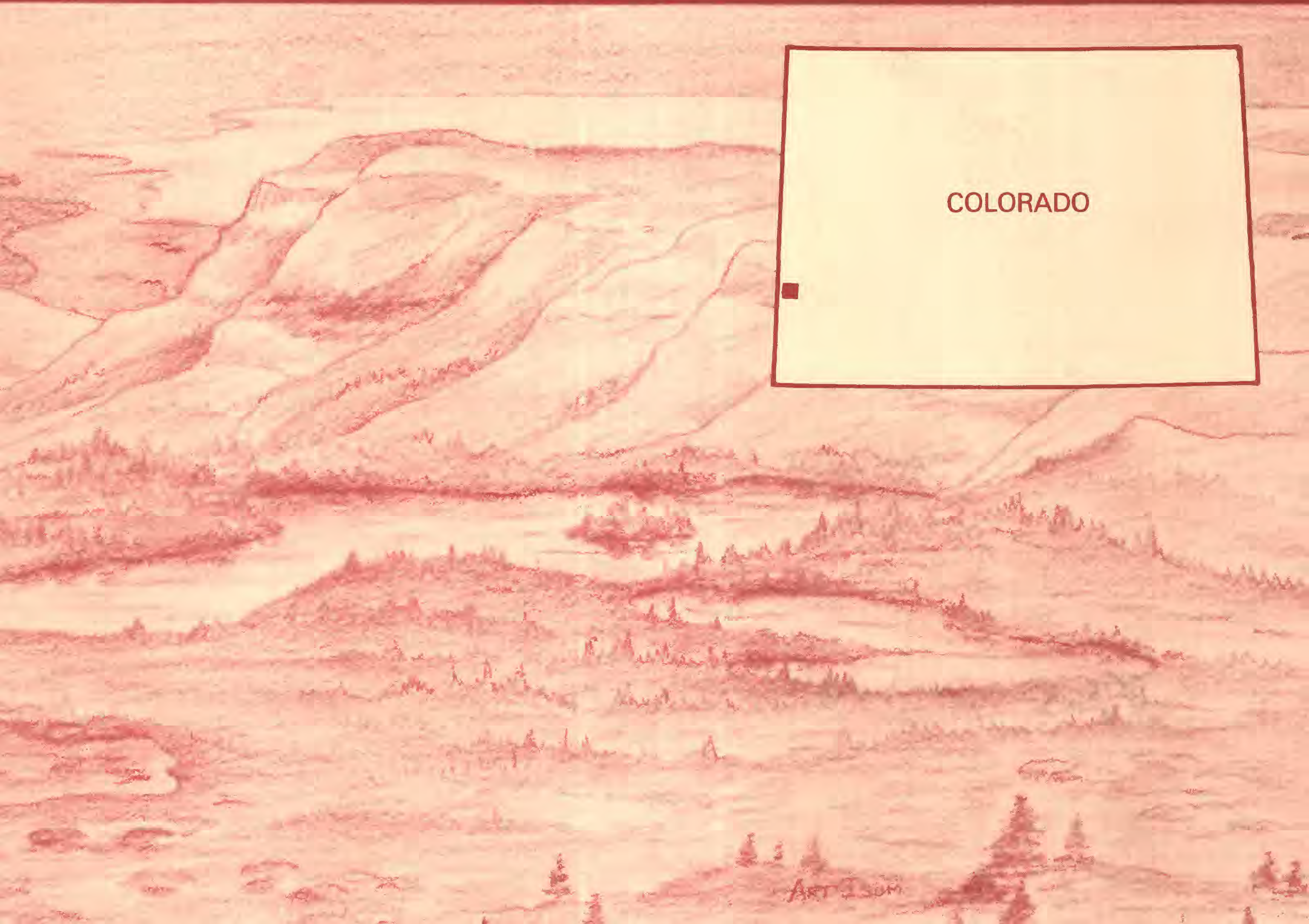
Mineral Resources of the Dolores River Canyon Wilderness Study Area, Montrose and San Miguel Counties, Colorado

U.S. GEOLOGICAL SURVEY BULLETIN 1715–C



Chapter C

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MINERAL RESOURCES OF WILDERNESS STUDY AREAS—
SOUTHWESTERN COLORADO

DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, 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 Dolores River Canyon Wilderness Study Area (CO–030–290), Montrose and San Miguel Counties, Colorado.

CONTENTS

PLATE

[Plate is in pocket]

FIGURES

Mineral Resources of the Dolores River Canyon Wilderness Study Area, Montrose and San Miguel Counties, Colorado

By Carol N. Gerlitz, Harlan N. Barton, *and* Dolores M. Kulik
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SUMMARY

Abstract

The Dolores River Canyon Wilderness Study Area (CO-030-290) includes 28,366 acres in southwestern Colorado in Montrose and San Miguel Counties. A joint mineral resource study of the area was completed in 1987 by the U.S. Bureau of Mines and U.S. Geological Survey. Inferred subeconomic resources of sandstone, sand, and gravel were identified during this study, but no mineral production from the study area has been recorded. The study area has a moderate mineral resource potential for oil, gas, and placer gold. The resource potential is low for other metals, geothermal energy, industrial minerals (the evaporites—gypsum, anhydrite, salt (halite), and potash) in exposures of the Hermosa Formation, and uranium in the Morrison Formation. Resource potential for evaporites in the remainder of the study area is unknown because it is uncertain whether the evaporite-containing Paradox Member of the Hermosa Formation extends beneath the study area. Resource potential for uranium in the Chinle Formation is unknown because the presence of the possible host rock, the Moss Back Member of the Chinle, is uncertain. There is no resource potential for coal within the study area.

Character and Setting

The Dolores River Canyon Wilderness Study Area (CO-030-290) is located about 15 mi (miles) west of Naturita, Colorado, and is accessible by dirt roads from Colorado Highways 90 and 141 (fig. 1). The Dolores River and its tributaries have carved a spectacular canyon through a thick sequence of nearly flat-lying sedimentary rocks that form a highland between the collapsed salt anticlines of Paradox Valley and Big and Little Gypsum Valleys (fig. 1; pl. 1). The boundary of the study area closely follows the canyon rim. Sedimentary rock units exposed in the canyon walls and along the mesa tops consist of siltstone, mudstone, shale, gypsum, limestone, sandstone, and conglomerate that range in age from Pennsylvanian to Cretaceous (see geologic time chart in Appendix).

Identified Resources

Inferred subeconomic resources of sand and gravel and sandstone suitable for building material are present in the study area, but local markets for these resources can be supplied by deposits outside the study area.

Mineral Resource Potential

Fine-grained stream-sediment samples and heavy-mineral panned concentrates were collected at 34 sites along the Dolores River and its tributaries. Both sample types were analyzed for 31 elements by an emission spectrographic method; in addition, stream sediments were analyzed by specific chemical methods for seven elements, including gold and uranium. A few geochemical anomalies were found in the study area. Most of the scattered anomalies found in heavy-mineral-concentrate samples and a single anomalous uranium value found in stream sediments appear to be related to known mines or prospects outside the study area upstream from the sample sites. Anomalous gold and tin concentrations may represent

