Mineral Resources of the Gunnison Gorge Wilderness Study Area, Montrose and Delta Counties, Colorado

U.S. GEOLOGICAL SURVEY BULLETIN 1715–D

Chapter D

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U.S. GEOLOGICAL SURVEY BULLETIN 1715

MINERAL RESOURCES OF WILDERNESS STUDY AREAS—
SOUTHWESTERN COLORADO

DEPARTMENT OF THE INTERIOR
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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 Gunnison Gorge Wilderness Study Area (CO–030–388), Montrose and Delta Counties, Colorado.

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PLATE

[Plate is in pocket]

FIGURES

Mineral Resources of the Gunnison Gorge Wilderness Study Area, Montrose and Delta Counties, Colorado

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ABSTRACT

The Gunnison Gorge Wilderness Study Area (CO–030–388; 21,038 acres) is located in Montrose and Delta Counties, southwestern Colorado. Inferred subeconomic resources of gypsum in the Wanakah Formation and coal in the Dakota Sandstone are present in parts of the study area. The entire study area has a low mineral and energy resource potential for undiscovered base metals (copper, lead, and zinc), precious metals (gold and silver), uranium, and geothermal sources (fig. 1). Outside of the inferred subeconomic resources of gypsum in the Wanakah and of coal in the Dakota, the potential for undiscovered resources of these commodities is low. There is no potential for undiscovered resources of oil and gas.

SUMMARY

Character and Setting

The Gunnison Gorge Wilderness Study Area (CO–030–388; 21,038 acres) is located in Montrose and Delta Counties, Colo., 6 miles northeast of Montrose and 12 miles southeast of Delta (fig. 1). Access to the east side of the study area is along unmaintained jeep roads, but to reach the river requires off-trail hiking across rugged terrain. Access from the west side is along U.S. Bureau of Land Management-maintained jeep roads. Access to most of the study area along the Gunnison River is by raft or by hiking in rugged, steep terrain. The Gunnison Gorge Wilderness Study Area adjoins the northwest boundary of the Black Canyon of the Gunnison National Monument.

The gorge formed by superimposition of the Gunnison River, in which down cutting through a relatively soft cover of sedimentary rocks trapped the course of the river in underlying hard crystalline rocks in the core of the Gunnison uplift. The gorge is characterized by flaring canyon walls of Mesozoic (see geologic time chart in Appendix) sedimentary rocks at the top, surmounting an inner gorge cut through a variety of Proterozoic igneous and metamorphic rocks. Upstream along the Gunnison River and southeast of the study area, the upper canyon walls are less defined by sedimentary rocks than by Tertiary volcanic welded tuffs, but the spectacular lower walls still consist of Proterozoic basement rocks.

The Mesozoic sedimentary section in the study area consists of, from oldest to youngest, Entrada Sandstone, Wanakah Formation, Morrison Formation, Burro Canyon Formation, and Dakota Sandstone. The Mancos Shale, which overlies the Dakota Sandstone, occurs mainly outside of the study area. The Tertiary volcanic rocks that overlie the sedimentary section to the east are not found within the study area.

The Proterozoic basement rocks consist of a variety of igneous and metamorphic rocks in the vicinity of the study area. The most abundant rock type in the study area is the Pitts Meadow Granodiorite; the granodiorite is intruded by felsite, pegmatite, several types of granitic rock, and diabase. Amphibolite, mica schist, and several gneiss units crop out in the southern part of the study area.

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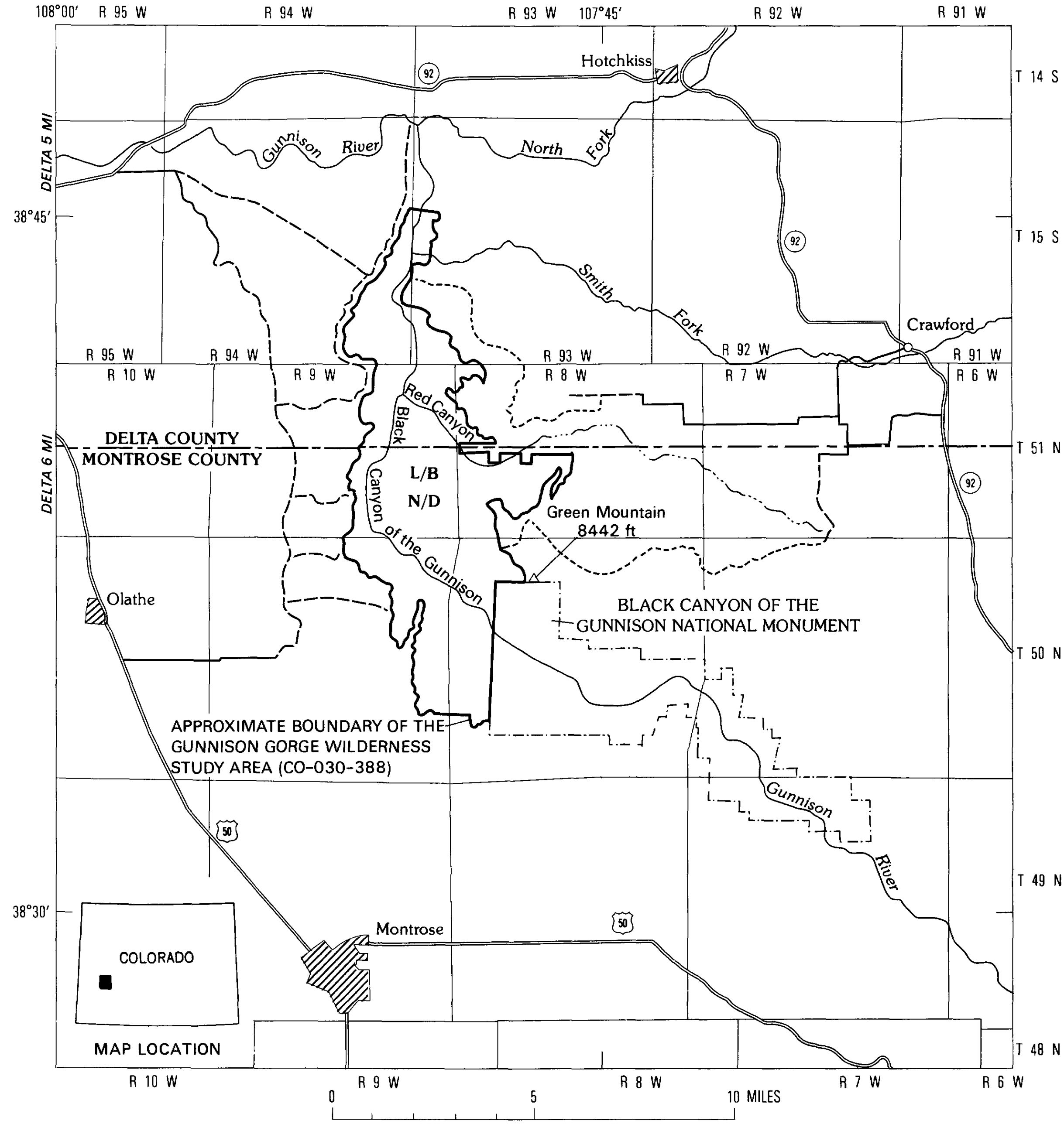

Figure 1 (above and facing page). Mineral and energy resource potential and location of the Gunnison Gorge Wilderness Study Area, Montrose and Delta Counties, Colorado.

