest along the northeast-trending gravity gradient of anomaly D (fig. 7) and through the structural uplifts and associated low and high anomalies respectively at Cisco dome (E) and Yellow Cat dome (F) and the gravity saddle southeast of the low point of anomaly I. Zone II extends southwest along the northeast-trending gravity gradient of anomaly C; through the high anomalies A and B, which are flanked to the south by a line of local high anomalies, and continues through local high and low anomalies southwest of the Uncompahgre fault and along the northeast-trending anomaly associated with the San Rafael Swell. The crest of the San Rafael Swell is along the inferred fault zone. The Tertiary rocks north of the Uncompahgre fault zone thicken rapidly to the northwest across this inferred transverse zone (Bruhn and others, 1983; Dickinson and others, 1986) and indicate an abrupt plunge of the uplift to the northwest or possible faulting down to the northwest of this end of the uplift. Zone III encompasses two short subparallel trends. The northwestern trend extends along the northeast-trending gradient of anomalies L and K and dies out in a series of small deviations in the north-northwest-trending gradient at the western edge of the map area. The southeastern trend begins along the gradient of anomaly L and traverses a line of local high and low anomalies that are within composite anomaly K and which extend southwest of the Uncompahgre fault zone.

All three inferred zones of transverse faulting are characterized in the gravity data by a northeast-trending gradient that marks the northwestern termination of a regional west-trending high anomaly (fig. 7). (Zones I and II continue to the northeast along a gradient that marks the southeastern boundary of a closed high within the regional anomaly. The gravity data do not extend far enough to determine if this is also the case for zone III). In all three zones a line of local high and low gravity anomalies parallels the inferred transverse fault zones across the Uncompahgre fault. All three inferred zones are characterized in the magnetic data by termination of anomalies, deviations in linear anomaly trends, and by small isolated anomalies along the inferred fault trends (fig. 6).

Local gravity anomalies occur over Cisco dome (E, fig. 7) and Yellow Cat dome (F, fig. 7) superimposed on a gravity saddle that crosses the northwest-trending gravity low associated with a syncline in Sagers Wash (fig.

7). Relatively high values extend northwest and southeast from Yellow Cat dome, suggesting that a slice of Precambrian rocks extends southwest of the major uplift block, and that the Cisco and Yellow Cat domes developed on this imbricate fault wedge. Precambrian rocks are interpreted to lie at shallower depths below the domes than in the area to the west (Joesting and Case, 1962). A similar gravity high extends southwest beyond the gradient associated with the Uncompahgre fault zone south and west of anomaly A. The high suggests a similar structural configuration to that at Cisco and Yellow Cat domes. Local gravity highs similar to those over the domes also occur southeast of anomalies A and B (fig. 7) and extend northeast parallel to the inferred transverse fault. Local gravity highs G and H are similar in size and magnitude but appear to be associated with the buried crest of the Uncompahgre uplift.

Major short-wave-length gravity highs (A and B, fig. 7) lie near the intersection of the Uncompahgre fault zone and inferred transverse fault zone II. Anomaly A occurs at the boundary of two magnetic surveys where the configuration of the contours are in doubt, but the anomaly is well defined by more than a dozen stations. Anomaly B is defined by only one gravity station, thus its magnitude is in doubt, but the –215 and lower contours are well defined by the data. Anomaly B approximately coincides with a weak magnetic nose (feature 2, fig. 6). The anomalies may be caused by intrusive rocks localized by the intersecting fault zones, although no surface faulting, alteration, or hot springs have been reported. No geochemical anomalies were identified in the immediate area.

Both a gravity high (L, fig. 7) and a magnetic high (3, fig. 6) occur in the northeastern corner of the map area. Both are long-wavelength anomalies and trend east-west; they are probably caused by lithologic contrasts in the basement. In the southwestern corner of the map area gravity and magnetic highs are associated with rocks of the San Rafael Swell (fig. 7).