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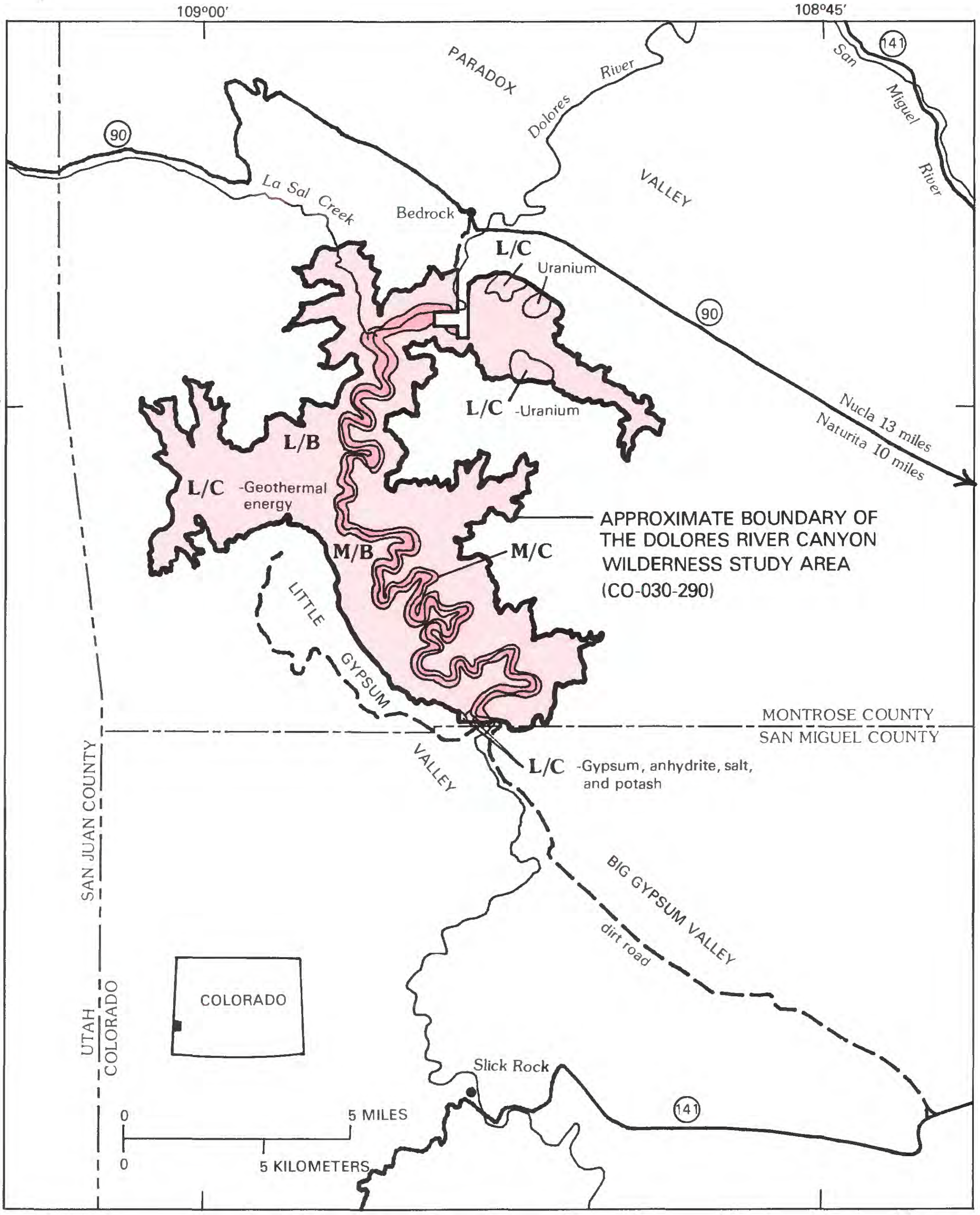


Figure 1. Summary map showing mineral resource potential and identified resources of the Dolores River Canyon Wilderness Study Area, Montrose and San Miguel Counties, Colorado.

placers in the Dolores River. The remaining anomalous concentrations are too scattered and isolated to provide evidence for the presence of any type of mineral resources. Scintillometer surveys were conducted on mesa tops, where the mesas extend into the study area, and along the canyon bottom to search for anomalous radiation levels but none were detected.

Northwest-trending gravity lows occur south and north of the study area over the collapsed salt anticlines of Big and Little Gypsum Valleys and Paradox Valley, respectively (fig. 1);

the gravity lows appear to define the limits of salt units beneath the thick sedimentary rocks through which the Dolores River Canyon has been cut. Magnetic gradients in the vicinity of the study area generally coincide with gravity gradients, suggesting that the location and (or) development of the anticlines may have been controlled by faults within Proterozoic basement rocks.

A study of Landsat Multispectral Scanner (MSS) imagery of the study area revealed no limonite anomalies or other indications of hydrothermal alteration, uranium deposits, or hydrocarbon leakage. The imagery did indicate a major lineament northwest of the study area, which coincides with a northwest-trending collapsed anticline.

Although the Dolores River Canyon study area lies in the Uravan mineral belt, no uranium mines or mineral deposits are known within the study area. Except for a few areas bordering Wild Steer Canyon in the northeasternmost part of the study area (fig. 1), very little of the uranium-bearing Morrison Formation occurs within the study area; where it does exist, there is no evidence of uranium mineralization. The resource potential for uranium in the Morrison Formation in the study area is low, with certainty level C (see Appendix). Although the upper part of the Chinle Formation crops out along the bottom of the Dolores River Canyon in the northern half and in the southern tip of the study area, there is no indicaton of uranium mineralization in these rocks; information for the subsurface is lacking to determine whether the usual uranium-bearing host, the Moss Back Member of the Chinle, is present. Hence, resource potential for uranium in the Chinle Formation in the study area is unknown, with certainty level A.

Heavy-mineral-concentrate samples taken from stream gravels and terraces along the Dolores River have detectable gold concentrations. No gold has been mined within the study area, but production of placer gold has been reported from La Sal Creek, upstream from the study area, and a small amount was found in ores from the Cashin and Cliffdweller mines just outside the northern study area boundary. The study area has a moderate resource potential for gold, with a certainty level of C (fig. 1).

Resource potential for other metals in the study area is low, with certainty level B; copper- and silver-bearing faults outside the boundary do not extend into the study area, and there is no evidence of other types of metals in other formations.

The wilderness study area is underlain by sedimentary units that have yielded hydrocarbons elsewhere in the region, but little is known about the subsurface structure of these rocks within the study area. Although virtually the entire study area is under lease for oil and gas and a few test holes have been drilled, there has been no hydrocarbon production. The study area has moderate resource potential for oil and gas, with a certainty level of B (fig. 1).

Although the Paradox Member of the Hermosa Formation contains gypsum, anhydrite, salt (halite), and potash elsewhere in the region, no significant deposits of these minerals were observed in exposures of the Paradox Member at the southern end of the Dolores River Canyon Wilderness Study Area. Resource potential for evaporites in the Paradox Member outcrop area is therefore low, with certainty level C. Because it is uncertain whether the Paradox Member extends beneath the study area, mineral resource potential for evaporites in the remainder of the study area is unknown, with certainty level A.

No geothermal sources are known within the study area; resource potential for geothermal energy is therefore low, with certainty level C. Because no coal-bearing units exist within the study area, there is no mineral resource potential for coal at certainty level D.

EXPLANATION

[Entire area has inferred subeconomic resources of sandstone, and canyon bottoms have inferred subeconomic resources of sand and gravel in terraces and alluvium. Entire area has no mineral resource potential for coal, at certainty level D]

M/B **Geologic terrane having moderate mineral resource potential for oil and gas, certainty level B**—Applies to entire study area

M/C **Geologic terrane having moderate mineral resource potential for gold, certainty level C**—Applies only to stream gravels of the Dolores River and La Sal Creek

L/B **Geologic terrane having low mineral resource potential for metals other than gold and uranium, certainty level B**—Applies to entire study area

L/C **Geologic terrane having low mineral resource potential for uranium, geothermal energy, and the evaporites; gypsum, anhydrite, salt, and potash, certainty level C**—Applies to outcrop area of Morrison Formation for uranium; applies to entire study area for geothermal energy; applies to outcrop area of Hermosa Formation for evaporites

INTRODUCTION

The Dolores River Canyon Wilderness Study Area (CO-030-290) covers 28,366 acres about 15 mi west of the small towns of Nucla and Naturita in Montrose and San Miguel Counties, Colorado (fig. 1). During 1986 and 1987 the U.S. Geological Survey (USGS) and U.S. Bureau of Mines (USBM) conducted a joint mineral resource study of the entire wilderness study area, at the request of the U.S. Bureau of Land Management (BLM). In this report the area studied is called the "wilderness study area" or simply the "study area."