Neither gravity nor aeromagnetic data indicate the presence of geologic structures or other features related to localization of potential mineral deposits. Remote-sensing data can be used to detect lineaments and to target limonite occurrences; the former could reflect structural features conducive to mineral localization and the latter could reflect the presence of hydrothermal alteration associated with mineralization. The regional lineaments identified in this investigation are not considered to have a direct influence on structure within the study area. Spectral processing of the remote-sensing data to find limonite occurrences failed to identify any occurrences of potential interest.

Geochemical analyses of stream sediments, heavy-mineral panned concentrates of stream sediments, and rock samples for 31 elements by semiquantitative spectroscopy, and for gold, uranium, and five other elements by specific chemical methods show only a few measurable occurrences of these elements. A few samples contain barely detectable silver, but no anomalous amounts of typically associated elements. One sample collected from stream sediments along the main channel of the Gunnison River contains anomalous amounts of a variety of elements, but the source of the heavy minerals in the sample is not known.

EXPLANATION OF MINERAL AND ENERGY RESOURCE POTENTIAL

[Inferred subeconomic resources of gypsum and coal occur in parts of the study area—see plate 1. Outside of these known occurrences of gypsum and coal, the mineral and energy resource potential for these commodities is low, with certainty level B]

L/B	Geologic terrane having low mineral and energy resource potential for base metals (copper, lead, and zinc), precious metals (gold and silver), uranium, and geothermal sources, with certainty level B—Applies to entire study area
N/D	Geologic terrane having no energy resource potential for oil and gas, with certainty level D—Applies to entire study area
	Certainty levels
B	Data indicate geologic environment and suggest level of resource potential
D	Data clearly define geologic environment and level of resource potential, and indicate activity of resource-forming processes in all or part of study area
————	Improved road
– – – – –	Unimproved road
-----------	Trail
—···—···—	Intermittent stream

Identified Resources and Mineral and Energy Resource Potential

Inferred subeconomic resources contained in rocks of the study area include gypsum in the Wanakah Formation and coal in the Dakota Sandstone. The gypsum forms thin beds beneath thick overburden and is distant from potential markets; the coal is in discontinuous lenses covered by thick overburden and is distant from potential markets. Neither of these is likely to be developed. No identified resources of any metallic minerals or of gypsum and coal outside of the Wanakah and Dakota, respectively, are present.

The mineral resource potential for undiscovered base metals (copper, lead, and zinc), precious metals (gold and silver), and uranium is low because no mineralized areas were observed and no geochemical anomalies were detected. The energy resource potential for undiscovered geothermal sources is low because no warm or hot springs occur in or near the study area. There are no known occurrences of gypsum and coal outside of the Wanakah Formation and Dakota Sandstone, respectively, so the mineral and energy resource potential for undiscovered resources of these commodities is low. There is no energy resource potential for undiscovered oil and gas because of the absence of known hydrocarbon source beds and because of the presence of a thin sedimentary cover that lacks potential traps.

INTRODUCTION

The USGS (U.S. Geological Survey) and the USBM (U.S. Bureau of Mines) studied the 21,038-acre Gunnison Gorge Wilderness Study Area (CO–030–388) in Montrose and Delta Counties, Colo. (fig. 1), as requested by the BLM (U.S. Bureau of Land Management). In this report the area studied is referred to as the "wilderness study area" or simply the "study area." The study area is 6 mi (miles) northeast of Montrose and 12 mi southeast of Delta (fig. 1). The study area adjoins the northwest corner of the Black Canyon of the Gunnison National Monument and is the downstream continuation of the same canyon. The Gunnison River in this area has been designated a Gold Medal trout stream by the Colorado State Division of Wildlife. The west side of the study area and the river are accessed along several BLM-maintained dirt roads and trails. The east side of the study area is accessed by a few unmaintained jeep roads, but to reach the river requires off-trail hiking across rugged terrain. Elevations within the study area range from about 5,120 ft (feet) along the river at the north end of the study area, to about 8,400 ft on Green Mountain near the national monument boundary. The gorge is 2,000 ft deep and 5,000 ft wide at the southern end of the study area and about 800 ft deep and 4,400 ft wide at the northern end.

This report presents an evaluation of the mineral endowment (identified resources and mineral resource potential) of the study area and is the product of several studies by the USGS and the USBM. Identified resources are classified according to the system of the USBM and USGS (1980), which is shown in the Appendix of this report. Identified resources are studied by the USBM. Mineral resource potential is the likelihood of occurrence of undiscovered metals and nonmetals, industrial rocks and minerals, and of undiscovered energy sources (coal, oil, gas, oil shale, and geothermal sources). It is classified according to the system of Goudarzi (1984) and is shown in the Appendix. The potential for undiscovered resources is studied by the USGS.

Investigations by the U.S. Bureau of Mines

USBM personnel conducted a comprehensive literature search for information on mines and mineralized areas in and near the study area. Discussions on the mineral resources of the study area were held with BLM personnel at the district office in Montrose. BLM records were checked for information on mining claims and oil and gas leases in and around the study area.

The USBM field team spent 20 employee days investigating prospects and suspected mineralized areas within the study area and about 1 mi beyond. Most dirt roads and jeep trails were driven, and foot traverses were made across potentially mineralized areas. In addition, a raft trip was taken down the Gunnison River to search for workings and mineralized structures in places otherwise inaccessible. A total of 44 samples was collected during the field investigation. Six samples collected from gypsum outcrops were analyzed for gypsum content and purity according to the American Society for Testing and Materials standards. Seven panned-concentrate samples were taken from stream sediments along secondary drainages, and 31 samples were taken from possibly mineralized rock. Thirty-seven of the 38 samples were analyzed for gold by fire assay–neutron activation analysis, and 21 of the 38 samples were analyzed for 32 elements by inductively coupled plasma–atomic emission analysis.

Investigations by the U.S. Geological Survey

Geologic maps that include the area of the Gunnison Gorge Wilderness Study Area have been published by Hansen (1968, 1971) and Hail (1972) and provide the basic geologic framework of the area, as shown on plate 1. In the field, outcrops of the various geologic units were examined for evidence of mineralization, and traverses were made across the sedimentary section with a hand-held scintillation counter to identify possible uranium occurrences. A series of Proterozoic intrusive rocks was collected for petrographic examination. Gravity, aeromagnetic, and remote-sensing studies were conducted within and adjacent to the study area. The main goal of these geophysical studies was to identify regional and local features that may be related to mineralization.

APPRAISAL OF IDENTIFIED RESOURCES

By S. Don Brown
U.S. Bureau of Mines

Mining History

The only evidence of recent mining activity in the study area is a block of unpatented claims in its southern part (fig. 2). The claims are mostly over Mancos Shale and were presumably staked for gold (BLM staff, Montrose District Office, Montrose, Colo., oral commun., July 1987). About 1¼ mi west of the study area is a small recent open cut in Mancos Shale. Elsewhere near the study area, two adjacent mining claims adjoin the northern boundary.