A low gravity anomaly (K) in the northwestern part of the map area is the southernmost extension of a major low anomaly associated with the Uinta Basin north of the mapped area. The low is broken by a complex pattern of short-wave-length high and low anomalies with amplitudes of as much as 25 mGal. The gradients between the local high and low anomalies superposed on anomaly K suggest that the underlying rocks are highly faulted and (or) have high density contrasts such as are common in evaporite deposits, and that the anomalies are caused by a source near the surface. The inferred traces of the Uncompahgre fault zone and the Garmesa fault zone, which bound the Uncompahgre uplift on the south and north, respectively, are approximately defined by gradients bounding the low anomaly K on the southwest and northeast. The major magnetic high associated with the Uncompahgre uplift extends into and culminates in the area of the gravity low. The magnetic anomaly is attributed to the buried Precambrian crystalline rocks of the Uncompahgre uplift, whereas the composite low gravity anomaly K is probably caused by lower density Phanerozoic sedimentary rocks. Bruhn and others (1983) and Dickinson and others (1986) suggested that a large Paleogene delta system with thick deposits of low-density sedimentary rocks was built in the area. A northeast-trending structural element, across which sedimentary units thicken, is apparent in isopach maps (Sanborn, 1981) of rocks as old as Mississippian and Devonian in the area of inferred transverse fault zone II. Isopach maps (Sanborn, 1981) show that Permian and Pennsylvanian rocks thicken across inferred fault zone II to 2,500 ft in the area of anomaly K. Kulik previously suggested (Gerlitz and others, 1988), on the basis of the correlation of gravity lows and magnetic highs, that the Paradox basin salt-cored anticlines to the south were controlled by faults that parallel the Uncompahgre uplift and offset the basement rocks. If salt or other low-density evaporite deposits are the cause of the broad low anomaly K, these deposits do not seem to have been deformed into the long, narrow anticlines typical of those in the Paradox basin. The occurrence of salt beneath anomalies J and K would be north and west of all known occurrences associated with the Paradox basin. The apparent lack of basement fault controls similar to those interpreted for the salt structures in the Paradox basin suggests that evaporites inferred as the source for anomalies J and K were deposited on the upper plate of the Uncompahgre fault. Salt beds and associated deformation and structural relief may be present as well beneath the overriding Uncompahgre fault, and the geophysical expression of those features may be masked by the upper plate.

Mineral and Energy Resources

Coal

Coal exists in four distinct coal zones along with assorted other coal beds in the Cretaceous Neslen Formation throughout most of the study areas. The coal beds crop out in the southern part of the Coal Canyon Wilderness Study Area and dip gently to the north and northwest beneath all three study areas. Numerous measured sections of coal in and around the area of this study have been published (Fisher, 1936; Doelling, 1972a; Albee, 1979). Coal reserves and subeconomic coal resources have been calculated and reported in the section on "Identified Resources" in this report. Most of the study areas lie 3 mi or more from a measured section of coal and thus lie outside the limits for estimating coal resources. This area is known as the area of hypothetical coal resources. Five wells drilled for oil and gas exploration within or very near the study areas in the area of hypothetical coal resources have drilled one or more zones of coal at the stratigraphic level of the Neslen Formation (fig. 4). Reports from these wells were not detailed enough to make accurate coal-resource calculations, but they confirm the existence of coal in the subsurface in the northern three quarters of the study areas. Although coal is known to exist in some locations in the Cretaceous Dakota Sandstone, no such occurrences are known where the Dakota Sandstone crops out south of the study areas nor is any coal reported from this stratigraphic horizon in wells drilled for oil and gas in or north of the study areas. Based on these criteria, the northern one-half of the Coal Canyon Wilderness Study Area and all of the Spruce Canyon and Flume Canyon Wilderness Study Areas are regarded as having a high resource potential for coal in the Neslen Formation at depths to 3,700 ft, with a certainty level of D.