The study area is accessible from the south by a dirt road that runs northwest through Big and Little Gypsum Valleys from Colorado Highway 141 (fig. 1); to the north, dirt roads reach the study area from Colorado Highway 90 in the Paradox Valley (pl. 1; fig. 1). The study area is drained by the Dolores River, which flows northward through a narrow, steep-walled canyon, and by several tributaries that have cut smaller side canyons. The boundary of the irregularly shaped study area generally follows the canyon rim. The study area is dominated by deep canyons and adjacent flat-topped mesas. Elevations in the study area range from 4,960 ft (feet) where the Dolores River exits the canyon at the north boundary of the study area to 6,660 ft about 2.7 mi southeast on the north edge of Skein Mesa (pl. 1).

This report presents an evalution of the mineral endowment (identified resources and mineral resource potential) of the study area and is the product of several separate studies by the USBM and the USGS. Identified resources are classified according to the system of the U.S. Bureau of Mines and U.S. Geological Survey (1980) which is shown in the Appendix of this report. Identified resources 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 also is shown in the Appendix. Undiscovered resources are studied by the USGS.

Investigations by the U.S. Bureau of Mines

A mineral investigation of the study area was done by the USBM in May and August 1986. Field investigation was preceded by a survey of relevant literature regarding the geology and mineral resources of the region. Information regarding land and mineral ownership, oil and gas leases, claims, and prospecting activity was researched from records of the U.S. Bureau of Land Management state office in Lakewood, Colo.

Field investigation included the examination and sampling of mineralized areas in and near the study areas, taking scintillometer readings to detect anomalous radioactivity at sample sites and during foot and vehicle traverses, placer sampling of stream bars and terraces along the Dolores River, and the collection of minus-80-mesh (less than 0.17 mm (millimeters)) stream sediments to determine the extent of mineralized areas. A total of 83 samples was taken, including 54 rock samples, 3 stream-sediment samples, and 26 panned-concentrate samples. All rock and stream-sediment samples were analyzed by Chemex Labs, Inc., of Sparks, Nev. Samples from uranium mines were analyzed for uranium by fluorometry; all other rock samples and stream-sediment samples underwent semiquantitative analysis for 30 elements by inductively coupled plasma-atomic emission spectroscopy. To check whether mineralized faults at the Cashin and Cliffdweller mines, outside the study area, could have been the source of gold detected in sediments of La Sal Creek and the Dolores River, rock samples from these mines were analyzed for gold by neutron activation analysis. Panned-concentrate samples were amalgamated and weighed to determine gold content. Sample site locations and results of the analyses are found in Martin (1987). Additional information concerning the study is available from the USBM Intermountain Field Operations Center, Building 20, Denver Federal Center, Denver, Colo. 80225.

Investigations by the U.S. Geological Survey

A mineral resource assessment of the Dolores River Canyon Wilderness Study Area by the USGS during 1986 and 1987 included a field check of previous geologic mapping in the area; a scintillometer survey of Morrison Formation exposures in the study area; collection of stream-sediment and heavy-mineral-concentrate samples and subsequent chemical analysis of the samples; a gravity survey in and adjacent to the study area to supplement existing regional data; and studies of existing magnetic data and Landsat Multispectral Scanner imagery data. Aerial photographs were used to supplement field observations. The study area extends into six 7½-minute quadrangles, and the previously published geologic maps of these quadrangles (Carter and Gualtieri, 1957; Cater, 1954, 1955a, 1955b; Weir and others, 1960; and Withington, 1955) provided geologic data for this report. The simplified geologic map (pl. 1) was compiled by digitizing these maps using GSMAP (Selner and Taylor, 1987).

Acknowledgments.—We are grateful to many people for their help with this project. A.B. Wilson assisted during the field evaluation. Janet Jones and R.G. Eppinger assisted in the stream-sediment sampling. Chemical analyses were performed by P.H. Briggs, J.H. Bullock, and K.R. Kennedy. Thanks also are due to J.L. Jones and John Sering in the BLM office in Montrose, Colo., and Richard Arnold in the Colorado State Office of the BLM for their assistance.

APPRAISAL OF IDENTIFIED RESOURCES

By Clay M. Martin U.S. Bureau of Mines

Mining and Leasing Activity

No mineral production has been recorded from the study area. Commodities produced or prospected for near the study area include uranium, vanadium, radium, copper, gold, and silver.

The study area lies in the Uravan mining district, near the western margin of the Uravan mineral belt, an elongated, arcuate area in Mesa, Montrose, and San Miguel Counties which contains more abundant, large, closely spaced, high-grade uranium-vanadium deposits than the surrounding region (Fischer and Hilpert, 1952). Carnotite-rich ores have been mined in the Uravan district since the end of the 19th century for uranium and several associated metals. Radium was produced from 1898 to about 1923, with a total yield of over 200 g (grams). Demand for vanadium was high from about 1918 through World War II; total production was approximately 24,000,000 lb (pounds) vanadium oxide (V_2O_5). From about 1946 through the late 1970's, more than 63,000,000 lb of uranium oxide (U_3O_8) and 332,000,000 lb of coproduct V_2O_5 were produced from the district (Chenoweth, 1978).

Copper and silver deposits were discovered in 1896 along La Sal Creek about ½ mi north of the Dolores River Canyon study area (Emmons, 1906). In this vicinity, copper and silver were produced intermittently at the Cashin and Cliffdweller mines from 1899 to 1945. Total combined production from the two mines in the peak production years of 1934–45 was about 1,060,000 lb copper, 97 oz (troy ounce) gold, and 60,000 oz silver; additionally, about 500 oz gold and 116 oz silver were produced from placers in La Sal Creek (Vanderwilt, 1947). Attempts at reopening the Cashin mine in recent years (through 1987) have not resulted in additional production.

Thousands of unpatented lode claims for uranium are located throughout the Uravan district. Many claims staked for uranium in the Morrison Formation outside the study area extend into the area. Blocks of patented lode claims cover the Cashin and Cliffdweller mines near the study area (fig. 2). Most of the study area is under lease for oil and gas (Martin, 1987), except for a small area at the south end of the study area where the Dolores River enters the canyon.

