Mineral Resources of the Cross Mountain Wilderness Study Area, Moffat County, Colorado

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Chapter A

Mineral Resources of the Cross Mountain Wilderness Study Area, Moffat County, Colorado

By KARL V. EVANS, JAMES G. FRISKEN, and
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U.S. Geological Survey

JOHN R. THOMPSON
U.S. Bureau of Mines

U.S. GEOLOGICAL SURVEY BULLETIN 1759

MINERAL RESOURCES OF WILDERNESS STUDY AREAS—
MISCELLANEOUS STATES

DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

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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 Cross Mountain Wilderness Study Area (CO–010–230), Moffat County, Colorado.

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Mineral Resources of the Cross Mountain Wilderness Study Area, Moffat County, Colorado

By Karl V. Evans, James G. Frisken, *and*
Dolores M. Kulik
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ABSTRACT

The Cross Mountain Wilderness Study Area (CO–010–230) comprises about 14,081 acres in Moffat County, northwestern Colorado, between the town of Maybell and Dinosaur National Monument. The study area contains high-purity limestone of the Morgan Formation suitable for industrial and agricultural use; dolomitic limestone of the Madison Limestone suitable for agricultural use; and limestone, dolomite, sandstone, and sand and gravel suitable for use as construction materials. There has been no mining within the study area. The entire study area has low mineral resource potential for sediment-hosted copper in the Uinta Mountain Group, and parts of the study area have low resource potential for sandstone-type uranium-vanadium in sedimentary rocks of the Chinle Formation, Entrada and Glen Canyon Sandstones, Curtis Formation, Morrison Formation, and Browns Park Formation. The entire study area has low resource potential for all other metals and geothermal resources. It has high energy resource potential for oil and gas in the eastern part of the area and moderate potential elsewhere. The study area has no mineral resource potential for coal.

SUMMARY

Character and Setting

The Cross Mountain Wilderness Study Area (CO–010–230), hereafter referred to as the "study area," comprises about 14,081 acres about 15 mi (miles) west of Maybell, Moffat County, northwestern Colorado (fig. 1). As requested by the U.S. Bureau of Land Management, field work was conducted by the U.S. Geological Survey (USGS) and U.S. Bureau of Mines (USBM) to assess the mineral resource potential and appraise the identified mineral resources of the study area. Cross Mountain is on the southwestern edge of the Wyoming Basin physiographic province, a known producer of uranium, coal, and oil and gas. The Maybell uranium mining district is about 20 mi east of Cross Mountain, but the study area has no history of mining.

The Cross Mountain area is a fault-bounded, doubly plunging anticline cored by the Proterozoic Uinta Mountain Group (see geologic time chart in the Appendix of this report). Above the Uinta Mountain Group are several unconformity-bounded packages of Paleozoic and Mesozoic sedimentary rocks, which are in turn overlain by the Tertiary Bishop Conglomerate and Browns Park Formation. Faulting in the region probably occurred intermittently from the Middle Proterozoic to Tertiary time.

A geochemical study of stream sediments showed seven low-level anomalies, each of which was a single-element anomaly representing a separate sample site. These are not considered indicative of mineral deposits.

Gravity and aeromagnetic results do correlate well with major regional structures identified by mapping at the 1° × 2° scale; however, they do not indicate the presence of any mineral resources in the study area.

Identified Resources

There are no identified resources in the study area, but dolomite and high-purity limestone are present. The Morgan

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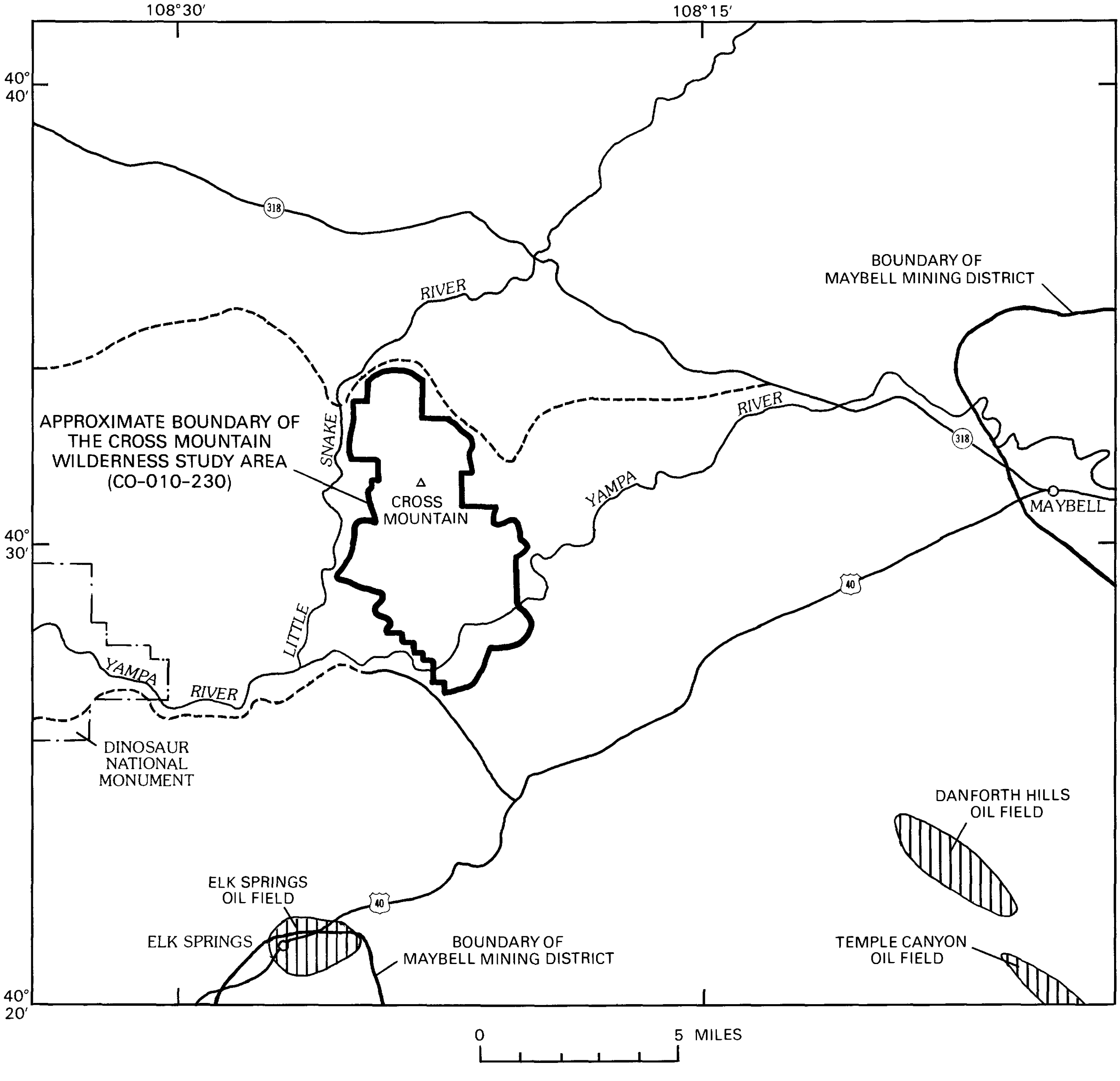


Figure 1. Index map showing the location of the Cross Mountain Wilderness Study Area, Moffat County, Colo. Dashed lines are dirt roads.

Formation contains high-purity limestone, which could be used as a scrubber in local power plants, a purifier in the sugar beet industry, or as dusting in underground coal mines. The Madison Limestone could be used as agricultural dolomite, construction material, and aggregate.

Sandstone and sand and gravel are also present in the study area, but much larger and more accessible deposits are found in the lowlands outside the boundaries of the study area. Rocks were examined and sampled for evidence of metallic mineral deposition, but only low concentrations of metals were found. Hematite zones were examined for suitability for iron oxide pigments, but the concentrations of toxic and heavy metals are too high for commercial use.

Mineral Resource Potential

The entire Cross Mountain Wilderness Study Area is underlain by the Uinta Mountain Group, which has a low mineral resource potential, at certainty level C (fig. 2), for sediment-hosted copper. This conclusion is based on the lack of geochemical anomalies and only partial correlation with known mineral deposit models.

A low mineral resource potential, at certainty level C, for sandstone-type uranium-vanadium deposits is assigned to parts of the study area containing several stratigraphic units known to host such deposits in neighboring regions. This evaluation is based on the lack of field and scintillometer evidence for uranium-vanadium deposition and on the presence of only one low-level vanadium anomaly.