Several old adits, shafts, and prospect pits in and near the study area were driven on faults and shear zones, apparently in search of metals. In addition to these prospects, bulldozer cuts were made in the Morrison

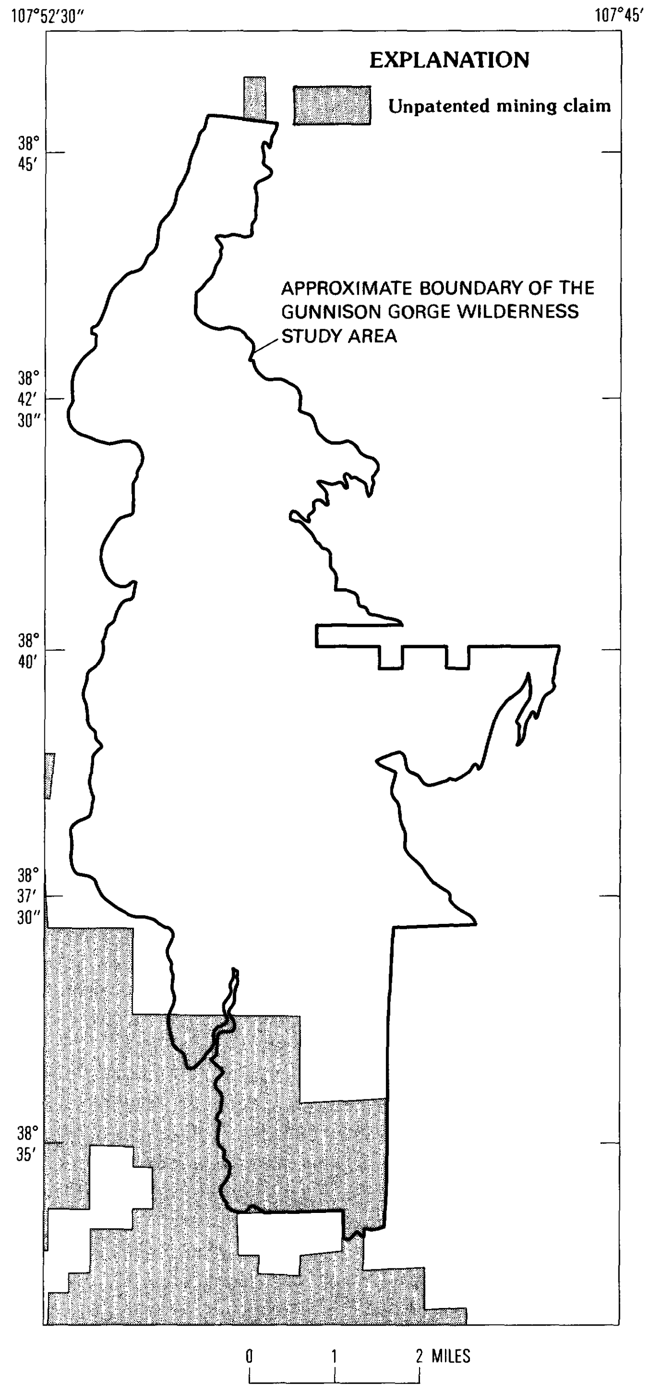

Figure 2. Unpatented mining claims within and near the Gunnison Gorge Wilderness Study Area, Colorado.

Formation in a search for uranium, and a number of pits, trenches, bulldozer cuts, and an adit were made in gypsum beds of the Wanakah Formation at several places in and near the study area.

No records of mineral production were found for the study area and vicinity, but a small amount of gypsum appears to have been produced from a few of the pits.

Mineral and Energy Occurrences

Vast quantities of gypsum are present in the Wanakah Formation throughout the study area, but these are inferred subeconomic resources and are unlikely to be developed. Dakota Sandstone crops out over about 6 mi² in the study area, and coal occurs locally in this formation. Due to the thin and discontinuous nature of the coal seams, the coal is not an economic resource. No identified resources of any metallic minerals were found in the Gunnison Gorge Wilderness Study Area.

Gypsum

The Wanakah Formation underlies approximately 60 percent of the study area, and gypsum beds are present in a middle member throughout the extent of the formation. Most of the Wanakah is covered by younger sedimentary units; the overlying units are the Morrison Formation, Dakota Sandstone, and, in the southwestern part of the study area, the Mancos Shale. At most places along the canyon walls where the Wanakah is exposed, talus and ground cover conceal the outcropping gypsum beds. Thus, exact gypsum bed thicknesses are difficult to determine. At places where gypsum beds are well exposed, the thickness ranges from about 5 to 40 ft. Also, as many as three parallel gypsum beds are evident at places in the study area.

Prospect pits, trenches, bulldozer cuts, and an adit have been dug in the gypsum beds in and near the study area. At two places east of the study area boundary, evidence of previous mining suggests a small amount of gypsum was produced (Brown, 1988, pl. 1, sample localities 3 and 35). At sample locality 35 (Brown, 1988), an old kiln adjacent to some gypsum workings suggests that the gypsum was calcined, possibly to make plaster for local house construction.

Six samples were collected from gypsum outcrops to test for purity (Brown, 1988, table 1). These samples contain from 64.4 to 99.0 percent calcium sulfate plus combined water. The gypsum at four of these sampled sites is pure enough for use in wallboard manufacturing, which requires approximately 85 percent or more calcium sulfate plus combined water (L. Davis, USBM, oral commun., February 1988). All of the gypsum sampled could be used for other industrial and agricultural purposes, such as soil conditioner.

In 1985, three companies reported crude gypsum output in Colorado totaling 233,000 tons at an average value of $7.73 per ton. This was less than 2 percent of the national production of gypsum. The nearest place to the study area where gypsum was produced was near the town of Gypsum, about 100 mi distant (Starch, 1987).

Gypsum is a low-cost, high-tonnage commodity that generally requires integrated mine and wallboard plant units strategically located for the market area. In 1987, the average price of gypsum was $6.50 per ton (USBM, 1988). Domestic resources, as well as foreign resources, are enormous. Supplies of gypsum in the United States are more than adequate to meet demands to the year 2000 (Pressler, 1985). The gypsum in the Gunnison Gorge Wilderness Study Area is an inferred subeconomic resource and would not be economical to mine because of several factors, including relatively thin beds of gypsum and generally thick overburden which make mining costs prohibitive. The remoteness from markets would make transportation costs prohibitive.

Coal

Coal occurs locally in the Dakota Sandstone in and adjacent to the study area. Much of the study area boundary coincides with the base of the Dakota, thereby excluding much of the coal-bearing strata from the study area. However, there are several places where sizeable outcrops of Dakota occur within the study area boundary, such as the approximate 2-mi² outcrop south of Red Canyon (pl. 1). In western Colorado, coal seams in the Dakota are generally thin, discontinuous, and mostly of poor quality due to high ash content (Hornbaker and others, 1976, p. 4). Near the study area, the only known evidence of coal mining or prospecting in the Dakota is an adit in a coal seam about 1 mi west of the study area in SW¼ sec. 10, T. 50 N., R. 9 W. (pl. 1). The coal that was removed from this adit was probably used locally for home heating. Coal lenses occur in the Dakota within the study area but, because of the coal's discontinuous nature and the thick overburden, the coal is considered to be an inferred subeconomic resource. The study area is about 16 mi from three major coal fields, two of which are currently producing coal. The coal in these fields, along with most of the coal in western Colorado, is in the Mesaverde Group, which does not occur in or near the study area.