Oil and Gas

Exploration for oil and gas has been occurring in the Grand Valley near the study areas since 1921 and in the Book Cliffs since 1955. Currently three gas fields are partly or wholly within the wilderness study areas (Diamond Ridge, Book Cliffs, and Left Hand Canyon), four oil and gas fields are adjacent to the study areas (Cisco Dome, Cisco Springs North, Pear Park, and Westwater), and many others are in the surrounding region. Oil and gas have been produced from the Castlegate and Dakota Sandstones, Cedar Mountain Formation (its equivalent east of the Colorado state line is the Burro Canyon Formation in some oil-field reports), Morrison Formation, and Entrada Sandstone. Production from the Castlegate and Dakota Sandstones and the Cedar Mountain and Morrison Formations has largely been from stratigraphic traps in fluvial sandstone, whereas the Entrada Sandstone produces from structural traps. Shows of oil have been noted in sandstone lenses in the Mancos Shale, though there has been no production (Mahoney and Kunkel, 1963). The source of the hydrocarbons is believed to be the organic-rich shale of the Mancos Shale and possibly the carbonaceous mudstone in the Dakota Sandstone (Hendel, 1961). In places, carbon dioxide is found in quantity with natural gas in the Entrada Sandstone, and helium has been found in the Morrison Formation (Mahoney and Kunkel, 1963).

Several drill holes have penetrated to Precambrian crystalline rocks, and their logs show that the Uncompahgre Plateau dips to the northwest beneath the study areas. In these drill holes the oldest sedimentary formations above the crystalline Precambrian rocks are the Triassic Chinle and Moenkopi Formations (Mahoney and Kunkel, 1963) or the Permian Cutler Formation (Campbell and Bacon, 1976). Seismic and drill-hole data indicate that Precambrian crystalline rocks have been thrust westward along the western margin of the Uncompahgre Plateau over deeper Paleozoic sedimentary rocks (Frahme and Vaughn, 1983). This relationship suggests the possibility for deep drilling in the western part of the wilderness study areas to discover the Paleozoic carbonates that have been so productive in other parts of the Paradox basin (Carter, 1963).

All the important factors for favorable geologic terrane for oil and gas occur within the study areas; reservoir rocks, cap rocks, source rocks, thermal maturity, and structural and stratigraphic traps (Goudarzi, 1984). Oil and gas have been discovered within and adjacent to the wilderness study areas. Molenaar and Sandberg (1983) gave the region that contains the study areas a high potential for small- to medium-size gas fields and small oil fields in Cretaceous sedimentary rocks. Other geologic data (Frahme and Vaughn, 1983) suggest the possibility of oil and gas deposits in deeper Paleozoic rocks beneath the thrust-faulted Precambrian rocks. The study areas are assigned a high potential for the discovery of further resources of oil and gas, with a certainty level of D.

Oil Shale

The largest oil-shale deposits in the world are in the Piceance, Green River, and Uinta Basins of northwestern Colorado, southwestern Wyoming, and northeastern Utah, respectively. The thickest and highest grade oil-shale deposits occur in the depositional centers of these basins. The bulk of these deposits are found in the Parachute Creek Member of the Green River Formation, and a lesser amount is found in the Evacuation Creek Member of the Green River Formation. The most persistent and one of the richest oil-shale horizons is the Mahogany bed, which is also a widespread marker bed in the vicinity of the wilderness study areas (Cashion, 1957, 1967; Gualtieri, 1988).

The term "oil shale" as used here refers to a kerogen-bearing dolomitic marlstone. A marlstone is a calcareous mudstone to clayey limestone, and kerogen is a precursor to petroleum that can mature into petroleum if subjected to the appropriate temperatures for the proper amount of time. The kerogen in the Green River Formation originated from aquatic organisms, waxy spores, and pollen. The marlstone bodies of the Green River Formation were deposited in a lacustrine environment and contain as much as 50 percent kerogen (Cashion, 1957; Abbott, 1957).