The mineral resource potential for oil and gas is rated high in the eastern part of the study area, at certainty level C, on the basis of geologic mapping, unpublished seismic data, and information from several wells drilled near the study area. The western part of the area is rated as having moderate energy resource potential because of the apparent lack of upturned units beneath the overhanging western margin of the Cross Mountain uplift. A certainty level of B is given because of the lack of direct drilling data.

No coal-bearing units are present within the study area; nor does available evidence suggest their presence at depth. Therefore the study area has no mineral resource potential for coal, at certainty level D. No thermal springs are present, and the area has low potential, at certainty level B, for geothermal resources. For all other metals, the geochemical data do not indicate significant single or multi-element anomalies and no appropriate deposit models fit the geologic setting. Therefore, the resource potential for all other metals is low, at certainty level B.

INTRODUCTION

The Cross Mountain Wilderness Study Area covers approximately 14,081 acres in Moffat County, northwestern Colorado (fig. 1). The study area is about 15 mi west of Maybell, Colo., and about 5 mi east of Dinosaur National Monument. U.S. Highway 40 and Colorado Highway 318 diverge near Maybell to pass south and north of Cross Mountain, respectively. Gravel roads nearly encircle Cross Mountain, providing ready access to the study area. The Little Snake River runs immediately west of the study area, and the Yampa River has carved Cross Mountain Canyon through the southern part of the area. Cross Mountain rises abruptly above the alluvial plain of the Little Snake River at about 5,650 ft (feet) to its highest point at 7,804 ft.

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 separate studies by the U.S. Bureau of Mines and the U.S. Geological Survey. 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 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 resources (coal, oil, gas, oil shale, and geothermal sources). It is classified according to the system of Goudarzi (1984), which is shown in the Appendix of this report. The potential for undiscovered resources is determined by the USGS.

Investigations by the U.S. Bureau of Mines

The Cross Mountain Wilderness Study Area was examined by the USBM in 1987 (Thompson, 1988). Prior to the field investigation, a detailed literature search was made for pertinent geologic, mining, and land status information. U.S. Bureau of Land Management and county records were examined for locations of patented and unpatented mining claims and oil and gas leases in and near the study area. Ten employee-days were spent doing foot and vehicle reconnaissance including sampling of prospects and mineralized areas. Twenty-one rock samples and twenty-two stream-sediment samples of minus-80 mesh were collected for analysis.

All samples were analyzed for 27 elements and six limestone samples were subjected to whole-rock analysis by Chemex Labs, Inc., of Sparks, Nev., using inductively coupled plasma–atomic emission spectroscopy. Pertinent data are included in Thompson (1988), and detailed data may be obtained from the U.S. Bureau of Mines, Building 20, Denver Federal Center, Denver, CO 80225.

Investigations by the U.S. Geological Survey

The geology of the study area had been mapped previously by Dyni (1968) and McKay (1974) and was examined in reconnaissance in May 1987 for this study. A simplified geologic map of the study area is presented in this report; for more detailed information, consult the maps of Dyni (1968) and McKay (1974). Geochemical data were evaluated by J.G. Frisken and geophysical data were compiled by D.M. Kulik.

Acknowledgments.—We would like to thank David Brady (BLM, Craig office) and Kermit Witherbee (BLM, Lakewood office) for providing information on the study area. Discussions with C.W. Spencer, P.R. Spencer, D.B. Seavey, D.S. Stone, J.J. Connor, C.J. Wandrey, T.J. Hainsworth, and A.R. Wallace are gratefully acknowledged.

APPRAISAL OF IDENTIFIED RESOURCES

By John R. Thompson U.S. Bureau of Mines

Mining and Leasing Activity

No mining has taken place and no mining claims are within the study area, although there are prospects and there has been mining nearby. The study area is near the Maybell mining district, where uranium has been mined in two areas. The major uranium-producing area is about 10 mi east of the study area and the smaller one is about 8 mi south of the study area (Collier and others, 1978). The district has produced more than 1.6 million tons of ore from the Tertiary Browns Park Formation, which surrounds the study area. Although the Maybell mining district was inactive for many years, some of the old mines were reactivated in 1978 and about 200,000 tons of ore were processed by heap-leaching (Nelson-Moore and others, 1978, p. 253).

A few tons of limestone have been quarried for an undetermined use from the Pennsylvanian Morgan Formation about 1 mi south of the study area. This formation is highly fossiliferous and has been explored for marine invertebrate fossils. On the west boundary of the study area several iron oxide zones in limestone have been explored by bulldozing.

Drilling for hydrocarbons has been common in northwestern Colorado from the 1930's to the present. The Sand Wash basin to the north and the Piceance basin to the south both contain oil and gas fields that produce from formations of Pennsylvanian to Tertiary age (Scanlon, 1983). Within 22 mi of the study area, four fields in the Sand Wash basin have produced a combined total of more than 200 million MCF (thousand cubic feet) of gas and more than 5 million bbl (barrels) of oil. Within 18 mi of Cross Mountain, six fields in the Piceance basin have produced more than 14 million MCF of gas and more than 11 million bbl of oil (Scanlon, 1982, p. 26). Oil and gas leases covered almost the entire study area (fig. 3) as of May 1987 (Thompson, 1988).

Mineral Appraisal

Limestone and Dolomite

Limestone is composed mostly of the mineral calcite ($CaCO_3$), and dolomite is composed mostly of the mineral dolomite ($(Ca,Mg)CO_3$). Ultrahigh-calcium limestone is more than 97 percent $CaCO_3$, high-calcium limestone is more than 95 percent $CaCO_3$, and high-purity dolomite is more than 95 percent $(Ca,Mg)CO_3$ and contains more than 47.5 percent magnesium carbonate. Dolomitic limestone containing 25–45 percent magnesium carbonate is called "high magnesian," and that containing 5–25 percent magnesium carbonate is called "low magnesian" (Carr and Rooney, 1983, p. 836).

In the study area, limestone occurs in the Pennsylvanian Morgan Formation and the Mississippian Madison Limestone. The Morgan Formation crops out in the northwestern and southern parts of the area. Limestone from this formation was quarried about 1 mi outside the southern boundary of the wilderness study area, but the use of the quarried material is not known. Chemical analyses of three samples ranged from 87 to 97 percent $CaCO_3$ and from 0.8 to 7 percent $MgCO_3$. Combined $CaCO_3$ and $MgCO_3$ content ranged from 93 to 98 percent. The Morgan Formation contains high-purity limestone suitable for a stack-gas scrubber in coal-fired power plants, mine dusting in coal mines, a purifier in sugar-beet refining, and agricultural limestone.

The Madison Limestone crops out in the northeastern and central parts of the study area. Three samples were collected and chemically analyzed. $MgCO_3$ content ranged from 24 to 39 percent and $CaCO_3$ content ranged from 49 to 60 percent. Combined $MgCO_3$ and $CaCO_3$ content ranged from 84 to 92 percent. The Madison Limestone contains dolomitic limestone suitable for agricultural dolomite and aggregate.

Limestone samples were taken from outcrops, where weathering can affect the amount of calcium and other minerals present. An accurate assessment of the limestone can be ascertained only by excavating or core drilling into unweathered material. If subsurface sampling reveals higher calcium content, then both formations could be suitable for additional uses, such as cement.

Transportation is a significant factor in the cost of marketing limestone because it is a high-bulk, low-unit-value commodity. Trucking costs of high-purity limestone to coal-burning power plants at Craig (a distance of about 50 mi) would be about \$6.00 per ton. The current price of limestone at the mine is about \$35 per short ton; actual value and present mineability would depend on the saleability of the limestone based on local demand.