Gold

Numerous unpatented mining claims occur near the southwest end of the study area, encompassing about 4 mi² of the study area (fig. 2). The majority of these claims was staked over Mancos Shale, presumably for gold. Six samples were collected from the Mancos in and near the study area and analyzed for gold (Brown, 1988, tables 2 and 3, pl. 1, sample localities 39–44), and one of the six samples was analyzed for 32 elements (Brown, 1988, pl. 1, sample locality 43). Gold was detected in one sample (Brown, 1988, pl. 1, sample locality 44) at a concentration of 2 ppb (parts per billion). This value is below the average abundance of gold in shale for the

Earth's crust (Levinson, 1980, p. 43). No other metal concentrations of significance were detected in sample number 43 (Brown, 1988).

Several faults and shear zones have been prospected for metals in and near the study area. The largest known underground working in the study area is a 137-ft-long adit (Brown, 1988, fig. 3) driven on a prominent fault in Proterozoic metamorphic rocks. No ore minerals were recognized in the workings; six samples collected from this adit contain low metal concentrations (Brown, 1988, tables 2 and 3, pl. 1, sample localities 6–11). At sample localities 15–22 (Brown, 1988, fig. 4) two small adits and a prospect pit explore a dike emplaced in a major fault; the fault is traceable along the surface for about 2,000 ft. No ore minerals were recognized in this dike, and samples contain no significant concentrations of any metals (Brown, 1988, table 2). In Red Canyon, a 70-ft-long adit has been driven in a major fault in Proterozoic metamorphic rocks (Brown, 1988, fig. 5). About 2,000 ft northwest of this adit, outside of the study area boundary, a shaft at least 60 ft deep and a prospect pit were dug on a shear zone in similar rocks (Brown, 1988, pl. 1, sample localities 27–29). No ore minerals were recognized at these workings, but the samples contain low concentrations of several metals (Brown, 1988, table 2), showing the fault and shear zones to be weakly mineralized. Near Smith Fork, a 27-ft-long adit was driven in a fault in Proterozoic metamorphic rocks just outside of the study area boundary (Brown, 1988, pl. 1, sample localities 1 and 2). Samples from this adit contain low metal concentrations (Brown, 1988, table 2), but no ore minerals were recognized.

Seven panned-concentrate samples were collected from major tributaries of the Gunnison River to test for placer gold and other metal concentrations. Gold was not observed in any of the samples, but assay results indicate the presence of a small amount of gold in all the samples (Brown, 1988, pl. 1, sample localities 4, 5, 14, 23, and 36–38). The highest gold value is 600 ppb (0.017 ounces/ton) (Brown, 1988, table 4, pl. 1, sample locality 36). No other significant metal concentrations were indicated in the assay results. Small placer workings occur on a gravel bar along the Gunnison River about 1 mi north of the study area boundary (not shown on pl. 1). Any gold production from this deposit would have been small. No evidence of placering is known inside the study area.

Uranium

The most important uranium-producing district in western Colorado is the Uravan mineral belt, about 45 mi west of the study area. The major vanadium-uranium deposits are hosted by the Salt Wash Member of the Morrison Formation. Although the Salt Wash underlies about 40 percent of the study area, there are no known occurrences of uranium or vanadium in or near the study area. During the field investigation, bulldozer cuts in the Morrison were observed at one place inside the study area (Brown, 1988, pl. 1, sample locality 12). Scintillometer readings taken at these workings were twice the background reading of 100 counts per second. Uranium was not detected in a sample taken at this location (Brown, 1988, tables 2 and 3). Additional scintillometer traverses were made across the Morrison at other localities, but no readings above background were noted.

Oil and Gas

As of January 1988, the oil and gas leases nearest the study area are about 1½ mi to the west in secs. 20 and 29, T. 51 N., R. 9 W. (not shown on pl. 1). No oil and gas occurrences are known in or near the study area.

Building Stone

Some of the rocks of the study area could be used for common construction purposes. However, these rocks have no unique characteristics to make them more desirable than similar rocks outside the study area that are closer to markets.

ASSESSMENT OF POTENTIAL FOR UNDISCOVERED RESOURCES

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Geology

Geologic Setting

The Gunnison gorge, which is the downstream extension of the Black Canyon of the Gunnison River, is a classic example of a superimposed valley (Thornberry, 1954, p. 117), formed by the down-cutting action of the Gunnison River. The down-cutting action in late Tertiary time incised the river across the Gunnison uplift, a Laramide structural block whose bounding faults probably originated in Proterozoic time (Hansen, 1981, p. 149).

Rocks of the Gunnison uplift comprise Proterozoic metamorphic and igneous rocks cut by sparse Proterozoic(?) pegmatites and lamprophyres and Cambrian diabase dikes. During Middle and Late Jurassic time, nonmarine sediments of the Entrada Sandstone and Wanakah and Morrison Formations were deposited unconformably on a nearly flat erosion surface on top of the Proterozoic rocks. In Cretaceous time, environments evolved from fluvial to littoral to marine, represented by the Burro Canyon Formation, the Dakota Sandstone, and the Mancos Shale. Younger sedimentary formations are not present, either because of nondeposition or because of later erosion.

Near the end of the Cretaceous Period the Gunnison uplift developed as a result of renewed movement along preexisting structures. This uplift and the subsequent erosion to a nearly featureless plain predated the middle Tertiary eruptions of thick intermediate-composition lava flows and volcanic breccias originating from volcanos in the West Elk and San Juan Mountains (Hansen, 1981, p. 150). Welded tuffs were then erupted from the San Juan volcano, followed by eruption of mafic, alkaline lavas in Miocene time. The course of the modern Gunnison River was established in postvolcanic time, when regional uplift caused down cutting through volcanic and sedimentary rocks into underlying hard Proterozoic crystalline rocks. The nature of the erosion and the necessary coincidences of geology, uplift, erosion, and other processes are discussed by Hansen (1965, 1981).

Hansen (1981, p. 145) divided the Black Canyon of the Gunnison into three sections, lower, middle, and upper, on the basis of physiography and geology. All three sections share an inner gorge of steep, sheer walls cut into the Proterozoic metamorphic and igneous basement. The Gunnison gorge occupies the lower section of the Black Canyon, and it is described by Hansen (p. 146) as "... flaring walls of bright-colored Mesozoic sedimentary rocks, 300 m thick and nearly free of soil, surmount(ing) a narrow inner gorge of dark Pitts Meadow Granodiorite." The middle section contains the Black Canyon of the Gunnison National Monument. The inner gorge of Proterozoic rocks is deepest in this section; sedimentary rocks have been eroded from the south rim and are hidden by vegetation on the north rim and thus are not an obvious scenic part of the Black Canyon. In the upper section of the canyon, volcanic welded tuffs lie upon the Proterozoic basement and the canyon rim is uneven and partly indefinite. This report deals with the lower section of the Black Canyon called the Gunnison gorge.

Proterozoic Rocks

Metamorphic and igneous rocks of Proterozoic age are well exposed within the inner part of the gorge. In the southern part of the gorge, between the boundary of the national monument and the southern edge of Pitts Meadows, the most abundant Proterozoic rocks are layered quartzitic gneiss and mica schist (Hansen, 1968, 1971). These rocks, assigned an age of greater than 1,700 Ma (million years ago) (Hansen and Peterman, 1968), comprise metamorphosed arenite, graywacke, and pelite, mainly of almandine-amphibolite grade (Hansen, 1987, p. 322).