Studies (Quigley and Price, 1963; Cashion, 1967) show that the wilderness study areas are outside of the part of the Uinta Basin determined to have 15 gallons of oil or more per ton of oil shale. The oil-shale beds are at least 15 ft thick in that part of the basin. Mapping by Gualtieri (1988) shows that the Mahogany bed, the most prominent oil-shale zone in the southern part of the Uinta Basin, is less than 3 ft thick anywhere in Grand County, Utah, although one measured section by Cashion (1967) shows the Mahogany bed to be about 3 ft thick in the very northern part of the Flume Canyon Wilderness Study Area. The thickness of the Mahogany bed gradually increases to the north, away from the study area, and it becomes part of the much thicker Mahogany oil-shale zone. Towards the center of the basin there are other oil-shale beds beneath the Mahogany bed, but these grade into marginal lacustrine rocks towards the basin margin and do not exist in or near the study area (Cashion, 1957). Field work completed in May 1988 for this study revealed that the Mahogany bed, which crops out along Diamond Ridge adjacent to the Flume Canyon Wilderness Study Area and along Westwater Point within the study area, consists of less than 3 ft of calcareous gray shale and 1–2 in. of kerogen-rich marlstone. The stratigraphic section below the Mahogany bed is magnificently well exposed in canyons throughout the study area, but no oil-shale-bearing beds were discovered in or near the study areas.

The wilderness study areas are assigned a low resource potential for the occurrence of oil shale, with a certainty level of C. Parts of the Green River Formation below the Mahogany bed were found to be barren, and all parts above the Mahogany bed have been removed from the study areas by erosion. The Mahogany bed itself is not considered to be an oil-shale resource within the study areas, and studies of the regional stratigraphy (Cashion, 1967) suggest that it is a resource only many miles to the north of the study areas.

Tar Sand

Many of Utah's largest and most productive tar-sand deposits are in the Uinta Basin. The P.R. Springs deposit, the sixth largest in Utah, is the southernmost deposit in the Uinta Basin and adjoins the study areas. The tar sands (also known as asphaltic sandstone) in this deposit contain between 0.2 and 32.4 gallons of petroleum per ton of rock but average 14.7 gallons, with reserves estimated at 87 million barrels (U.S. Bureau of Mines, 1964; Campbell and Ritzma, 1979).

The tar sands of the P.R. Springs deposit are in a 250-ft interval near the top of the Douglas Creek Member of the Green River Formation, just below the oil shale of the Parachute Creek Member and the Mahogany bed. Within this interval are one to five principal beds that range in thickness from 30 to 85 ft (U.S. Bureau of Mines, 1964). Drilling has shown that these asphaltic beds dip to the north and continue in the subsurface for many miles. The tar, or asphalt, is localized in deltaic arkoses of the upper part of the Douglas Member on the southern perimeter of the Uinta Basin that are updip from stratigraphically equivalent lacustrine mudstone beds towards the basin center. These mudstones are believed to have been the source of the petroleum found in the tar sands. Updip migration of petroleum was further controlled by gentle northwest-trending folds, particularly the Hill Creek-Winter Ridge anticline and the Main Canyon anticline northwest of the study areas (Byrd, 1970). As the oil-impregnated beds lie at or near the surface, the volatile components have escaped, leaving the more viscous material in the sandstone. Several oil seeps are present in the P.R. Springs deposit, but these appear to be driven by water flowing down a hydrologic gradient steeper than the regional dip of the asphaltic sandstones (Byrd, 1970).