EXPLANATION

[Entire study area has low mineral resource potential for sediment-hosted copper in the Uinta Mountain Group, at certainty level C; low mineral resource potential for all other metals not otherwise shown below, at certainty level B; low mineral resource potential for geothermal resources, at certainty level B; and no mineral resource potential for coal, at certainty level D]

H/C	Geologic terrane having high mineral resource potential for oil and gas, at certainty level C
M/B	Geologic terrane having moderate mineral resource potential for oil and gas, at certainty level B
L/C	Geologic terrane having low mineral resource potential for sandstone-type uranium-vanadium deposits, at certainty level C
	Levels of certainty
B	Data indicate geologic environment and suggest level of resource potential
C	Data indicate geologic environment and give good indication of level of resource potential, but do not establish activity of resource-forming processes
D	Data clearly define geologic environment and level of resource potential and indicate activity of resource-forming processes in all or part of the area

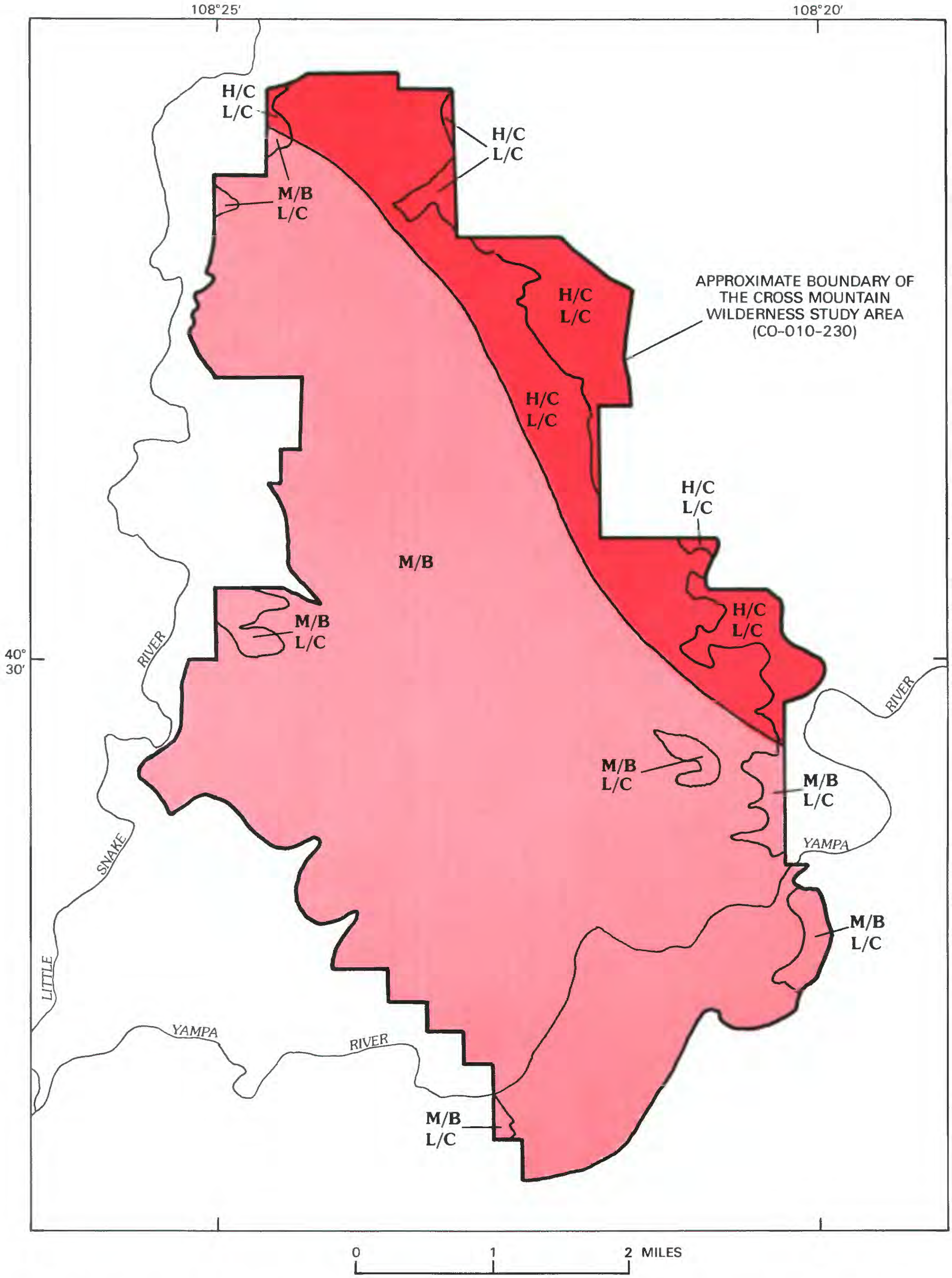


Figure 2 (above and facing page). Summary map showing mineral resource potential of the Cross Mountain Wilderness Study Area, Moffat County, Colo.

Iron Oxide Pigments

Iron oxides are unique among mineral pigments because they are the only significant colored minerals found in a natural state and suitable for use as a pigment after being pulverized. Natural pigments are derived from iron oxide ore, are selected for their special physical and chemical properties, and can command a premium price. Color is the most important characteristic of a pigment. The chemical composition of the pigment is also important, as is the type and form of the minerals associated with it. For example, quartz would be undesirable because it would make grinding difficult, and calcination would be required to decompose organic matter (Hancock, 1983, p. 350).

Samples of two thin hematite zones were analyzed for their possible use as mineral pigments. In the northeast corner of the study area (fig. 3) a 1-ft-wide hematite zone in limestone has been exposed for about 20 ft in a bulldozer cut. A sample from the zone contained 1.48 percent iron, 140 ppm (parts per million) arsenic, 42 ppm chromium, and 42 ppm molybdenum. On the western boundary of the study area, a 2-ft-wide hematite zone has also been exposed in a bulldozer cut (fig. 3). This zone contains some chert. A sample from the zone contains 0.97 percent iron and 252 ppm chromium (Thompson, 1988). These element concentrations are common in hematite zones and may not indicate any greater mineral concentration at depth.

Most pigmentary iron ore is chemically inert and contains only traces of heavy or toxic metals. Lead, antimony, arsenic, chromium, cadmium, mercury, and selenium should be at very low concentrations (Hancock, 1983). Samples of the two hematite zones contained relatively high concentrations of some of these undesirable metals. Both hematite zones contain toxic metals and are too small and low in grade to be of use as mineral pigments.

Uranium

Uranium was produced near Maybell, about 10 mi east of the study area, where a crushing and sampling station operated until 1979 (Collier and others, 1978). Uranium was mined from the Tertiary Browns Park Formation, which is almost completely eroded from the study area. The Triassic Chinle Formation is the only unit in the area that is known to bear uranium elsewhere, and only a very thin zone crops out on the southwestern edge of the study area. The Chinle and other formations and structures in the study area were checked for radioactivity by a scintillometer, and samples were analyzed for uranium. The average background level for radiation in this area is 60 cps (counts per second); the highest scintillometer reading never exceeded 150 cps. All rock samples contained less than 10 ppm uranium. There are no surface indications of uranium resources in the Chinle in the Cross Mountain study area.

Metals

Mineral deposits commonly occur along faults and altered zones. The northwest-trending faults and breccia zones in the western and northern parts of the study area were sampled for precious and base metals. Maximum concentrations of elements in the structures were 200 ppm arsenic, 620 ppm barium, 280 ppm chromium, 13 ppm copper, 42 ppm molybdenum, 4 ppm lead, 360 ppm vanadium, and 119 ppm zinc (Thompson, 1988). These concentrations are too low to be of economic interest.

Redbed sandstone elsewhere has been mined for copper and silver deposits, and five different redbed formations were sampled for these and other elements. Maximum concentrations of elements in the sandstone formations were 240 ppm barium, 238 ppm chromium, 2 ppm copper, 4 ppm molybdenum, and 29 ppm zinc (Thompson, 1988). Analytical data for samples from the structures and the sandstone do not indicate any economic mineral concentrations.

Construction Materials

Limestone, dolomite, sandstone, and sand and gravel exist in the study area. The high-purity limestone in the Morgan Formation and dolomitic limestone in the Madison Limestone are suitable for construction aggregate and road metal. Sandstone beds in the Uinta Mountain Group and Lodore Formation, which have a wide range of textures, colors, and chemical and physical properties, are suitable for use as dimension or building stone. Small occurrences of sand and gravel are common on the east and west sides of Cross Mountain where alluvium and colluvium have washed down from higher elevations. The access to the sandstone near the core of the Cross Mountain anticline is difficult, and vast quantities of sand and gravel are available at the flood plain of the Yampa and Little Snake Rivers. The difficult access to the sandstone and small quantity of sand and gravel preclude any likely development.