North and downstream from the outcrops of metamorphic rocks, nearly all the inner gorge and major tributaries are cut into Pitts Meadow Granodiorite. In the lower section of the gorge, the Pitts Meadow Granodiorite appears to be an intrusion of batholithic proportions, partly massive and partly gneissic. The granodiorite locally contains abundant dark-colored xenoliths and dikes and sills of red felsite, pegmatite, pink granitic rock, light-gray, fine-grained granitic rock, and diabase. Studies of samples of Pitts Meadow Granodiorite (pl. 1) show medium- to coarse-grained rocks consisting of quartz (12.6–28.7 percent, 21.5 percent average), microcline (5.9–17.7 percent, 12.2 percent average), sodic plagioclase at or near oligoclase in composition (41.0–56.1 percent, 49.0 percent average), biotite (3.7–18.2 percent, 9.7 percent average), containing or not containing hornblende (maximum 15.2 percent), and accessory amounts of opaque minerals, sphene, apatite, zircon, and myrmekite. Minor chlorite formed by alteration of biotite; muscovite and epidote formed by alteration of plagioclase; and leucoxene formed by alteration of sphene. Some sparse calcite has been added to the rock. All samples fall within or adjacent to the field of Streckeisen's (1976) granodiorite.

Paleozoic Rocks

No Paleozoic rocks are present in or near the gorge, although some undoubtedly were deposited but were removed by erosion. Hansen (1981, p. 152) assumed that shallow seas covered the area until Pennsylvanian time, but that during and after Pennsylvanian time, the Uncompahgre highland was eroded to a low, featureless plain now represented by the unconformity between the Proterozoic rocks and overlying Mesozoic sedimentary rocks.

Mesozoic Rocks

Entrada Sandstone.—Sedimentation resumed in Jurassic time with deposition of wind-blown and river floodplain sediments. The Middle Jurassic Entrada Sandstone lies upon the Proterozoic rocks in the gorge. This unit is lithologically similar throughout western Colorado, eastern Utah, northern Arizona, and northwestern New Mexico, and an equivalent unit occurs east of the Rocky Mountains in Colorado and New Mexico. It is mostly a fine-grained, light-colored, crossbedded sandstone, although the upper part tends to be evenly bedded in western Colorado. Thickness ranges from about 40 to 100 ft. In the study area, fine-grained, yellow to pink, crossbedded, eolian sandstone of the Entrada lies unconformably on a relatively smooth surface cut on the Pitts Meadow Granodiorite and Proterozoic metamorphic rocks. Two measured sections within the Black Ridge 7½-minute quadrangle (Hansen, 1968) yield thicknesses of 53 and 60 ft. At Red Rock Canyon, just upstream from the study area, the Entrada is 85 ft thick; it thins upstream and eventually disappears toward the east (Hansen, 1971).

The Entrada Sandstone hosts vanadium, uranium, and chromium deposits, and vanadium has been mined from deposits near Placerville, Rico, and Durango, Colo., south of the gorge, and from the Entrada and Wingate(?) Sandstones near Rifle, Colo., north of the gorge. The most abundant vanadium ore mineral is roscoelite, a dark-gray micaceous mineral; uranium is present as carnotite and black oxides; the chromium mica mariposite coats sand grains and colors the chromium-rich layers pale green. The pale-green layer that contains chromium near Placerville and Durango is present just below the top of the unit in the gorge, and it ranges in thickness from a few inches to several feet. However, the clay minerals include kaolinite and well-crystallized illite, but no mariposite, and the green color is due to iron, present in amounts near 6 weight percent Fe_tO_3 (total iron oxide), rather than chromium (G.N. Breit, oral commun., 1988). The vanadium-uranium layer commonly associated with the chromium-bearing layer in other areas is not found in the study area.

Wanakah Formation.—The Middle Jurassic Wanakah Formation occurs throughout the Gunnison gorge area; it also persists throughout the Black Canyon of the Gunnison National Monument area, but thins toward the east. Upstream from the national monument, the Wanakah lies directly upon the Proterozoic rocks because of the absence of the Entrada Sandstone. The Wanakah correlates with the Summerville Formation of the southern Colorado Plateau (Tyler, 1981, p. 52). The Wanakah was divided by Hansen (1968) into several units in the study area. From oldest to youngest, the units are (1) the Pony Express Limestone Member, a thin, silty, gray limestone, (2) a pale-pink unit of interbedded gypsum, gypsiferous sandstone, and gypsiferous mudstone, (3) the Junction Creek Sandstone Member, a discontinuous, fine-grained, crossbedded, light-gray sandstone, and (4) an interbedded, light-gray, silty mudstone and medium-gray, algal, cherty limestone. What Hansen (1968) referred to as the Junction Creek Sandstone Member of the Wanakah Formation is now considered not to be Junction Creek but instead is a sandstone in the Morrison Formation (Steven and Hail, in press). The entire Wanakah Formation as mapped by Hansen (1968) averages about 250 ft thick within the Black Ridge 7½-minute quadrangle (Hansen, 1968).

Morrison Formation.—The Upper Jurassic Morrison Formation overlies the Wanakah and forms cliffs that help define the gorge, and provide natural boundaries for the study area. The Morrison Formation consists of mudstone, siltstone, claystone, sandstone, conglomerate, and minor limestone (Cadigan, 1967, p. 8), deposited in degrading alluvial, and aggrading alluvial, paludal, and lacustrine environments (Cadigan, 1967, p. 108). Sources of material were west and south of the Colorado Plateau. Four members of the Morrison are recognized in the Colorado Plateau west of the gorge. They are, from oldest to youngest, the Salt Wash Member, the Recapture Member, the Westwater Canyon Member, and the Brushy Basin Member. Only the Salt Wash and Brushy Basin Members are present in the study area.

The Salt Wash Member consists of light-gray, massive to crossbedded, fine-grained, cliff-forming sandstone interbedded with red silty shale (Hansen, 1968). The sandstone beds are lenticular channel fills. As mapped by Hansen (1968), the member ranges in thickness from 118 to 170 ft. The Salt Wash hosts a number of major vanadium-uranium ore-producing districts in the Colorado Plateau, including the Uravan mineral belt (Chenoweth, 1981), the Henry Mountains mineral belt (Peterson, 1980), and others, yielding over 17 million tons of ore (Thamm and others, 1980, p. 33). The principal ore-bearing horizon is an upper lenticular sandstone layer whose thickness ranges from 16 to 80 ft; the size of the ore bodies is proportional to the thickness of the sandstone layer (McKay, 1955).

The Brushy Basin Member overlies the Salt Wash and, in the study area, consists of multicolored mudstone and silty shale, gray massive siltstone, and fine-grained, light-gray sandstone (Hansen, 1968) derived from fluvial and lacustrine environments (Craig and others, 1955). The Brushy Basin ranges in thickness from 315 to 360 ft. In the Colorado Plateau, it is composed predominantly of claystone that contains abundant volcanic ash (Fischer, 1974). The source areas of the Brushy Basin and Salt Wash sediments appear to be similar (Craig and others, 1955, p. 157).

Burro Canyon Formation.—The Morrison Formation is overlain by the Lower Cretaceous Burro Canyon Formation. The dominant lithology is light-gray, crossbedded, cliff-forming, conglomeratic sandstone and pebble conglomerate and minor discontinuous beds of light-gray shale (Hansen, 1968). The maximum thickness of the Burro Canyon in the study area is about 115 ft. The boundary of the study area closely parallels the base of the Burro Canyon in many places.