Erosion has removed the Green River Formation from most of the study areas except along the tops of ridges in the northern and northwesternmost part of the Flume Canyon Wilderness Study Area and the northwestern part of the Spruce Canyon Wilderness Study Area. Field studies completed in May 1988 for this report discovered a thin (1–3 ft) asphaltic sandstone above the Mahogany bed along the edge of the Flume Canyon Wilderness Study Area on Diamond Ridge (sec. 1, T. 18 S., R. 12 E.), and on Jumping Off Point (sec. 16, T. 17 S., R. 22 E.). Cashion (1967) reported two asphaltic sandstone beds 12 and 14 ft thick above the Mahogany bed in a measured section in the extreme northern part of the Flume Canyon Wilderness Study Area (sec. 20, T. 17 S., R. 22 E.). These tar sands were not observed on Westwater Point within the study-area boundary. No tar sands were observed anywhere within the Flume Canyon Wilderness Study Area in the Douglas Creek Member below the Mahogany bed, though such occurrences were noted north of the study area. This survey does not preclude the possibility that asphaltic sandstone exists within the wilderness study areas but remains undetected beneath rockfall deposits or colluvium. Such occurrences would not be very thick, however, because the thicker arkosic sandstone of the Green River Formation tends to crop out as cliffs. The only places hidden tar sands could be present in the study area would be along Westwater Point or Diamond Ridge, as these are the only places within the study-area boundary where the upper part of the Douglas Creek Member exists. Available data (Byrd, 1970; Campbell and Ritzma, 1979; Ritzma, 1979; U.S. Bureau of Mines, 1964) show that significant tar-sand deposits extend many miles north of the wilderness study areas. The likelihood of undiscovered tar-sand deposits occurring within the study-area boundaries is low, with a certainty level of C, except along Diamond Ridge in the northwestern part of the Spruce Canyon Wilderness

Study Area and along Westwater Point in the northwestern part of the Flume Canyon Wilderness Study Area, where there is a moderate mineral resource potential for tar sands, with a certainty level of B.

Gilsonite

Gilsonite is a brittle, black, tarry-appearing residue of natural petroleum. It is used for making metallurgical coke and gasoline, as well as having many other industrial applications. As of 1967 all of the world's gilsonite production came from the Uinta Basin, and the majority of that from the southeastern part of the basin, northeast of the study areas. In this part of the Uinta Basin, gilsonite occurs in vertical northwest-trending fracture-controlled veins between 0.5 and 7 mi long and as much as 18 ft wide. These veins have been exploited for gilsonite since 1900 (Cashion, 1964, 1967).

The gilsonite veins in the southeastern part of the Uinta Basin are in the Wasatch, Green River, and Uinta Formations. These veins are thickest in the massive sandstone beds at the base of the Uinta Formation and thin upward in the mudstone of the Uinta Formation and downward into the mudstone and marlstone of the Green River Formation, pinching out completely in the Mahogany bed. Gilsonite veins that are below the Mahogany bed are thickest in the sandstone of the Douglas Creek Member of the Green River Formation and Renegade Tongue of the Wasatch Formation, attenuating downward in mudstone and upward in the oil shale of the Mahogany bed. Some of the larger veins are known to extend vertically as much as 1,500 ft. Although the source of the gilsonite is not definitively known, hydrocarbon-rich beds in lacustrine facies of the Green River Formation appear to be the most plausible source. These hydrocarbons are believed to have flowed into open fractures along gently northwest-plunging anticlines in the southeastern part of the Uinta Basin (Cashion, 1964, 1967).

The gilsonite veins in the southeastern part of the Uinta Basin are more than 30 mi to the north and northeast of the wilderness study areas. Although there are gentle northwest-plunging anticlines and rocks of the Renegade Tongue of the Wasatch Formation and Douglas Creek Member of the Green River Formation within the study areas, these two features do not occur together. Very few northwest-trending faults or fractures are known to exist in the study areas. Field investigations carried out in May 1988 failed to discover any evidence of gilsonite veins within or near the study areas. The wilderness study areas are therefore assigned a low resource potential for the occurrence of gilsonite, with a certainty level of C.