Uranium

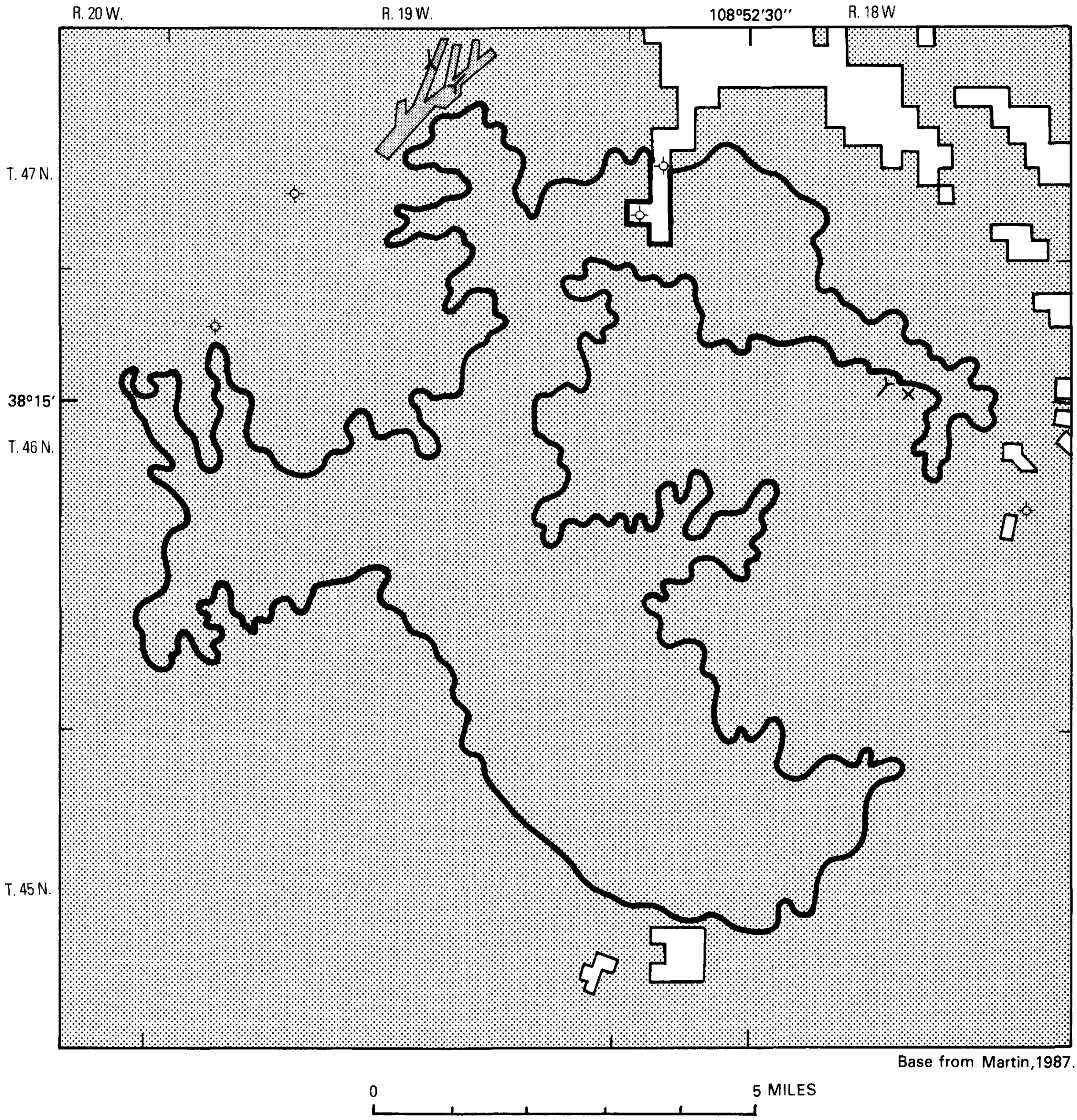
The numerous isolated tablelands surrounding the study area are all capped by the Upper Jurassic Morrison Formation (pl. 1) and have been extensively mined and prospected for uranium; virtually all known uranium deposits in this part of the Uravan mineral belt occur in the Salt Wash Member of the Morrison. The study area, however, includes little of the mesa tops and, therefore, little of the Morrison Formation and no known uranium deposits.

The part of the study area underlain by the Morrison Formation, along the north and south rims of Wild Steer Canyon near the northeastern boundary, comprises about 1.5 mi^2 (square miles) of surface area. A scintillometer survey was conducted on foot traverses along all outcrops of Morrison Formation in this area. No anomalous radioactivity was detected, and no surface evidence of uranium occurrences, prospects, or mining activity was found in or near the study area. The nearest mining activity was on the south side of Wild Steer Canyon, within ¼ mi of the study area boundary. In this vicinity, one abandoned adit, the Henry Z mine, and several prospects (pl. 1) about ½ mi to the east are located in the Salt Wash Member. The Henry Z mine was not examined extensively or sampled due to high levels of radon in the mine, but samples from inside the portal and from the mine dump contained 49 ppm (parts per million) and 400 ppm U_3O_8, respectively. Samples from surface prospects ½ mi east contained as much as 8,000 ppm (0.80 percent) U_3O_8. However, a scintillometer survey between these two sites showed no indication of anomalous radioactivity and mineral continuity. This lack of continuity of mineralized rock is consistent with the nature of uranium deposits in the area (Cater, 1954).

Copper and Silver

Copper-silver deposits in faults in the Upper Triassic Wingate Sandstone in the Paradox fold and fault belt have been known since the late 19th century, although little production has resulted from mining in the area. Typical deposits of this type are at the Cashin and Cliffdweller mines located on patented claims along La Sal Creek just outside the northern boundary of the study area (fig. 2). The mines are about ¼ mi apart and follow two separate northeast-trending normal fault zones in the Wingate Sandstone. Ore bodies at the mines are similar and are replacement- and hydrothermal-vein deposits of chalcopyrite, covellite, and massive native copper, according to Fischer (1936). Little evidence of these minerals exists in USBM samples; however, the portions of the fault zones observed commonly contain copper-bearing minerals, such as malachite and azurite. Strong limonite staining in samples from the mineralized zone is probably from oxidization of chalcopyrite. Ore minerals are confined to crushed sandstone, gouge, and breccia in the fault zone and are confined to the adjacent wallrock of Wingate Sandstone. Silver is contained in accessory argentiferous covellite (Withington, 1955). Gangue minerals in the fault zones include calcite and barite.

At the Cliffdweller mine, the mineralized fault trends N. 17° E., dips 65–70° SE., and is downthrown on the southeast (pl. 1). Workings at the Cliffdweller mine



EXPLANATION

(Oil and gas lease information from the U.S. Bureau of Land Management; current as of February 1987)

- **Adit**
- **Prospect pit**
- **Dry oil and gas test hole**
- **Oil and gas leases**
- **Patented mining claims**
- **Approximate boundary of Wilderness Study Area**

Figure 2. Index map showing approximate location of patented mining claims, oil and gas leases, and selected mines, prospects, and dry wells, in and near the Dolores River Canyon Wilderness Study Area.

consist of two adits at different levels in the fault zone, totalling 1,400 ft of underground workings (Withington, 1955). This mine is partially collapsed and was not mapped during this study. A select sample taken from the mine dump contains 60 ppm silver and more than 1 percent copper (1 percent (10,000 ppm) is the upper quantitative limit for copper using the inductively coupled plasma-atomic emission spectroscopy analytical method).

At the Cashin mine, the mineralized fault trends approximately N. 50° E. and dips 65–75° NW. (pl. 1). Fault displacement appears to be about 50 ft and is downthrown on the northwest. Workings consist of three adits following the fault at different levels. The lowermost adit is a decline at about the level of La Sal Creek; it was flooded to within 40 ft of the portal in 1986. The upper two adits follow the fault zone closely. The adits are driven mostly in the fault zone and footwall; the hanging wall forms the left or northwestern rib of the adits. The middle adit is about 250 ft long; the upper adit is about 850 ft long. Both adits have been stoped upwards along the fault zone for as much as 50 ft; the uppermost stopes of the middle adit are only a few feet below the floor of the upper adit. The upper stopes of both adits are inaccessible.

Forty-four samples were taken from the Cashin mine area. Copper concentrations ranged from 0.13 percent to over 1 percent; silver concentrations ranged from 1 to more than 200 ppm (the upper detection limit). The highest silver concentrations are from samples of back-fall material from the upper stopes of the mine and from outcrops of fault material left as pillars between the lower part of the adit and the stopes above. Gold content of the samples was very low, with concentrations ranging from less than 1 ppb (parts per billion) (the lower detection limit) to 4 ppb. Assay results from the lower parts of the adits may not be indicative of the character of mineralization in the upper, inaccessible portions of the fault zone, or in the unmined parts of the fault beyond the adits.

Neither of the faults at the Cashin and Cliffdweller mines trends into the study area, and ground reconnaissance and air-photo study indicate no related faults in the study area. There is no evidence that metallic deposits similar to those found in the the Cashin and Cliffdweller mines occur in the study area.

Placer Gold

Placer gold has been produced sporadically from gravels in the Dolores River and two of its tributaries in the vicinity of the study area, the San Miguel River and La Sal Creek (fig. 1; pl. 1). Mining of gold along the Dolores was limited to parts of the river below the confluence with the San Miguel River, which is 11 miles downstream from the study area. Although production of placer gold has been reported from the La Sal Creek drainage, the location of mining operations is unreported and may have been well upstream from the study area.