Dakota Sandstone.—The Upper Cretaceous Dakota Sandstone overlies the Burro Canyon. Hansen (1968) has combined the Dakota and the Burro Canyon into one map unit because of their lithologic similarities. The Dakota has a maximum thickness of about 115 ft in the vicinity of the study area. The Dakota contains small, thin, lensoid, discontinuous beds of impure coal near its base. Because of the placement of the study area boundary, the base of the Dakota, and therefore most of the coal beds, have been excluded from the study area.

Mancos Shale.—Small patches of dark-gray silty clay shale containing lenses of friable gray sandstone and calcareous siltstone concretions have been identified by Hansen (1968, 1971) as the Upper Cretaceous Mancos Shale. This unit overlies the Dakota; it is very widespread outside the study area but it is rare within.

Cenozoic Rocks

The Tertiary volcanic rocks erupted from centers in the West Elk and San Juan Mountains and were deposited upon the sedimentary sequence east of the study area, but have been removed by erosion within the study area. Thus, these formations are not discussed in this report. Quaternary deposits include debris flows, chiefly originating in the Jurassic sedimentary rocks, and bouldery talus that occupies the bottom of the gorge.

Geochemistry

Sample Media and Collection

Stream sediments, heavy-mineral panned concentrates derived from stream sediments, and rocks were selected as the primary sample media for this study. Stream-sediment samples represent composite samples of rocks and soils exposed in the drainage basin upstream. Their analysis provides information that helps identify those basins containing unusually high concentrations of elements that may be related to mineral occurrences.

Chemical analysis of heavy minerals concentrated from stream sediments provides information about the chemistry of certain high-density, resistant minerals eroded from the drainage basin upstream. By removing most of the rock-forming silicates, clays, and organic material from the samples by panning, certain elements in the concentrate that are not generally detectable in bulk stream sediments can be determined by the analytical methods available. Some of these elements can be constituents of minerals related to ore-forming processes rather than rock-forming processes.

Both sample types, bulk stream sediment and heavy-mineral concentrate, were collected from active alluvium of a total of ten first- or second-order streams flowing into the Gunnison River in the study area to give a sampling density of one site per 3.3 mi^2. Seven rock samples were collected from five sites. Samples that appeared unaltered were collected to provide information on geochemical background values. Altered and mineralized samples were collected to determine suites of elements associated with the observed alteration or mineralization.

Sample Preparation

The dry stream-sediment samples were sieved through minus-80 mesh (0.0067 in.) stainless steel screens. The portion passing through was pulverized to minus-100 mesh (0.0058 in.) prior to analysis.

To produce the heavy-mineral concentrates, bulk stream sediment was first sieved through a minus-10 mesh (0.058 in.) screen. Approximately 10 pounds of the portion passing through was panned to remove the quartz, feldspar, organic materials, and clay-size material. The panned concentrates were separated into light and heavy fractions by flotation in bromoform (specific gravity 2.8). Material of specific gravity greater than 2.8 was then separated on the basis of magnetic susceptibility into three fractions. The nonmagnetic fraction contains most ore minerals, as well as accessory minerals such as sphene, zircon, apatite, and rutile; this fraction was hand ground prior to analysis. The magnetic fraction consists primarily of magnetite, and the paramagnetic fraction consists principally of ferromagnesian silicates and iron oxides; these were saved but not analyzed.

Rock samples were pulverized to minus-100 mesh prior to analysis.

Sample Analysis

Stream-sediment, heavy-mineral concentrate, and rock samples were all analyzed using a semiquantitative emission spectrographic method for 31 elements (Grimes and Maranzino, 1968). In addition, stream-sediment and rock samples were analyzed for arsenic, antimony, bismuth, cadmium, gold, uranium, and zinc by specific chemical methods (J.H. Bullock, Jr., and others, unpub. data, 1988). Analytical data, sample sites, analysis method references, and a detailed description of the sampling and analytical techniques are given in J.H. Bullock, Jr., and others (unpub. data, 1988).

Results

Anomalous concentrations of various elements, defined as being above the upper limits of normal background values, were determined in the various sample media by inspection of the analytical data rather than by statistical techniques. Only a few samples (ten stream sediments and heavy-mineral concentrates, and seven rocks) were collected, and many elements were detected in only a few of these samples. For some elements (gold, arsenic, silver, bismuth, cadmium, antimony, tin, tungsten, thorium, and uranium), any value above the detection limit is considered anomalous.

Heavy-mineral-concentrate samples from two tributary drainages to the Gunnison River were weakly anomalous in silver. The heavy-mineral-concentrate sample from Red Canyon contained 2 ppm (parts per million), and that from an unnamed tributary from the west, 1.2 mi south of Smith Fork, contained 1 ppm (locations and data in J.H. Bullock, Jr., and others, unpub. data, 1988). The absence of any other associated anomalous elements and the very low values obtained indicate that the anomaly is not significant.

Both stream-sediment and heavy-mineral-concentrate samples from one site on the Gunnison River were anomalous in a number of elements. The site is midway between Red Canyon and Smith Fork in the northern part of the study area (J.H. Bullock, Jr., and others, unpub. data, 1988). The stream-sediment sample contains obvious mafic heavy minerals, and contains anomalous concentrations of iron, manganese, cobalt, chromium, lanthanum, nickel, lead, vanadium, yttrium, zinc, and zirconium. The heavy-mineral-concentrate sample contained the following concentrations: silver, 20 ppm; bismuth, 500 ppm; cadmium, 50 ppm; molybdenum, 30 ppm; lead, 1,000 ppm; tin, 700 ppm; tungsten, 700 ppm; yttrium, 500 ppm; and zinc, 1,000 ppm. This placer deposit of heavy resistate minerals is derived from unknown sources in its drainage basin upstream and is not representative of any source within the study area.

The Salt Wash Member of the Morrison Formation, a favorable host for uranium mineral occurrences in the Colorado Plateau, crops out in the upper reaches of the tributary drainages sampled in the study area. No anomalous amounts of uranium were detected in any of the samples.

Geophysics

Geophysical data provide information on the subsurface distribution of rock masses and their structural framework. Gravity, aeromagnetic, and remote-sensing studies were undertaken as part of the mineral resource assessment of the Gunnison Gorge Wilderness Study Area. Geophysical data available for this study are sufficient only to identify regional features.