ASSESSMENT OF POTENTIAL FOR UNDISCOVERED RESOURCES

By Karl V. Evans, James G. Frisken, and Dolores M. Kulik
U.S. Geological Survey

Geology

The Cross Mountain Wilderness Study Area is on a north-northwest-trending, doubly plunging anticline that lies directly between the southeast-trending axis of

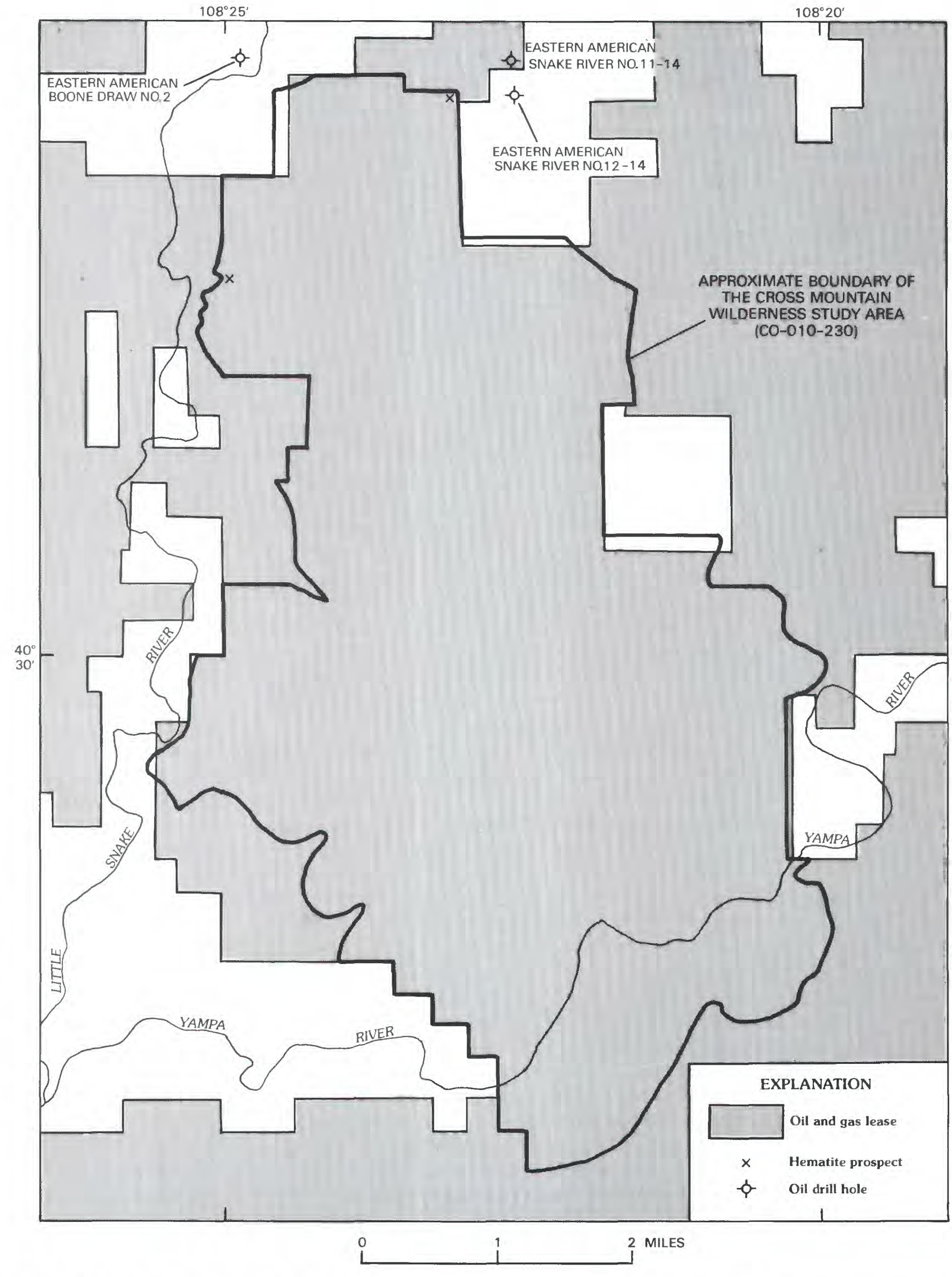
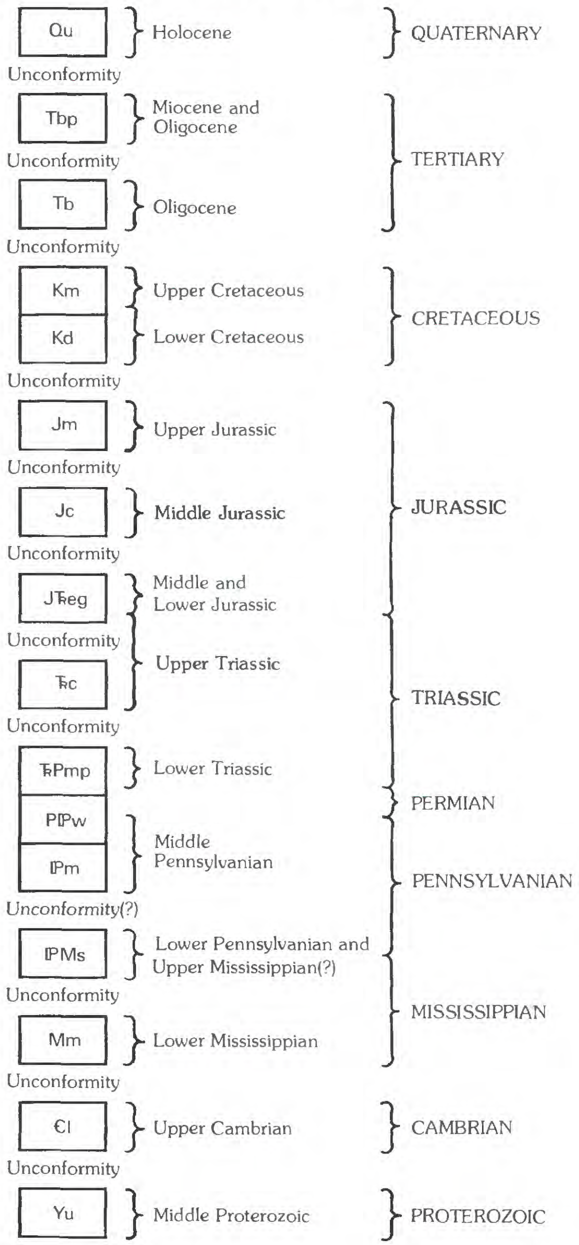


Figure 3. Map showing oil and gas leases and hematite prospects in and near the Cross Mountain Wilderness Study Area, Moffat County, Colo.

CORRELATION OF MAP UNITS



LIST OF MAP UNITS

Qu	**Alluvium, colluvium, landslide, and terrace debris (Holocene)**
Tbp	**Browns Park Formation (Miocene and Oligocene)**
Tb	**Bishop Conglomerate (Oligocene)**
Km	**Mancos Shale (Upper and Lower Cretaceous)**
Kd	**Dakota Sandstone (Lower Cretaceous)**
Jm	**Morrison Formation (Upper Jurassic)**
Jc	**Curtis Formation (Middle Jurassic)**
JTReg	**Entrada Sandstone (Middle Jurassic) and Glen Canyon Sandstone (Lower Jurassic and Upper Triassic)**
TRc	**Chinle Formation (Upper Triassic)**
TRPmp	**Moenkopi Formation (Lower Triassic) and Park City Formation (Permian)**
PIPw	**Weber Sandstone (Permian and Pennsylvanian)**
IPm	**Morgan Formation (Middle Pennsylvanian)**
IPMs	**Shale, sandstone, limestone, and dolomite (Lower Pennsylvanian and Upper Mississippian(?))**
Mm	**Madison Limestone (Lower Mississippian)**
€l	**Lodore Formation (Upper Cambrian)**
Yu	**Uinta Mountain Group (Middle Proterozoic)**