Twenty-six panned-concentrate samples were taken from the lower Dolores River Canyon near the northern boundary of the study area in order to gain an indication of gold content in areas upstream. Twenty samples were taken from gravel bars in the present stream bed, and three were taken from terrace gravel deposits above present river level. Individual samples were also taken from lower Wild Steer Canyon, lower La Sal Creek, and the Dolores above the mouth of La Sal Creek to evaluate the gold contribution from the tributary streams. Each panned-concentrate sample was obtained by panning a 10-quart bucket full of stream gravel. Visible gold, ranging in size from flour gold to occasional flakes up to 3 mm in diameter, occurred only in samples from gravels in and immediately above the bed of the Dolores River. Of the 26 samples taken, 17 contained more than the measurable lower limit of gold (0.002 mg (milligrams)). Measurable amounts of gold varied from 0.002 mg to 0.439 mg per sample; the value of the gold in the best sample (0.439 mg) is equivalent to 45 cents per cubic yard, based on a gold price of $400 per ounce. These amounts of gold do not indicate a placer gold resource in the study area. Estimated value of placer gold would have to be greater than $1.50 per cubic yard to be mined economically in this area.

Industrial Rocks and Minerals

Inferred subeconomic resources of sandstone occur in the study area in a wide range of textures, colors, cementations, and bedding thicknesses. Many of the sandstone units would be suitable for use as dimension stone, flagstone, or concrete aggregate; however, vast quantities of sandstone of equal or higher quality are available throughout the region at locations closer to current markets, which minimizes the likelihood of development of sandstone resources from the study area.

Inferred subeconomic resources of sand and gravel suitable for construction aggregate are common in canyon bottoms in the Dolores River Canyon study area, particularly in the river canyon and its larger tributaries where alluvial terraces are developed. However, ample resources of sand and gravel are available elsewhere in the region, outside of the study area, at locations closer to current markets.

ASSESSMENT OF POTENTIAL FOR UNDISCOVERED RESOURCES

By Carol N. Gerlitz, Harlan N. Barton, and Dolores M. Kulik
U.S. Geological Survey

Geology

Geologic Setting

The Dolores River Canyon Wilderness Study Area, which extends along the Dolores River Canyon and several tributary canyons (pl. 1), is located in the northern part of the Colorado Plateau, in the salt anticline region described by Cater and Craig (1970). The northwest-trending front of the Uncompahgre uplift lies about 20 mi to the northeast. The entrenched meanders of the Dolores River have carved a spectacular canyon through a thick sequence of Paleozoic and Mesozoic sedimentary rocks in a broad synclinal highland between collapsed salt anticlines which now form Paradox Valley and Big and Little Gypsum Valleys (fig. 1).

Description of Rock Units

Rock units in the region consist of a thick sequence of sedimentary rocks of late Paleozoic and Mesozoic age. Proterozoic crystalline rocks, whose presence beneath the thick sedimentary cover is indicated by the magnetic data (fig. 4), are not exposed within the study area.

The Middle Pennsylvanian Hermosa Formation crops out in a small area at the south end of the study area, where the Dolores River enters its canyon from Big Gypsum Valley (pl. 1). The formation consists of a gray fossiliferous limestone member overlying thick gypsum and salt beds of the Paradox Member of the Hermosa. The Paradox Member, which contains the oldest rocks exposed in the study area, forms the cores of salt anticlines in the surrounding region.

The Upper Triassic Chinle Formation forms the floor and lower slopes of the Dolores River Canyon at its north and south ends (pl. 1). North of the study area the Chinle lies unconformably on the Lower and Middle(?) Triassic Moenkopi Formation; it unconformably overlies the Hermosa Formation at the south end of the study area. The Chinle consists of interbedded orange-red siltstone, fine-grained sandstone, and shale that are together 200 to 500 ft thick within the study area.

The Upper Triassic Wingate Sandstone conformably overlies the Chinle. This reddish-brown to grayish-orange, fine-grained, massive, crossbedded sandstone forms sheer cliffs up to 300 ft high that are cut by vertical joints. Total thickness of the unit ranges from 200 to 325 ft in the study area.

The Upper Triassic(?) Kayenta Formation consists predominantly of red, buff, and gray thin-bedded, flaggy, fine- to coarse-grained sandstone that is interbedded with fluvial shale, siltstone, and conglomerate. The formation forms a series of benches and ledges that protect the underlying Wingate from erosion and is from 180 to 260 ft thick within the study area.

The Triassic(?) and Jurassic Navajo Sandstone, conformably overlies the Kayenta. The sandstone in this unit is white to buff, fine-grained, massive, and contains sweeping crossbeds up to a few hundred feet in lateral extent that clearly indicate its eolian origin. The Navajo is the most widely exposed unit in the study area and throughout most of the region forms a hummocky erosion surface on slopes and benches. In some of the canyons, vertical cliffs are developed in the Navajo where it is protected by overlying rocks. In the southern part of the study area the Navajo is about 300 ft thick, but just north of the study area it pinches out completely.

The Middle Jurassic Entrada Sandstone is composed of two units in the study area. The lower unit is the Dewey Bridge Member which consists of nonresistant red siltstone and fine-grained sandstone that rests unconformably on the Navajo Sandstone and ranges in thickness from 10 to 90 ft. The orange, buff, and white, fine- to medium-grained, massive, crossbedded sandstone that makes up the overlying Slick Rock Member forms an unscalable cliff and is 110 to 150 ft thick in the study area.

The Middle Jurassic Wanakah Formation, mapped as Summerville Formation prior to the work of R.B. O'Sullivan (1980, 1981), conformably overlies the Entrada Sandstone. The red, gray, green, and brown sandy shales and mudstones of this slope-forming unit are interbedded with thin limestone and sandstone layers. Unpublished sections measured by O'Sullivan (oral commun., 1987) show the Wanakah is at least 82.5 ft thick in the study area.

The Upper Jurassic Morrison Formation, which unconformably overlies the Wanakah Formation, is divided into three members that form a series of slopes and clifflike ledges atop the mesas surrounding the Dolores River Canyon. The lowermost Tidwell Member, composed of reddish-brown and gray mudstone with minor gray sandstone and limestone, interfingers with the grayish-brown sandstone and minor red or gray mudstone of the overlying Salt Wash Member. Unpublished sections measured by R.B. O'Sullivan (oral commun., 1987) indicate that the Tidwell Member ranges from 21 to 41 ft thick within the study area. The Salt Wash Member is about 350 ft thick on mesas surrounding the Dolores River Canyon, except in the southwest where it thickens abruptly to 500 ft near The Hat (Withington, 1955). Because the Morrison Formation has been eroded from the canyons, little more than the basal 50–100 ft of these two members remains in most of the study area. The uppermost Brushy Basin Member consists primarily of gray, green, red, and purple bentonitic mudstone with interbedded fluvial sandstone and conglomerate. The Brushy Basin is also up to 500 ft thick near the study area, but except for a small area on Skein Mesa (pl. 1) it has been completely eroded within the boundary.

According to R.B. O'Sullivan (oral commun., 1987), the Tidwell was mapped as upper beds of the Wanakah (formerly Summerville) Formation in the vicinity of the study area; it is therefore included with the Wanakah on plate 1.

Structure

The dominant structural feature in the study area is the broad syncline between the collapsed salt anticlines that form the northwest-trending Paradox Valley and Big and Little Gypsum Valleys (fig. 1; pl. 1). In the vicinity of Muleshoe Bend, the southeastward-plunging crest of the Pine Ridge anticline enters the study area from the northwest. Sedimentary units within the study area are nearly flat lying or strike northwest and dip gently into the syncline. Major high-angle, northwest-trending faults along the northeast and southwest edges of the study area are associated with the collapse of the salt anticlines. Other faults trend northeast across La Sal Creek canyon just outside the study area and north-northwest across Coyote Wash in the study area (pl. 1).