Gravity Data

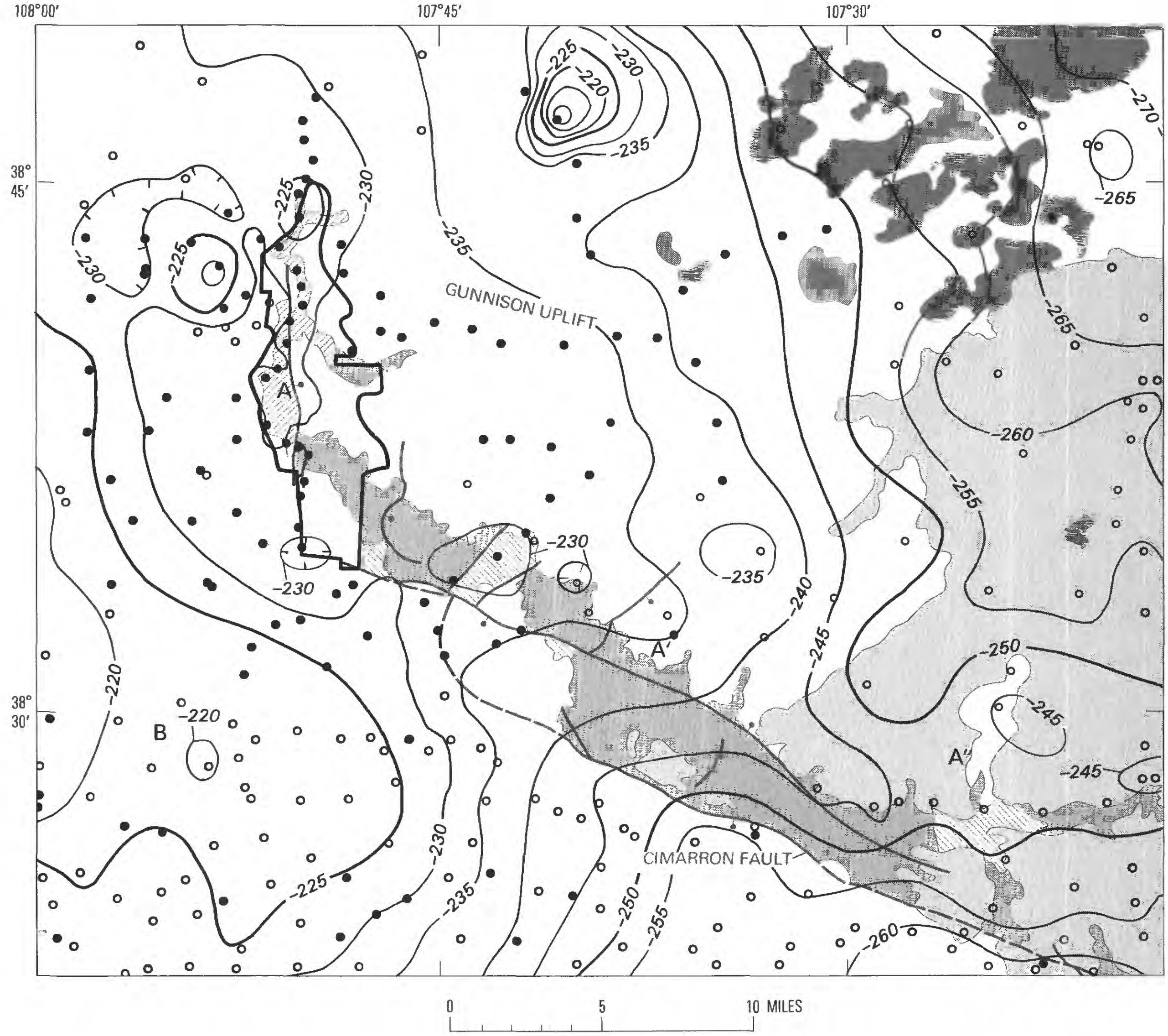
Regional gravity data were obtained from files maintained by the U.S. Department of Defense, and were supplemented by data collected in and around the study area in 1987. Stations measured for this study were established using a Worden W–177 gravimeter. The data were tied to the International Gravity Standardization Net 1971 (U.S. Defense Mapping Agency Aerospace Center, 1974) at base station ACIC 4023–1 at Delta, Colo. Station elevations were obtained from benchmarks, spot elevations, and estimates from topographic maps at 1:24,000 scale, and are accurate to within 20 ft. The error in the Bouguer values is less than 1.2 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 g/cm^3 (grams per cubic centimeter). Mathematical formulas are given in Cordell and others (1982). Terrain corrections were made by computer for a distance of 100 mi from the station using the method of Plouff (1977). The data are shown as a complete Bouguer anomaly map on figure 3.

A gravity high (fig. 3, A) is associated with outcropping Proterozoic rocks in the northern part of the study area. An elongate gravity high (A′–A″) extends southeast of the study area where the Proterozoic rocks are only thinly overlain by Mesozoic and Cenozoic sedimentary and volcanic rocks. A plateau in the gravity values extends just east of the study area where Mesozoic sedimentary rocks overlie the Proterozoic basement rocks, and the values decrease further eastward where the low-density sedimentary and volcanic rocks thicken. In the southeastern part of the map area of figure 3 a gravity gradient is associated with the Cimarron fault, which marks the southern boundary of the Gunnison uplift. Low gravity values are associated with Mesozoic and Cenozoic sedimentary and volcanic rocks south of the fault. A gravity high (fig. 3, B) in the southwestern corner of the map area of figure 3 is the southeastern extension of a major positive anomaly that extends approximately 75 mi to the northwest over the Uncompahgre uplift, which is cored by higher density Proterozoic basement rocks.

Aeromagnetic Data

The aeromagnetic data are shown as a residual intensity magnetic anomaly map on figure 4 and are from the U.S. Department of Energy (1983). Flight lines were flown east-west at approximately 4-mi intervals and 400 ft above the ground surface.

An aeromagnetic high (fig. 4, A) located east and southeast of the study area trends northeast. It is probably caused by an intrusive body in the basement at a depth of 15,000–20,000 ft as estimated by half-width and tangent methods (Dobrin, 1960, p. 311–313). The body is probably related to the intrusive rocks that crop out at the northeast corner of the map area of figure 4. Magnetic highs of lesser magnitude (B and C) extend



EXPLANATION

- -225 **Gravity contour**—Contour interval 5 milligals. Hachures indicate closed low
- **Gravity station**
  - ● **From this study**
  - o **From U.S. Defense Mapping Agency Aerospace Center (1974)**
- A **Gravity anomaly**—Referred to in text
- **Approximate boundary of Gunnison Gorge Wilderness Study Area**
- **Contact**
- **Fault**—Dashed where concealed. Bar and ball on downthrown side

- **Ash-flow tuff and pre-ash-flow andesitic lava flows and breccias (Oligocene)**
- **Intrusive rocks (Miocene and Oligocene)**
- **Sedimentary rocks (Mesozoic)**
- **Granitic rocks (Middle Proterozoic)**
- **Granitic rocks (Early Proterozoic)**
- **Biotitic gneiss and migmatite (Early Proterozoic)**

Figure 3. Complete Bouguer gravity anomaly contours of the Gunnison Gorge Wilderness Study Area and vicinity, Colorado. Geology modified from Tweto and others (1976).

northwest and southeast from anomaly A, respectively; part of magnetic high B is located over the northern part of the study area. Dikes and (or) sills of rocks similar to those of the intrusions in the northeast corner of the map