Contact

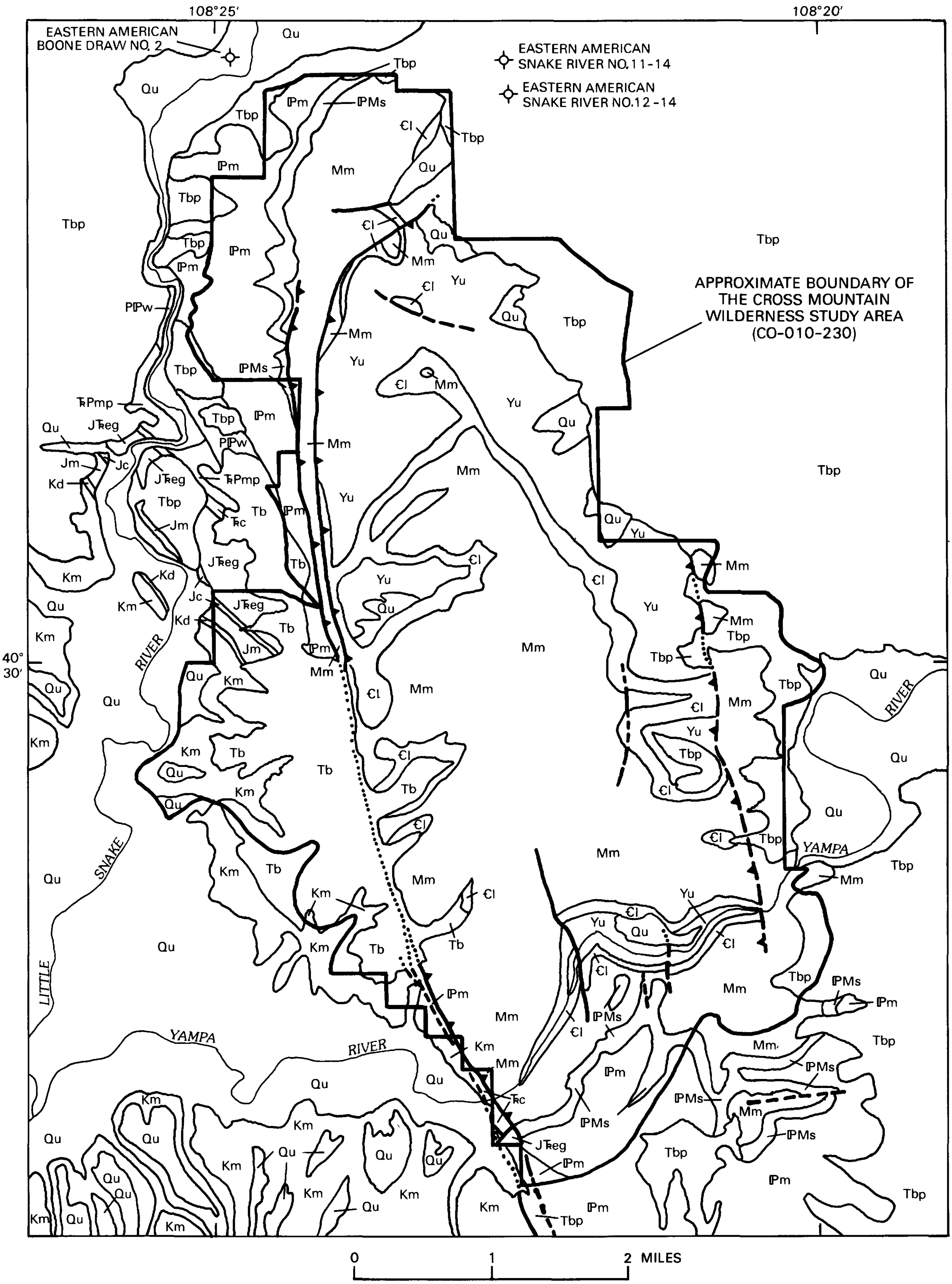
Fault—Dotted where concealed; dashed where approximately located

Reverse fault—Dotted where concealed; dashed where approximately located; sawteeth on upper plate

Figure 4 (above and facing page). Geologic map of the Cross Mountain Wilderness Study Area and vicinity, Moffat County, Colo. Geology simplified from Dyni (1968) and McKay (1974).

the eastern Uinta anticline (to the west) and the Axial Arch (to the east). The region is characterized by complex structures related to (1) formation of the Uinta Mountain aulacogen in the Proterozoic, (2) thrusting of both the northern and southern margins of the Uinta Mountains in the Mesozoic and Tertiary, and (3) subsequent normal faulting during the Tertiary (Gries, 1983a; Hansen, 1986a,b; Stone, 1986). Cross Mountain is essentially a "pop-up" block bounded by reverse faults on its east and west sides (fig. 4), as indicated by unpublished seismic lines and several oil wells drilled adjacent to the study area.

An incomplete stratigraphic section of Proterozoic through Tertiary rocks is present in the study area. The Middle Proterozoic Uinta Mountain Group is exposed primarily in the northern part of the study area, as well as in Cross Mountain Canyon, where erosion by the Yampa River has breached the anticline. The strata are reddish-brown, fine- to coarse-grained (in places conglomeratic) sandstone and arkose with minor interbeds of red shale.


108°25′
108°20′
EASTERN AMERICAN
BOONE DRAW NO. 2
EASTERN AMERICAN
SNAKE RIVER NO.11-14
EASTERN AMERICAN
SNAKE RIVER NO.12-14
APPROXIMATE BOUNDARY OF
THE CROSS MOUNTAIN
WILDERNESS STUDY AREA
(CO-010-230)
40°
30′
SNAKE RIVER
LITTLE SNAKE
YAMPA RIVER
YAMPA RIVER
0
1
2 MILES

Bedding is generally thick and strongly cross stratified. Maximum thickness in the study area is about 1,200 ft (McKay, 1974).

The Cambrian Lodore Formation unconformably overlies the Uinta Mountain Group with an angular discordance of about 8° in the study area (Kanizay, 1956), and its exposure closely follows that of the underlying Proterozoic rocks. The Lodore is light-gray and pale-green, glauconitic, fine- to coarse-grained sandstone and conglomeratic sandstone containing a few beds of red and green siltstone. The sandstone is thin to thick bedded and cross stratified. The maximum thickness is about 300 ft.

Mississippian Madison Limestone caps the crest of central Cross Mountain and is also exposed at the northwestern tip of the range. The formation is light-gray, partly brecciated, microcrystalline dolomitic limestone and dolomite that unconformably overlies the Lodore Formation. It generally is massive and forms thick cliffs and ledges. The maximum thickness is about 430 ft.

Unconformably above the Madison are Mississippian and Pennsylvanian sandstone, shale, limestone, and dolomite. This assemblage of lithologies is also found in three formal units, the Humbug Formation, Doughnut Shale, and Round Valley Limestone, which are the most likely correlatives (neither Dyni (1968) nor McKay (1974) assigned a formal stratigraphic name). Because these three formal units are composed of mixed lithologies, further work would be needed to separate and map the units in the field. The strata consist of interbedded gray dolomite containing red nodular chert, red and green shale, and earthy siltstone. These strata are poorly exposed and their maximum thickness is estimated at about 150 ft.

The Pennsylvanian Morgan Formation unconformably(?) overlies the shale and dolomite unit and is exposed at the northwestern and southern tips of the range. The Morgan is primarily a gray fossiliferous limestone containing abundant nodular red chert. Interbedded with the dominant lithology are yellowish-brown, crossbedded sandstone and lesser amounts of gray, red, and green shale. The maximum thickness is about 1,000 ft.

In northwestern Colorado the Morgan Formation is usually overlain conformably by the Permian Park City Formation and Triassic Moenkopi Formation. However, within the study area these units have been removed by faulting and will not be described here.

The Triassic Chinle Formation, which normally overlies the Moenkopi Formation unconformably, is present in the study area in two small fault blocks on the southwest side of the range. The Chinle is reddish brown overall but includes gray, green, and yellow interbeds. Lithologies are interbedded claystone, siltstone, sandstone, and mudstone-pebble conglomerate. The thickness regionally is about 285 ft.

The Triassic and Jurassic Glen Canyon Sandstone, which unconformably overlies the Chinle, and the unconformably overlying Jurassic Entrada Sandstone were mapped as one unit and crop out in several locations along the western margin of Cross Mountain. The rocks are grayish-orange, fine-grained to very fine grained, festoon crossbedded sandstone. A chert-pebble zone a few inches thick probably marks the regionally extensive J-2 unconformity (Pipiringos and O'Sullivan, 1978). The combined total thickness is about 700 ft.

The Jurassic Curtis Formation unconformably overlies the Entrada Sandstone and is exposed in the low hills in the west-central part of the range. The formation consists of interbedded olive-gray and greenish-gray, glauconitic sandstone, shale, and oolitic limestone. The thickness is about 100 ft.

Unconformably above the Curtis is the Jurassic Morrison Formation, present in the west-central part of the study area. The basal Morrison consists of white, lenticular crossbedded, well-sorted, medium-grained sandstone ranging from 40 to 150 ft in thickness. Above this are variegated siltstone and claystone containing lenses of poorly sorted gray sandstone (locally containing chert pebbles) and thin beds of light-gray limestone. The total thickness is about 500 ft.

The Cretaceous Dakota Sandstone unconformably overlies the Morrison and is divisible into three parts. The lower and upper parts consist of yellowish-brown to light-gray, medium- to coarse-grained, carbonaceous, quartzitic sandstone containing dark chert pebbles. Between these subdivisions are dark-greenish-gray and variegated, fissile shale. The total thickness varies from 70 to 150 ft.