Uranium

Uranium has been found in several formations in and near the Book Cliffs. Uranium occurs in the Book Cliffs approximately 8 mi west of the study areas in a mining district informally known as the Tuscher Canyon district (Doelling and Tooker, 1983). In these deposits carnotite is disseminated in crossbedded, poorly sorted, conglomeratic channel sandstone beds that also contain carbonaceous plant debris and carbonized logs near the base of the Wasatch Formation. Limonite staining and gray-green mudstone indicating a local reducing environment are also prevalent in these deposits (Wood, 1956; Isachsen and others, 1955; Finch, 1967). Very modest uranium production has been realized from the Joker claims (sec. 15, T. 19 S., R. 18 E.), the Pine Tree claims (sec. 20, T. 19 S., R. 19 E.), and the Lion claims (sec. 8, T. 18 S., R. 19 E.), and only the occurrence of uranium has been noted at the Ute claims (sec. 8, T. 20 S., R. 19 E.) 8–12 mi west of the study areas (McDonnell, 1988; W.I. Finch, oral commun., 1988).

Significant amounts of uranium have been produced from the Thompson mining district (fig. 1) 12–14 mi south of the wilderness study areas. The deposits are localized in the Salt Wash Member of the Morrison Formation in a geologic setting similar to that of the Wasatch Formation occurrences. Carnotite and tyuyamunite are in irregular zones and roll fronts in carbonaceous channel sandstone; limonite and gray mudstone are commonly associated with these deposits. Throughout the Colorado Plateau Province, sandstone uranium deposits occur in the basal conglomeratic channel sandstone beds of the Salt Wash Member. In the Thompson district, however, uranium deposits can occur in channel sandstone beds throughout the thickness of the Salt Wash Member, though the largest deposits tend to be in the lower 125 ft. The sequence of fluvial sandstone beds are postulated to be thicker and more persistent in the Thompson district than in many other parts of the Colorado Plateau. Location of the deposits appears to be independent of local faults or folds. Initial discoveries of uranium in the Thompson district were made on the basis of surface exposures, but later discoveries using local mapping, geobotanical sampling, and drilling were made in the sandstone beds that dip to the north beneath younger strata (Stokes, 1952; Stokes and Mobley, 1954).

Uranium deposits have also been found in similar conglomeratic channel sandstone beds near the base of the Triassic Chinle Formation south of the study areas near Moab (Finch, 1959). Studies undertaken to determine the favorability of the Chinle Formation for uranium deposits on a regional basis show the Chinle Formation to be favorable northwest of Moab, but the favorable terrane does not project beneath the Book Cliffs (Lupe, 1977). Furthermore, the Chinle Formation exists at depths not less than 4,300 and as much as 8,100 ft beneath the surface of the study areas.

Analytical data from the NURE ground-water and stream-sediment sampling program are available for the region of the Book Cliffs containing the wilderness study areas (Langfeldt and others, 1981). Anomalous ground-water samples of 1.0 to 2.0 (1,000 × U/conductivity) were taken from Thompson Canyon just west of the Coal Canyon Wilderness Study Area, and from Nash Canyon south of it. Anomalous values in samples of 2.0 to 5.0 (1,000 × U/conductivity) were taken from Sego Canyon south of the Coal Canyon Wilderness Study Area, and from upper Diamond Canyon within the Flume and Spruce Canyons Wilderness Study Areas. An anomalous value of 10 ppm (parts per million) uranium was found in a stream-sediment sample from She Canyon just north of the Coal Canyon Wilderness Study Area (Langfeldt and others, 1981).

In geochemical rock and stream-sediment samples collected for this report, there were four rock and two stream-sediment samples from in and near the study areas that contained anomalous amounts of uranium. None of these samples defined a specific anomalous region, and none of them overlapped anomalous samples from the NURE data. All anomalous samples from both surveys ranged from three to ten times background level for uranium for these types of rocks. Of the anomalous rock samples collected for this study, one was an iron oxide nodule, one was shaly sandstone, and two were limestone; none of these lithologies is representative of the type of uranium-bearing lithology common to the Wasatch Formation. The available data indicate that there may be small, isolated areas of slightly elevated concentrations of uranium in different rock types, but no indications of undiscovered uranium deposits of the type common to the Wasatch Formation seem to be within the study areas.