Geochemistry

Methods

A reconnaissance geochemical survey was conducted in the Dolores River Canyon Wilderness Study Area during the summer of 1986. Minus-80-mesh (less than 0.17 mm) stream sediments and heavy-mineral panned concentrates derived from stream sediments were selected as the primary sample media. Both types of sample were collected at 34 sites from the alluvium of first-order (unbranched) and second-order (below the junction of two first-order) streams to give a sampling density of one site per 1.3 mi^2. A gamma-radiation detector was used to determine radiation levels at all sampling sites as an indication of possible uranium or thorium mineralization. Sediments from gravel benches at selected locations throughout the Dolores River Canyon were panned to see if visible gold could be detected, but no stream-sediment samples for chemical analysis were taken at these sites.

Stream-sediment samples represent a composite of rock and soil exposed in the drainage basin upstream from each sample site. Analysis of these samples provides information that helps identify 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. The removal of most of the rock-forming silicates, clays, and organic material permits the determination of elements in the concentrate that are not generally detectable in bulk stream sediments. Some of these elements can be constituents of minerals related to ore-forming rather than rock-forming processes. Such minerals can include galena (PbS), cassiterite (SnO_2), chalcopyrite ($CuFeS_2$), gold (Au), and silver (Ag).

Stream-sediment and heavy-mineral-concentrate samples were analyzed for 31 elements using a semi-quantitative emission spectrographic method (Grimes and Marranzino, 1968). In addition, stream-sediment samples were submitted for analysis for arsenic, antimony, bismuth, cadmium, gold, uranium, and zinc by specific chemical methods (Crock and others, 1987). Analytical data, sample-site locations, and a detailed description of the sampling and analytical techniques, including limits of determination for analytical methods, is available in the files of J.H. Bullock and H.N. Barton at the USGS, Denver Federal Center, Denver, Colo., 80225.

Results

Anomalous concentrations, defined as being above normal background content, were determined for each element for the various sample media and analytical methods. This determination was made by inspection of the analytical data rather than by statistical techniques. A relatively low number of samples (34 each of stream-sediment and heavy-mineral-concentrate) were taken, and many elements had only a few detectable concentrations. For some elements (antimony, arsenic, bismuth, cadmium, gold, molybdenum, silver, thorium, tin, tungsten, uranium), any occurrence above the detection limit was considered to be anomalous. No occurrences of antimony, arsenic, bismuth, thorium, or tungsten were detected.

A single uranium anomaly (24.6 ppm) was detected in stream sediments taken from the mouth of an unnamed tributary to the Dolores River south of Bull Canyon (site 2 below); the sample site is downstream from several mines and prospects in the Salt Wash Member of the Morrison Formation, outside the study area. No anomalous radiation levels were detected at any of the sampling sites. No other elements were found to be anomalous in stream sediments.

Scattered anomalies were found in heavy-mineral-concentrate samples collected from the following tributaries to the Dolores River (see pl. 1): (1) Bull

Canyon (200 ppm copper, 10 ppm molybdenum); (2) an unnamed tributary to the Dolores River from the southeast, 0.5 mi south of Bull Canyon (20 ppm silver, 50 ppm cadmium, 300 ppm copper, 500 ppm lead); (3) Leach Creek (10 ppm silver); (4) an unnamed tributary from the north to Coyote Wash, 1.5 mi west of its confluence with the Dolores River (200 ppm molybdenum); (5) an unnamed tributary from the west to the Dolores River, 1.2 mi north of Coyote Wash (20 ppm gold); (6) La Sal Creek (100 ppm silver, 300 ppm copper, 150 ppm lead); (7) an unnamed tributary from the west to La Sal Creek, 0.5 mi north of its confluence with the Dolores River (1 ppm silver); and (8) Wild Steer Canyon (30 ppm molybdenum, 500 ppm lead). These sites are scattered throughout the area and, with the exception of (4), (5), and (7), are downstream from known mines or prospects. Some of the above values are at or near the lower detection limit for emission spectrographic analysis (10 ppm molybdenum, 50 ppm cadmium) but are significant because of their association with other anomalous elements.

Site 5 above, the unnamed tributary from the west, 1.2 mi north of Coyote Wash, contained the only anomalous gold value (20 ppm) with no anomalous values for other elements. The tributary was sampled near its confluence with the Dolores River, and the anomaly may represent placer gold deposited by the Dolores. Visible gold was found at three locations between Bull Canyon and Coyote Wash by panning bench gravels along the Dolores River.

Two adjacent drainage basins at the west end of Davis Mesa, approximately 1.5 mi south of the town of Bedrock, contained anomalous values of tin (100 and 200 ppm) in heavy-mineral-concentrate samples which may have been derived from paleoplacer deposits.

Geophysics

Gravity and Aeromagnetic Data

Gravity and aeromagnetic studies were undertaken as part of the mineral resource evaluation of the Dolores River Canyon Wilderness Study Area. These studies provide information on the subsurface distribution of rock masses and the structural framework. The gravity and magnetic data are of a reconnaissance nature and are adequate only to define regional features.

Gravity data were obtained in and adjacent to the study area during 1987 to supplement data maintained in the files of the Defense Mapping Agency of the Department of Defense. Stations measured during the course of this study were established using a Worden gravimeter W–177.[1] The data were tied to the International Gravity Standardization Net 1971 (U.S. Defense Mapping Agency, Aerospace Center, 1974) at base station ACIC 4653–1 at Uravan, Colo. Station elevations were obtained from benchmarks, spot elevations, and estimates from topographic maps at 1:24,000 scale and are accurate to ±40 ft. The error in the Bouguer anomaly is less than 2.5 mGal (milligals) for errors in elevation control. Bouguer anomaly values were computed using the 1967 gravity formula (International Association of Geodesy, 1971) and a reduction density of 2.67 g/cm^3 (grams/cubic centimeter). Mathematical formulas are given in Cordell and others (1982). Terrain corrections were made by computer for a distance of about 100 mi from the station using the method of Plouff (1977). The data are shown in figure 3 as a complete Bouguer anomaly map with a contour interval of 5 mGal.

Magnetic data are from the U.S. Department of Energy (1983). Flight lines were flown east-west at 2- to 5-mi intervals and 400 ft above ground level. The data are shown on figure 4 as a residual magnetic intensity contour map with a contour interval of 20 nT (nanoteslas).

The gravity data in the region surrounding the study area are strongly influenced by the distribution of salt in the sedimentary rock section. Gravity lows occur over the Gypsum Valley anticline (fig. 3, A) and the Paradox Valley-Dry Creek anticline (fig. 3, B). A low of less than 5 mGal occurs over the southeastern end of the Pine Ridge anticline (fig. 3, C). The termination of the gravity low (fig. 3, C) and the absence of other lows within the boundary of the study area suggest that the salt probably does not exist beneath the study area. The southernmost and westernmost parts of the study area lie on the flank of the Gypsum Valley anticline, and the northeasternmost part of the study area lies on the flank of the Paradox Valley anticline, as the anticlines are defined by the gravity data.

The magnetic data are influenced by the Proterozoic crystalline rocks beneath the virtually nonmagnetic cover rocks. The plateau in the magnetic values shown in the northeast part of the map (fig. 4, A) is part of a larger magnetic high that extends approximately 20 mi to the northwest and is associated with the crystalline basement rocks. The magnetic gradient southwest of anomaly A and similar gradients in the southwestern part of the map area parallel the Uncompahgre uplift and suggest that basement rocks are offset by faults parallel to those bounding the uplift northeast of the mapped area. The magnetic gradients which define the distribution of

[1]Use of brand names in this report is for descriptive purposes only and does not constitute endorsement by the U. S. Geological Survey.