Conformably above the Dakota is the Cretaceous Mancos Shale, which is subdivided into the Lower Cretaceous Mowry Shale Member, Upper Cretaceous Frontier Sandstone Member, and Upper Cretaceous "main body." All are exposed in the study area on the west side of the range, but the Mowry and Frontier Members are extremely restricted in extent. The Mowry is primarily a gray siliceous shale containing numerous thin interbeds of bentonite; the thickness is about 100 ft. The Frontier consists of a lower unit of brownish-gray shale containing thin interbeds of bentonite and an upper unit of interbedded gray, fossiliferous, calcareous sandstone and gray shale. The thickness of the Frontier is about 200 ft. The main body of the Mancos Shale consists of dark-gray marine shale beds and thick sandstone beds near the top and bottom. The total thickness is about 5,500 ft, but only the lower part is present in the study area.

Unconformably overlying older units is the Oligocene Bishop Conglomerate. Within and adjacent to the study area this unit was mapped as part of the Browns Park Formation, but we follow Hansen (1986a) and Rowley and others (1985), who reinterpreted the earlier work of Dyni (1968) and McKay (1974). The Bishop is exposed on a high bench overlooking the Little Snake River along the western margin of Cross Mountain. It consists primarily of light-gray and pink, poorly to moderately consolidated, fluvial, partly tuffaceous conglomerate and sandstone. The thickness is variable but reaches a maximum of about 135 ft in the study area.

Cross Mountain is virtually encircled by strata of the Oligocene and Miocene Browns Park Formation, which unconformably overlie the Mancos Shale, as well as most of the other stratigraphic units mentioned previously. Within the study area, exposure of the Browns Park Formation is sparse but widespread. The Browns Park is white, light-gray, and tan, poorly to moderately consolidated, crossbedded, tuffaceous sandstone and conglomerate. Regionally, the thickness varies from 0 to 1,600 ft.

Quaternary units are present as terrace deposits of sand and gravel capping pediment surfaces, landslide debris in Cross Mountain Canyon, colluvium developed on the steep flanks of the range, and alluvium along the Little Snake River.

Geochemistry

A reconnaissance geochemical survey of the study area was conducted by the U.S. Bureau of Land Management (BLM) between July and September of 1983 (Witherbee, 1983). Twenty sediment samples of active alluvium were collected from first- and second-order streams draining Cross Mountain. The samples were sieved to minus-80 mesh and were analyzed by Barringer Resources for 24 elements (Ag, As, Au, B, Ba, Be, Ca, Cu, Fe, F, Hg, Li, Mg, Mn, Mo, Pb, Sb, Sr, Th, Ti, U, V, W, and Zn) by atomic absorption, colorimetric, induction-coupled plasma emission spectrographic, neutron activation, or fluorometric methods having low detection limits. The sampling density and analytical methods employed by the BLM and Barringer Resources are comparable to those used by the USGS. Because of the lack of significant anomalies in the BLM studies and the additional surface sampling by the USBM, a decision was made by the USGS not to sample the study area further.

As part of the BLM study, frequency distribution histograms and log probability plots of cumulative frequency distribution were prepared for each element for 100 samples collected in the Cross Mountain and other wilderness study areas of this region. Threshold values were defined by inflection points on the plots.

Elements not present at concentrations above their detection limits (given in parentheses) are silver (0.1 ppm), gold (0.02 ppm), tungsten (4 ppm), antimony (1 ppm), and mercury (4 parts per billion)). Anomalous concentrations were found for molybdenum (one sample, 4 ppm), lead (one sample, 34 ppm), vanadium (one sample, 132 ppm), zinc (three samples, 64–92 ppm), and arsenic (one sample, 20 ppm). These concentrations are all low-level anomalies for the region and each is a single-element high representing a separate sample site. Witherbee (1983) did not give a threshold value for uranium, but most samples were below the detection limit of 0.2 ppm and the high value of 0.4 ppm is well below the average uranium concentration in sedimentary rocks (2 ppm).

Geophysics

Geophysical data provide information on the subsurface distribution of rock masses and the structural framework. Gravity and magnetic studies were undertaken as part of the mineral resource assessment of the Cross Mountain Wilderness Study Area. The geophysical data available for this study are generally sufficient only to identify regional features.

The gravity data were obtained in and adjacent to the study area in 1987 and were supplemented by data maintained in the files of the Defense Mapping Agency of the U.S. Department of Defense and by unpublished data obtained by D.M. Kulik during previous work in 1986–87. Stations measured for this study were established by means of 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 1751–2 at Craig, Colo. Station elevations were obtained from benchmarks, spot elevations, and estimations from topographic maps at 1:24,000 scale and are accurate to ±20 ft. The error in the Bouguer gravity value is less than 1.2 mGal (milligals) for errors in elevation control. Bouguer anomaly values were computed by means of 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 gravity anomaly map in figure 5.

The aeromagnetic data are shown as a residual-intensity magnetic anomaly map in figure 6 and are from the U.S. Department of Energy (Bendix Field Engineering Corporation, 1982). The survey was flown east-west at an approximately 3-mi flight-line spacing and 400 ft above the ground surface.

The study area lies on the gravity gradient between a major gravity low (A, fig. 5) associated with low-density

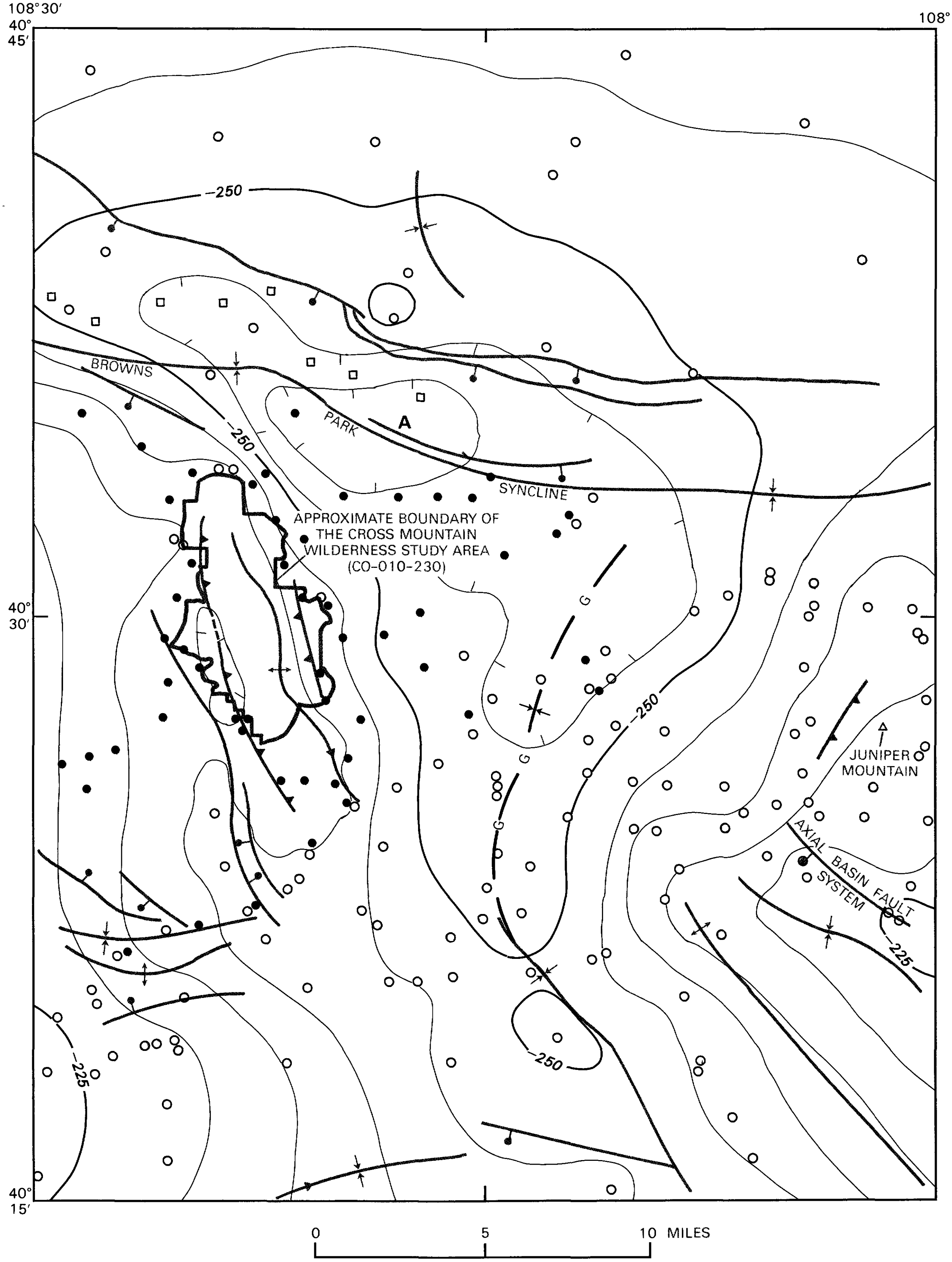


Figure 5 (above and facing page). Complete Bouguer gravity and generalized structure map of the Cross Mountain Wilderness Study Area and vicinity. Structure from Rowley and others (1985).