The Salt Wash Member of the Morrison Formation dips gently to the north beneath the wilderness study areas where it has been found in drill holes at depths from 3,400 to 7,200 ft beneath the surface. At such depths, exploring for and locating uranium deposits in the Morrison Formation would be difficult. Studies (Craig and others, 1955) and lithologic logs from some drill holes within the study areas strongly suggest that the character of the Salt Wash Member changes from predominantly fluvial conglomeratic sandstone near the Thompson district to predominantly mudstone and siltstone as the member dips to the north beneath the study areas. Such lithologies are less favorable for the occurrence of uranium deposits (McKay, 1955).

The Coal, Flume, and Spruce Canyons Wilderness Study Areas are assigned a low mineral resource potential for undiscovered deposits of uranium in the Wasatch, Morrison, and Chinle Formations, with a certainty level of C.

Other Metals

Although uranium and vanadium deposits, as discussed above, constitute the major type of metal deposit found in the Colorado Plateau Province, they are not the only type of metal deposit to exist there. Copper occurs in sandstone-type uranium deposits in the Chinle Formation and in collapse structures in the San Rafael Swell southwest of the study areas (Hawley and others, 1965). Copper is also found along fault zones and fractures in the Glen Canyon Group rocks in the La Sal mining district south of the study areas (Carter and Gualtieri, 1965). Placer-gold occurrences have been reported along the Colorado River south of the study areas (Dickerson and others, 1988) and along the San Miguel River further to the south (Vanderwilt, 1947).

Anomalous amounts of gold and silver were detected in two widely separated, panned heavy-mineral-concentrate samples collected from the Coal Canyon Wilderness Study Area. Neither of the two samples define a distinct source for the anomalous material. These samples were interpreted as representing material derived from a paleoplacer source within one of the fluvial sandstone bodies in the study areas. Fluvial sandstone exists in the Castlegate Sandstone, the Blackhawk and Neslen Formations, the Sego Sandstone, and the Farrer, Tuscher, and Wasatch Formations, and through geologic time these sandstones were deposited by fluvial systems that have drained many different source areas. The existence of gold or silver in paleoplacer deposits within any of these formations would be entirely dependent on the presence and abundance of gold in the source areas of these rocks, something that cannot currently be evaluated.

There are no known fractures or faults within any of the study areas that have been mineralized with copper or other metals. No altered rock was observed along any of the known faults within the study areas, and mineralized or altered faults and fractures are not known in the Book Cliffs area in general. Paleoplacer deposits of any kind are not known to exist within the Book Cliffs, and current geochemical data do not suggest the existence of anything more than locally elevated values of metals in small, widely scattered occurrences. The study areas are therefore assigned a low mineral resource potential for all metals other than uranium, with a certainty level of C.

Geothermal Energy

Only one hydrothermal convection system in the Colorado Plateau is known, and it is in the San Juan Mountains in southwestern Colorado. The Colorado Plateau has a low overall heat flow, but young volcanic features in northern New Mexico and Arizona are promising areas for geothermal exploration (Brooks and others, 1979). No recent volcanic features are anywhere near the study areas. Some workers (Brooks and others, 1979) suggested that, due to the low water table in some parts of the Colorado Plateau, some undiscovered geothermal systems may discharge completely in the subsurface and remain undetected. The study areas have no undetected geothermal systems, as the many springs attest that the water table is near the surface, and none of these springs has warm or hot water. The study areas therefore, are assigned a low resource potential for geothermal energy, with a certainty level of C.

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APPENDIX

DEFINITION OF LEVELS OF MINERAL RESOURCE POTENTIAL AND CERTAINTY OF ASSESSMENT

LEVELS OF RESOURCE POTENTIAL

- H HIGH mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate a high degree of likelihood for resource accumulation, where data support mineral-deposit models indicating presence of resources, and where evidence indicates that mineral concentration has taken place. Assignment of high resource potential to an area requires some positive knowledge that mineral-forming processes have been active in at least part of the area.
- M MODERATE mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate reasonable likelihood for resource accumulation, and (or) where an application of mineral-deposit models indicates favorable ground for the specified type(s) of deposits.
- L LOW mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics define a geologic environment in which the existence of resources is permissive. This broad category embraces areas with dispersed but insignificantly mineralized rock, as well as areas with little or no indication of having been mineralized.
- N NO mineral resource potential is a category reserved for a specific type of resource in a well-defined area.
- U UNKNOWN mineral resource potential is assigned to areas where information is inadequate to assign a low, moderate, or high level of resource potential.