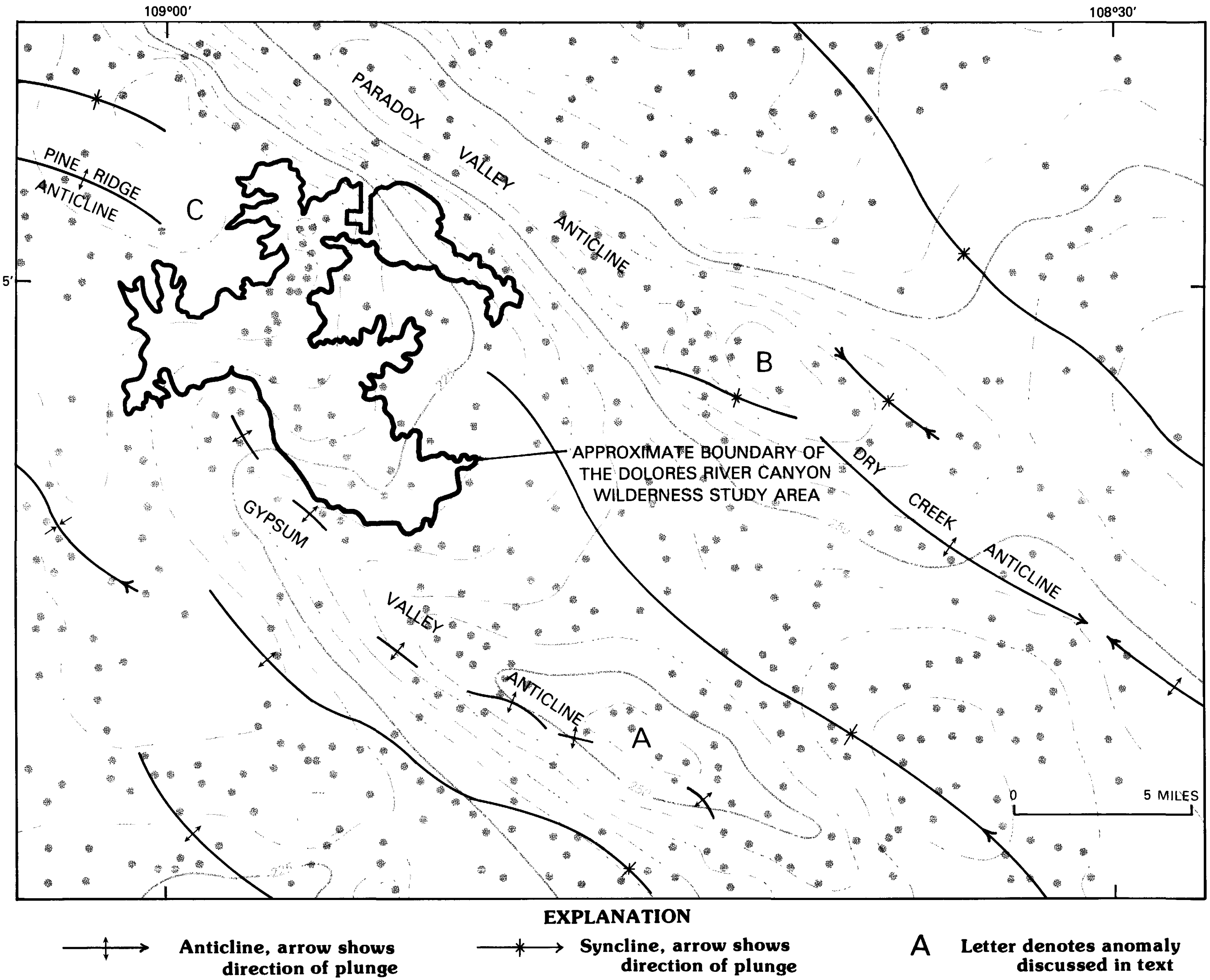


Figure 3. Complete Bouguer gravity anomaly and generalized structure map of the Dolores River Canyon Wilderness Study Area and adjacent areas . Contour interval 5 mGal. Station locations shown by dots. Structure adapted from Williams (1964).

basement rocks are generally coincident with the gravity gradients which define the salt-cored anticlines, suggesting that the location and (or) development of the anticlines may have been controlled by faults within the basement rocks.

Remote Sensing

Landsat Multispectral Scanner (MSS) imagery data provided the basis for a remote sensing investigation of the Dolores River Canyon Wilderness Study Area. The methods and results of this study are described in Lee (1988). The data were analyzed to target regional lineaments, hydrothermal alteration associated with mineralized rock, and limonite anomalies that may be associated with uranium deposits or hydrocarbon seepage.

The MSS data revealed no alteration or limonite anomalies. Lineament analysis showed that the study area lies near the southeastern end of a major lineament. This lineament coincides with a northwest-trending salt anticline structure typical of the region; the crestal graben of the anticline forms the Spanish Valley, 25 mi northwest of the study area.

Mineral and Energy Resources

Uranium

Sandstone-hosted uranium deposits, typical of the Colorado Plateau, are abundant in the Uravan mineral belt, where they occur most commonly in the Salt Wash Member of the Upper Jurassic Morrison Formation but also in the Moss Back Member of the Upper Triassic Chinle Formation. The Dolores River Canyon Wilderness Study Area is on the western edge of this mineral belt. Most of the known deposits are in the upper rim sandstone of the Salt Wash, although a few deposits have been found in lower rim sandstones. Both tabular and, less frequently, roll-type deposits are present in the Uravan mineral belt (Fischer, 1942; Shawe, 1956; Shawe and Granger, 1965). The roll-type deposits are the Uravan-type rolls described by Fischer (1970), not to be confused with roll-type deposits that occur in Wyoming and Texas (Austin and D'Andrea, 1978; Granger and Warren, 1979).

The Chinle Formation crops out along the bottom of the Dolores River Canyon at its north and south ends, but it is uncertain whether the Moss Back Member is present under the wilderness study area. No anomalous radiation was detected at any stream-sediment sampling sites along the bottom of the canyon. In the Slick Rock District, which is south of the study area, Shawe and others (1968) utilized well logs from an extensive drilling project to study the stratigraphy. They found that the Moss Back Member maintains a fairly constant thickness throughout the Slick Rock District, except where it pinches out on the flanks of the salt anticlines, and that in some of the drill holes core from the Moss Back contained uranium. D.R. Shawe (oral commun., 1987) suggests that the Moss Back Member may also exist in the subsurface beneath the Dolores River Canyon Wilderness Study Area and may include uranium deposits. However, it is uncertain whether the Moss Back is present beneath the study area, and it is equally uncertain whether, if present, it contains any uranium deposits. Thus, the mineral resource potential for uranium in the Chinle Formation is unknown, with certainty level A.

Peterson (1980) described favorable gray mudstones that are consistently and closely associated with ore-bearing sandstone beds in the Salt Wash Member of the Morrison Formation elsewhere on the Colorado Plateau. He noted that these favorable mudstones have also been found in the Salt Wash of the Paradox basin in western Colorado, where the most important depositional factor was a low-energy flow regime with conditions suited to the formation of lakes and ponds in which the mudstones could be deposited. Where the Morrison Formation caps the tablelands that surround the canyons of the study area, the formation is several hundred feet thick; the presence of uranium is confirmed by the myriad mines and claims that dot the mesa tops in the Salt Wash Member. However, because the study area boundary generally follows the canyon rim near the lower contact of the Morrison Formation, very little of the Salt Wash Member is included in the study area, and in many places even the lower rim of the Salt Wash is absent. The upper, potentially uranium-bearing sandstone probably occurs only above Wild Steer Canyon, at the west end of Davis Mesa and at the north edge of Skein Mesa (pl. 1). Foot traverses and air-photo study of these areas revealed no surface evidence of uranium occurrences, prospects, or mining activity, and no anomalous radioactivity was detected by scintillometer surveys. A single uranium anomaly was detected in stream sediments collected south of Bull Canyon downstream from several mines and prospects that are outside the study area in the Salt Wash Member. The lack of prospects and specific indicators of uranium deposits in the Morrison Formation where it extends into the study area, even though the surrounding countryside has been heavily prospected, suggests that the mineral resource potential for uranium in the Morrison is low, with certainty level C.