EXPLANATION

-250 **Gravity contours**—Contour interval 5 milligals; hachures indicate closed gravity low

A **Anomaly discussed in text**

— G — **Basin axis inferred from gravity data**

Gravity station

● Measured for this study

□ From USGS published data

○ From U.S. Department of Defense

Anticline—Arrow shows direction of plunge

Syncline—Arrow shows direction of plunge

Thrust or reverse fault—Dashed where covered or inferred; sawteeth on upper plate

Normal fault—Dashed where covered or inferred; bar and ball on downthrown block

Tertiary rocks and higher values to the west where higher density Mesozoic, Paleozoic, and Precambrian rocks are exposed. The configuration of the gravity low suggests that the structural axis of the mapped syncline in the southeast corner of the map area (fig. 5) continues northward where indicated by the dashed line identified by the symbol "G." The gravity high in the southeast corner is associated with a mapped anticline and Paleozoic rocks of relatively high density that crop out at Juniper Mountain.

The study area lies on a north-trending gravity gradient that increases to the west and is associated with the eastern flank of the Douglas Creek arch, identified south of the study area (see Gries, 1983b, and Stone, 1986, for location). The arch is interpreted from the gravity data to continue in the subsurface just west of the map area. The -240-mGal contour is deflected around the south end of the study area and an elongate enclosed gravity low borders the west side of the study area. This pattern results from uplift of high-density Paleozoic and Precambrian rocks along reverse faults having opposing dip, forming a minor "pop-up" structure. This structure may be on the leading edge of the fault system that bounds the Douglas Creek arch, but apparently is separated from that system by another north-trending fault. The gravity low along the southwestern part of the study area is caused by sedimentary rocks of relatively low density that thicken in a graben or faulted syncline between the study area and the main part of the Douglas Creek arch.

Magnetic data usually reflect differences in basement lithology or differences in depth to basement rocks. Two saddles in the magnetic data (A and B, fig. 6) at the extreme western edge of the map area mark the location of the north-trending fault that separates the main part of the Douglas Creek arch from Cross Mountain. The study area lies on an east-west-trending magnetic gradient. The magnetic high (C) north of the study area extends westward over the core of the Uinta Mountains, where Precambrian rocks are exposed. The magnetic low (D) to the south is south of an east-northeast-trending fault system that passes south of the study area where only Mesozoic and Paleozoic rocks crop out. The gradient may mark the location of one of the bounding faults of the Proterozoic Uinta basin where there is a change in depth to basement rocks and possibly a change in lithology as well.

The magnetic high (E) in the southeast corner of the map area probably is caused by Precambrian crystalline rocks in the core of the anticline southwest of the Axial Basin fault system, where no Uinta Mountain Group rocks are preserved (Stone, 1986). The gap in subsurface Uinta Mountain Group rocks continues into the area of the relatively high magnetic arch (F). A relatively low anomaly (G) occurs northeast of the Axial Basin fault system, where as much as 10,000 ft of Uinta Mountain Group rocks are preserved and the depth to crystalline rocks is correspondingly greater and where nonmagnetic Paleozoic rocks are exposed at the surface.

Mineral Resource Potential

The geology of the study area permits the occurrence of several types of mineral and energy deposits, including stratiform copper in the Uinta Mountain Group and sandstone-type uranium-vanadium in several Mesozoic sandstone units and the Browns Park Formation.

Sediment-Hosted Copper

Sediment-hosted ("redbed"-type) copper deposits commonly occur in thick, red, sandy units throughout the world. Typically, these deposits form in association with underlying, or minor interbedded, mafic volcanic rocks; are associated with evidence of an arid depositional environment, such as salt casts or evaporitic rocks (gypsum, for example); and occur at or near a chemically reduced (generally organic rich) unit interbedded with the dominant redbeds (Gustafson and Williams, 1981). Although the Uinta Mountain Group is a thick redbed sequence that underlies the entire study area, it lacks most of the other characteristics for such sediment-hosted deposits. This information, combined with the geochemical data, indicates that the Uinta Mountain Group in the study area has a low mineral resource potential at certainty level C for sediment-hosted copper deposits (fig. 2).

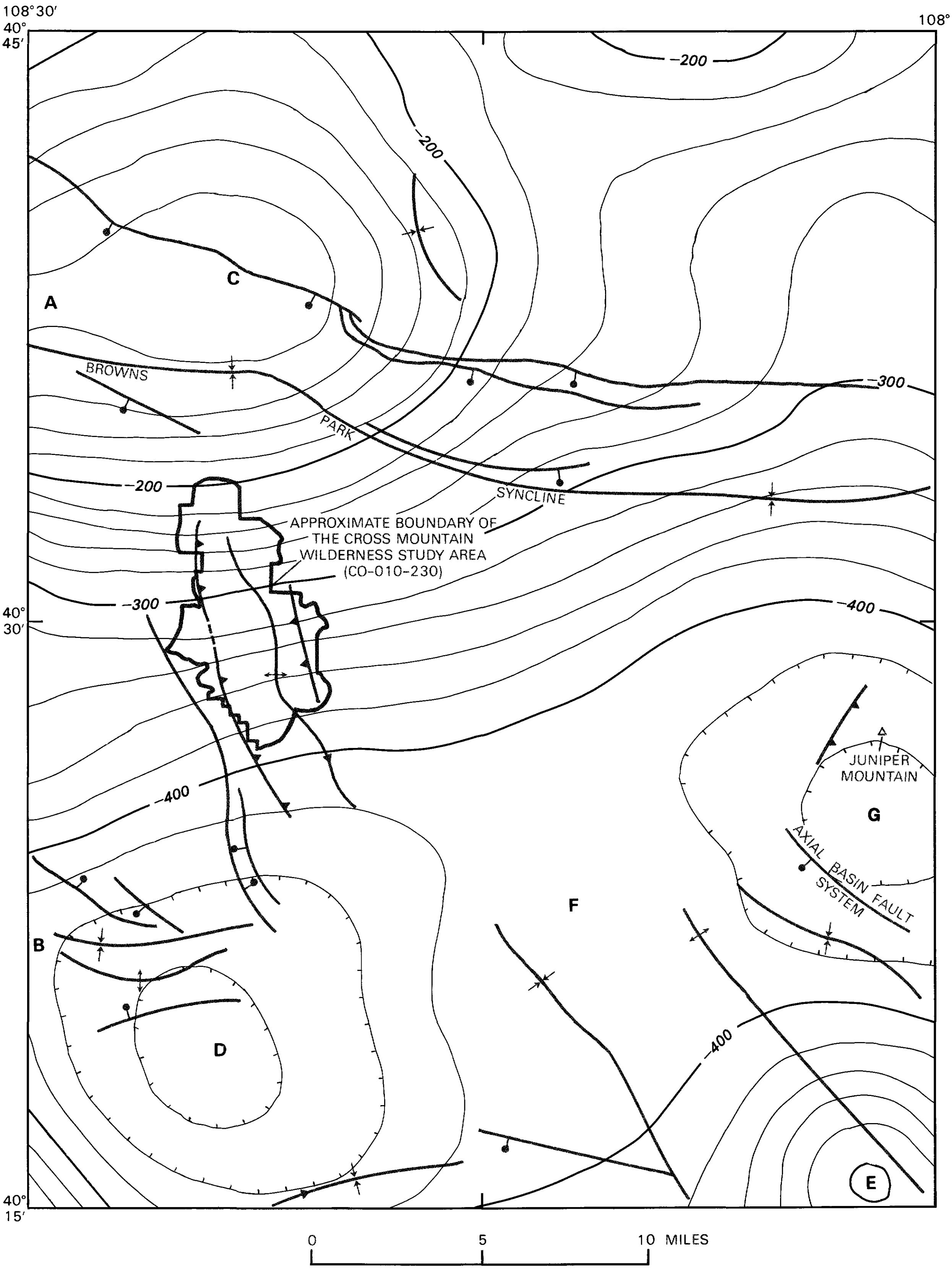


Figure 6 (above and facing page). Residual-intensity aeromagnetic and generalized structure map of the Cross Mountain Wilderness Study Area and vicinity. Structure from Rowley and others (1985).