LEVELS OF CERTAINTY

- A Available information is not adequate for determination of the level of mineral resource potential.
- B Available information only suggests the level of mineral resource potential.
- C Available information gives a good indication of the level of mineral resource potential.
- D Available information clearly defines the level of mineral resource potential.

LEVEL OF RESOURCE POTENTIAL →

<table>
<tr><th>A</th><th>B</th><th>C</th><th>D</th></tr>
<tr><td rowspan="4">U/A

UNKNOWN POTENTIAL</td><td>H/B
HIGH POTENTIAL</td><td>H/C
HIGH POTENTIAL</td><td>H/D
HIGH POTENTIAL</td></tr>
<tr><td>M/B
MODERATE POTENTIAL</td><td>M/C
MODERATE POTENTIAL</td><td>M/D
MODERATE POTENTIAL</td></tr>
<tr><td rowspan="2">L/B
LOW POTENTIAL</td><td rowspan="2">L/C
LOW POTENTIAL</td><td>L/D
LOW POTENTIAL</td></tr>
<tr><td>N/D
NO POTENTIAL</td></tr>
</table>

LEVEL OF CERTAINTY →

Abstracted with minor modifications from:

Taylor, R.B., and Steven, T.A., 1983, Definition of mineral resource potential: Economic Geology, v. 78, no. 6, p. 1268-1270.

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RESOURCE/RESERVE CLASSIFICATION

	IDENTIFIED RESOURCES			UNDISCOVERED RESOURCES	
	Demonstrated		Inferred	Probability Range (or)	
	Measured	Indicated		Hypothetical	Speculative
ECONOMIC	Reserves		Inferred Reserves		
MARGINALLY ECONOMIC	Marginal Reserves		Inferred Marginal Reserves		
SUB-ECONOMIC	Demonstrated Subeconomic Resources		Inferred Subeconomic Resources		

Major elements of mineral resource classification, excluding reserve base and inferred reserve base. Modified from McKelvey, 1972, Mineral resource estimates and public policy: American Scientist, v.60, p.32-40, and U.S. Bureau of Mines and U.S. Geological Survey, 1980, Principles of a resource/reserve classification for minerals: U.S. Geological Survey Circular 831, p.5.

GEOLOGIC TIME CHART

Terms and boundary ages used by the U.S. Geological Survey in this report

EON	ERA	PERIOD		EPOCH	AGE ESTMATES OF BOUNDARIES (Ma[1])
Phanerozoic	Cenozoic	Quaternary		Holocene	0.010
				Pleistocene	1.7
		Tertiary	Neogene Subperiod	Pliocene	5
				Miocene	24
			Paleogene Subperiod	Oligocene	38
				Eocene	55
				Paleocene	66
	Mesozoic	Cretaceous		Late	96
				Early	138
		Jurassic		Late Middle Early	205
		Triassic		Late Middle Early	~ 240
	Paleozoic	Permian		Late Early	290
		Carboniferous Periods	Pennsylvanian	Late Middle Early	~ 330
			Mississippian	Late Early	360
		Devonian		Late Middle Early	410
		Silurian		Late Middle Early	435
		Ordovician		Late Middle Early	500
		Cambrian		Late Middle Early	~ [2]570
Proterozoic	Late Proterozoic				900
	Middle Proterozoic				1600
	Early Proterozoic				2500
Archean	Late Archean				3000
	Middle Archean				3400
	Early Archean				3800?
pre-Archean[3]					4550

[1]Millions of years prior to A.D. 1950.

[2]Rocks older than 570 m.y. also called Precambrian, a time term without specific rank.

[3]Informal time term without specific rank.

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