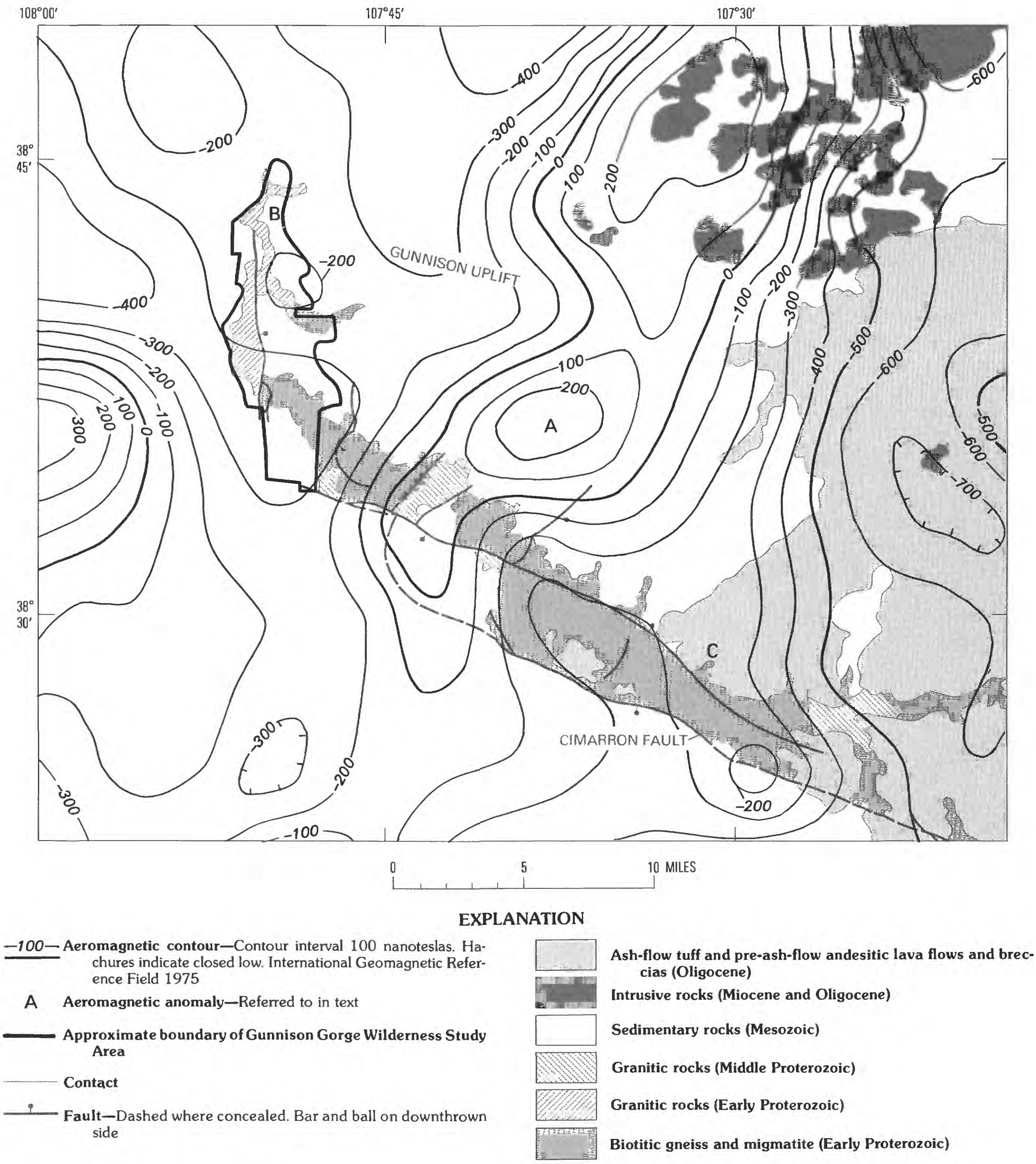


Figure 4. Residual intensity aeromagnetic anomaly contours of the Gunnison Gorge Wilderness Study Area and vicinity, Colorado. Geology modified from Tweto and others (1976).

area of figure 4 are present at the southeast end of magnetic high C. The northwest-trending high (B–C) lies generally along the faults that bound the Gunnison uplift, suggesting that intrusive rocks interpreted to have caused the anomaly may have been emplaced along the faults.

Remote-Sensing Data

A remote-sensing investigation was undertaken in support of the mineral resource appraisal. Anticipated resources were metallic mineral deposits.

Landsat MSS (Multispectral Scanner) images were used for a lineament analysis that covered a large area of the Colorado Plateau in western Colorado and eastern Utah. Lineaments are usually lines seen on the images that appear to be structurally controlled features such as faults, dikes, veins, and other linear features, or surface manifestations of structural features, such as stream courses and vegetation. Lineaments were investigated, along with geophysical surveys and deep drilling data, as possible representations of basement structures. The study area lies between two northwest-trending, regional lineaments. However, neither is thought to influence directly the structure of the study area.

The MSS images also were processed so that the presence of limonite could be mapped. Limonite occurrences might result from hydrothermal alteration associated with mineralization. Such occurrences can be recognized and mapped using color-enhanced band ratios of MSS and TM (Terra–Mar) data. In this study, an MSS image was used, and the image processing was done interactively on a TM digital image processing system. Spectral processing of the MSS data led to the mapping of several very small, discontinuous limonite occurrences within the study area. They are presumed to represent either weathering and oxidation of mafic minerals in the rocks or "false alarms" due to atmospheric scattering instead of hydrothermal alteration associated with mineralization.

Mineral and Energy Resource Potential

Results of geological, geophysical, and geochemical investigations indicate that the Gunnison Gorge Wilderness Study Area has a low mineral resource potential for base metals (copper, lead, and zinc), precious metals (gold and silver), and uranium, with certainty level B. Geophysical studies failed to identify any structures that may be related to any mineral-deposit-forming processes. Limonite concentrations, which would indicate possible hydrothermal alteration related to ore deposition, were not identified. Geochemical analysis of stream-sediment, panned-concentrate, and rock samples detected no anomalous concentrations of copper, lead, zinc, gold, silver, or uranium. The few samples that contained minimal silver concentrations had no associated values of other elements that are typically associated with mineral deposits. Special attention was given to the Morrison Formation in the study area, inasmuch as this formation contains uranium in other parts of western Colorado. None of the samples of the Morrison Formation, however, contained measurable amounts of uranium.

No oil and gas occurrences are known from the study area or surrounding area. Spencer (1982) rated the oil and gas potential as zero because of the absence of hydrocarbon source beds and because of the presence of a thin sedimentary cover that lacks potential traps. Favorable structures for the accumulation of oil and gas appear to be absent. Oil and gas leases do not occur within 1½ mi of the study area. There is no energy resource potential for oil and gas, with certainty level D.

There are no known occurrences of warm or hot springs in or near the study area, so the energy resource potential for geothermal sources is low, with certainty level B.

There are no known occurrences of gypsum and coal outside of the Wanakah Formation and Dakota Sandstone, respectively, so the mineral and energy resource potential for these commodities is low, with certainty level B.

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APPENDIX

DEFINITION OF LEVELS OF MINERAL RESOURCE POTENTIAL AND CERTAINTY OF ASSESSMENT

Definitions of Mineral Resource Potential

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 unlikely. This broad category embraces areas with dispersed but insignificantly mineralized rock as well as areas with few or no indications of having been mineralized.

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 a reasonable likelihood of resource accumulation, and (or) where an application of mineral-deposit models indicates favorable ground for the specified type(s) of deposits.

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.

UNKNOWN mineral resource potential is assigned to areas where information is inadequate to assign low, moderate, or high levels of resource potential.

NO mineral resource potential is a category reserved for a specific type of resource in a well-defined area.

Levels of Certainty

<table>
<tr><td rowspan="4">LEVEL OF RESOURCE POTENTIAL ↑</td><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>
<tr><td></td><td>A</td><td>B</td><td>C</td><td>D</td></tr>
<tr><td></td><td colspan="4">LEVEL OF CERTAINTY →</td></tr>
</table>

A. Available information is not adequate for determination of the level of mineral resource potential.
B. Available information 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.

Abstracted with minor modifications from:

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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 in this report

EON	ERA	PERIOD		EPOCH	BOUNDARY AGE IN MILLION YEARS
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	~ 570[1]
Proterozoic	Late Proterozoic				900
	Middle Proterozoic				1600
	Early Proterozoic				2500
Archean	Late Archean				3000
	Middle Archean				3400
	Early Archean				3800?
pre-Archean[2]					4550

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

[2] Informal time term without specific rank.

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