EXPLANATION

–400– Magnetic contours—Contour interval 20 nanoteslas; hachures indicate area of closed magnetic low

A Anomaly discussed in text

Anticline—Arrow shows direction of plunge

Syncline—Arrow shows direction of plunge

Thrust or reverse fault—Dashed where covered or inferred; sawteeth on upper plate

Normal fault—Dashed where covered or inferred; bar and ball on downthrown block

Tabular Uranium-Vanadium

Sandstone-type uranium-vanadium deposits are classically displayed on the Colorado Plateau south of Cross Mountain (Fisher, 1955; Nash and others, 1981) and to the east near Maybell (Chenoweth, 1987). The general model for deposition of these deposits requires leaching of uranium-vanadium, possibly from intercalated tuff beds in the sedimentary sequence, and deposition as primary ore minerals in a chemically reducing environment (Nash and others, 1981; Brownfield and others, 1986). In the study area possible host units for such deposits include the Chinle Formation, Entrada and Glen Canyon Sandstones, Curtis Formation, Morrison Formation, and Browns Park Formation. However, rock sample data and scintillometer surveys give no indication of uranium-vanadium mineralization at the surface and only one sample yielded a low-level vanadium anomaly. Therefore, the Chinle Formation, Entrada and Glen Canyon Sandstones, and Curtis, Morrison, and Browns Park Formations are rated as having a low mineral resource potential at certainty level C for sandstone-type uranium-vanadium deposits (fig. 2).

Oil and Gas

The oil and gas potential of the study area was rated as "zero" by Spencer (1983a,b), apparently because the Proterozoic Uinta Mountain Group is exposed in the core of the range. Based on data from recent wells drilled near the area and unpublished industry seismic studies, our evaluation differs from that of Spencer. We emphasize, however, that unlike Spencer's terminology, the ratings used in this report (see Appendix) evaluate only the energy resource potential for undiscovered oil and gas and carry no connotation as to the amount of any oil or gas that may be present.

Spencer (1983a) listed four critical factors required for hydrocarbon accumulations: (1) reservoir (porous) rocks, (2) hydrocarbon (organic-rich) source beds, (3) a relatively impermeable seal or barrier to prevent upward and lateral migration of hydrocarbons, and (4) favorable thermal history. All of these factors are met within or immediately adjacent to the eastern part of the study area.

Within the wilderness study area the typical reservoir and source rocks of the region (the Pennsylvanian strata) are exposed, which generally would negate any oil potential. However, drilling adjacent to the eastern margin of the study area indicates the presence of both reservoir and source beds beneath the Browns Park Formation.

Seismic and well data indicate that Cross Mountain is bounded on both sides by inward-dipping reverse faults, thereby forming a "pop-up" structure. Both faults probably dip in excess of 50°, but the easternmost fault is thought to dip less steeply than the westernmost fault. The Eastern American Snake River No. 12–14 well, located about 0.5 mi east of the northern tip of the study area (fig. 4), penetrated the Browns Park Formation and Uinta Mountain Group, went through a complex fault zone into steeply dipping, overturned Morgan, Weber, Moenkopi, and Morrison rocks, and finally encountered upright Morrison and older units, bottoming at 10,261 ft in the Weber Sandstone. Oil stains were common in both the overturned and upright sections. Similar results, as well as a good oil show in the Morrison(?) Formation and Dakota Sandstone (D.B. Seavey, Braxton and Associates, oral commun., 1988), were found in the nearby Eastern American Snake River No. 11–14 well. It is evident from the oil show and the numerous oil stains in the cored holes that appropriate thermal conditions for the generation of oil existed in the area.

Current work by the petroleum industry, essentially all unpublished, seems to indicate that a sandstone reservoir body forms a stratigraphic trap immediately east of the study area. In addition, part of this stratigraphic trap may lie beneath the structural overhang penetrated by the Eastern American Snake River wells. These data suggest that the mineral resource potential for oil and gas is high, at certainty level C, in the eastern part of the study area. The remainder of the area is given a moderate potential, at certainty level B, because seismic results do not appear to show an upturn of units beneath the overhang at the west side of Cross Mountain (fig. 2).

Coal and Geothermal Resources

No coal-bearing units are present within the study area and available information does not suggest their presence at depth. The study area thus has no mineral resource potential for coal, at certainty level D. No thermal springs are present, and the area has low potential, at certainty level B, for geothermal resources (fig. 2).

Other Metals

For all metals other than those mentioned previously, the geochemical data do not indicate significant single or multi-element anomalies, no appropriate mineral deposit models fit the geologic setting, and there is no past production. Therefore, for these metals the area has a low mineral resource potential at certainty level B (fig. 2).

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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.

★ U.S GPO: 1989 673-047/86,101

SELECTED SERIES OF U.S. GEOLOGICAL SURVEY PUBLICATIONS

Periodicals

Earthquakes & Volcanoes (issued bimonthly).
Preliminary Determination of Epicenters (issued monthly).

Technical Books and Reports

Professional Papers are mainly comprehensive scientific reports of wide and lasting interest and importance to professional scientists and engineers. Included are reports on the results of resource studies and of topographic, hydrologic, and geologic investigations. They also include collections of related papers addressing different aspects of a single scientific topic.

Bulletins contain significant data and interpretations that are of lasting scientific interest but are generally more limited in scope or geographic coverage than Professional Papers. They include the results of resource studies and of geologic and topographic investigations; as well as collections of short papers related to a specific topic.

Water-Supply Papers are comprehensive reports that present significant interpretive results of hydrologic investigations of wide interest to professional geologists, hydrologists, and engineers. The series covers investigations in all phases of hydrology, including hydrogeology, availability of water, quality of water, and use of water.

Circulars present administrative information or important scientific information of wide popular interest in a format designed for distribution at no cost to the public. Information is usually of short-term interest.

Water-Resources Investigations Reports are papers of an interpretive nature made available to the public outside the formal USGS publications series. Copies are reproduced on request unlike formal USGS publications, and they are also available for public inspection at depositories indicated in USGS catalogs.

Open-File Reports include unpublished manuscript reports, maps, and other material that are made available for public consultation at depositories. They are a nonpermanent form of publication that may be cited in other publications as sources of information.

Maps

Geologic Quadrangle Maps are multicolor geologic maps on topographic bases in 7 1/2- or 15-minute quadrangle formats (scales mainly 1:24,000 or 1:62,500) showing bedrock, surficial, or engineering geology. Maps generally include brief texts; some maps include structure and columnar sections only.

Geophysical Investigations Maps are on topographic or planimetric bases at various scales; they show results of surveys using geophysical techniques, such as gravity, magnetic, seismic, or radioactivity, which reflect subsurface structures that are of economic or geologic significance. Many maps include correlations with the geology.

Miscellaneous Investigations Series Maps are on planimetric or topographic bases of regular and irregular areas at various scales; they present a wide variety of format and subject matter. The series also includes 7 1/2-minute quadrangle photogeologic maps on planimetric bases which show geology as interpreted from aerial photographs. Series also includes maps of Mars and the Moon.

Coal Investigations Maps are geologic maps on topographic or planimetric bases at various scales showing bedrock or surficial geology, stratigraphy, and structural relations in certain coal-resource areas.

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Miscellaneous Field Studies Maps are multicolor or black-and-white maps on topographic or planimetric bases on quadrangle or irregular areas at various scales. Pre-1971 maps show bedrock geology in relation to specific mining or mineral-deposit problems; post-1971 maps are primarily black-and-white maps on various subjects such as environmental studies or wilderness mineral investigations.

Hydrologic Investigations Atlases are multicolored or black-and-white maps on topographic or planimetric bases presenting a wide range of geohydrologic data of both regular and irregular areas; principal scale is 1:24,000 and regional studies are at 1:250,000 scale or smaller.

Catalogs

Permanent catalogs, as well as some others, giving comprehensive listings of U.S. Geological Survey publications are available under the conditions indicated below from the U.S. Geological Survey, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225. (See latest Price and Availability List.)

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