Gold

The only gold that has been produced near the wilderness study area came from the vicinity of the

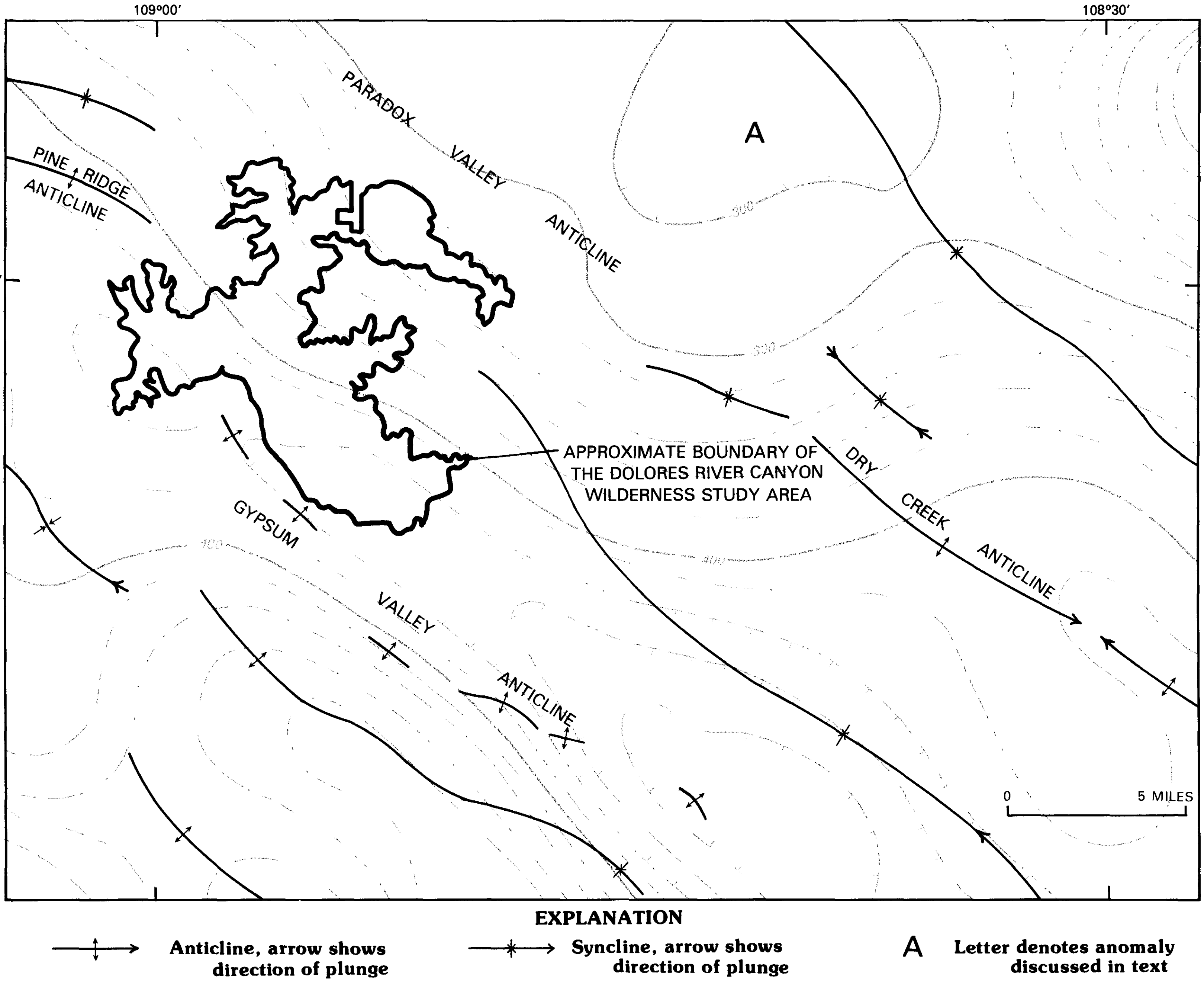


Figure 4. Residual magnetic intensity map and generalized structure map of the Dolores River Canyon Wilderness Study Area and adjacent areas. Contour interval 20 nT. Structure adapted from Williams (1964).

Cashin and Cliffdweller mines on La Sal Creek. The single anomalous gold value found in heavy-mineral-concentrate samples taken in the study area was from a site on the Dolores River upstream from the mouth of La Sal Creek. Visible gold was found at three locations between Bull Canyon and Coyote Wash by panning Dolores River stream sediments. Martin (1987) found both flour gold and visible flakes in gravel bars and stream terraces at the mouth of and downstream from La Sal Creek. These observations indicate a moderate resource potential for placer gold in the stream gravels of La Sal Creek and the Dolores River Canyon, with certainty level C.

Other Metals

No deposits of metals other than gold are known in the Dolores River Canyon Wilderness Study Area. None of the faults within the study area show evidence of the type of mineralized rock displayed just outside the boundary at the Cashin and Cliffdweller mines. Most of the anomalous metal values in geochemical samples reflect contamination from mines or prospects upstream from the sampling sites or, in the case of tin, probable paleoplacers; the remaining anomalies are too few and too isolated to be considered as evidence of metal deposits of another type. The study area is therefore regarded as having a low resource potential for other metals, with a level B certainty.

Oil and Gas

The Dolores River Canyon is underlain by sediments that are known to be hydrocarbon source beds and reservoirs, and, although no significant amounts of oil or gas have been discovered in the vicinity, virtually the entire study area is under lease for oil and gas (fig. 2; Martin, 1987). A well drilled just outside the study area south of the town of Bedrock during the spring of 1987 by the U.S. Bureau of Reclamation penetrated the Lower Permian Cutler Formation, Middle Pennsylvanian Hermosa Formation, and Lower Mississipian Leadville Limestone; these units are all known producers elsewhere in the region. This well produced a minor gas show (J.L. Jones, oral commun., 1987). Some gas production from recently drilled fields near the study area has come from Permian- and Pennsylvanian-age rocks in which structural traps developed against subsurface faults along the northeast limb of the Gypsum Valley anticline (Krivanek, 1981). Because little is known of the regional subsurface, Scott and Klipping (1981) suggested that an extensive seismic study be made to delineate subtle subsurface structures that do not coincide with surface structures and that may serve as hydrocarbon traps.

Spencer (1983) rated the Dolores River Canyon Wilderness Study Area as having a medium hydrocarbon potential. However, the present lack of information on the subsurface within the study area leaves open the question of oil and gas resources. The resource potential for oil and gas in the study area is therefore moderate, with certainty level B.

Coal

No coal occurrences are known in the study area. The Upper Cretaceous Dakota Sandstone, which contains the only known coal beds in the region, has been stripped away by erosion except high on the mesa tops outside the boundary. The study area is therefore regarded as having no resource potential for coal, with a certainty level of D.

Geothermal Energy

No geothermal resources are known within the study area; none were observed during the course of this appraisal. There are no volcanic rocks or other igneous rocks in the vicinity, and there is no known heat source for geothermal activity. Hot springs near Placerville and Dunton, Colo., about 45 mi southeast, are the nearest known geothermal waters (Pearl, 1980). The study area, therefore, has a low resource potential for geothermal energy, with certainty level C.

Industrial Minerals

The Paradox Member of the Hermosa Formation, which contains gypsum, anhydrite, salt, and potash elsewhere in the region, crops out at the southern end of the study area. Because no significant deposits were observed at the surface, the resource potential for these minerals in the outcrop area is low, with a certainty level C. Whether the Paradox Member and additional deposits of evaporites are present at depth beneath the study area is unknown; gravity data suggest that the salt core does not extend under the study area. Therefore, the resource potential for gypsum, anhydrite, salt, and potash in the remaining parts of the study area is unknown, with certainty level A.

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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

LEVEL OF RESOURCE POTENTIAL →

	A	B	C	D
	U/A UNKNOWN POTENTIAL	H/B HIGH POTENTIAL	H/C HIGH POTENTIAL	H/D HIGH POTENTIAL
		M/B MODERATE POTENTIAL	M/C MODERATE POTENTIAL	M/D MODERATE POTENTIAL
		L/B LOW POTENTIAL	L/C LOW POTENTIAL	L/D LOW POTENTIAL
				N/D NO POTENTIAL

LEVEL OF CERTAINTY →

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 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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