MINERAL RESOURCES OF THE MILL CREEK CANYON WILDERNESS STUDY AREA GRAND COUNTY, UTAH

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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 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 Mill Creek Canyon Wilderness Study Area, (UT-060-139A) Grand County, Utah.

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Abstract

At the request of the U.S. Bureau of Land Management, approximately 9,780 acres of the Mill Creek Canyon Wilderness Study Area (UT-060-139A) was evaluated for identified mineral resources (known) and mineral resource potential (undiscovered). In this report, the area studied is referred to as the "wilderness study area" or "the study area." Field work was conducted in 1988 to assess the mineral resources and resource potential of the area. No mineral resources were identified in the Mill Creek Canyon Wilderness Study Area. Placer gold is present in the eastern part of the study area but not in sufficient quantity to be considered a resource. Eolian sand and sandstone occur in the study area, but it is unlikely these will be developed. Oil and gas leases cover a small part of the study area; no geothermal resources are known to exist in the study area.

The entire study area has high potential for undiscovered mineral resources of potash and halite, and areas underlain by the Navajo Sandstone (Lower Jurassic) also have high potential for resources of flagstone. The top of Wilson Mesa also has high resource potential for small deposits of placer gold. The entire study area has moderate potential for resources of uranium, thorium, copper, vanadium, oil and gas, and carbon dioxide gas and has low potential for resources of helium gas and for geothermal energy.

Character and Setting

The Mill Creek Canyon Wilderness Study Area covers 9,780 acres of canyons and mesas in Grand County, Utah, 2 mi east of the town of Moab. The study area is bounded on the north by the dirt road that runs along the ridge between the North Fork of Mill Creek/Rill Creek drainage and Negro Bill Canyon. It is bounded on the south by Mill Creek and on the east by roads on Wilson Mesa. Access to the area is from U.S. Highway 191 on the southwest and from the Sand Flats Road on the north and east. In this semiarid region, vegetation on the mesas in the western parts of the study area consists of sagebrush and grasses; the steeper terrain in the east contains piñon pine and juniper with Mormon tea, sagebrush, squawbrush, and blackbrush. The study area is in the Paradox Basin fold and fault belt of the Colorado Plateau physiographic province. The exposed rocks consist of subhorizontal beds of Jurassic sandstone and minor amounts of shale and siltstone (see "Appendixes" for geologic time chart). The study area is on the northeastern limb of the Moab Valley-Spanish Valley salt anticline, which collapsed when the salt core was dissolved and removed by groundwater. Remaining evaporite deposits in the underlying strata may host deposits of potash, halite, oil, and gas.

Identified Mineral Resources

No mineral resources were identified in the Mill Creek Canyon Wilderness Study Area. Analyses of placer samples collected in and near the eastern part of the study area show traces of gold in detrital material. Eolian sand and sandstone in the study area may be suitable as foundry, fracturing, or filtering sand, but they are not likely to be developed because similar deposits are readily available elsewhere nearer possible markets. Oil and gas leases cover only a very small part of the study area. No geothermal resources are known to exist in the study area.

Mineral Resource Potential

Potash and halite are present in the Paradox Member (Middle Pennsylvanian) of the Hermosa Formation (Middle and Upper Pennsylvanian), which is present at depth within the study area. The entire area is therefore considered to have high mineral resource potential for potash and halite (fig. 2). The Navajo Sandstone (Lower Jurassic) is presently being quarried for flagstone for building materials in the lower reaches of Mill Creek outside the study area. The resource potential is high for additional flagstone in areas underlain by the Navajo Sandstone in the western part of the study area. Gold, which probably originated in the La Sal Mountains to the east, is present on Wilson Mesa in placer claims outside the study area; the host streams during the Pleistocene Epoch continued into the parts of the mesa that are within the study area. The top of Wilson Mesa, therefore, has high resource potential for small placer deposits of gold. Uranium is mined in nearby areas from the Cutler (Lower Permian), Chinle (Upper Triassic), and Morrison (Upper Jurassic) Formations. Also produced from these areas are vanadium from vanadium silicates and copper from chalcopyrite, bornite, and chalcocite. The Chinle, Cutler, and Morrison are present at depth in the study area, and it is possible that additional ore-bearing zones may be present within these three units. The entire study area, therefore, has moderate mineral resource potential for uranium, thorium, copper, and vanadium. No evidence of the presence of other metals related to deposition, structure, or intrusions was observed. Oil is produced in the region from the Paradox Member of the Hermosa Formation and from the Lower Mississippian Leadville Limestone, both of which are known to be present at depth beneath the study area. The same porous rocks that could contain oil and gas also could contain carbon dioxide gas and, less likely, helium gas. The resource potential is moderate for oil and gas and for carbon dioxide gas and is low for helium gas in the entire study area. No geothermal springs or wells were observed or are known to be present in the study area and no evidence of geothermal activity was seen. The National Oceanic and Atmospheric Administration (1980) reported that the regional heat flow over the area is low, and therefore the entire study area has low resource potential for geothermal energy.

INTRODUCTION

This mineral survey was requested by the U.S. Bureau of Land Management and is the result of a cooperative effort by the U.S. Geological Survey and the U.S. Bureau of Mines. An introduction to the wilderness review process, mineral survey methods, and agency responsibilities was provided by Beikman and others (1983). The U.S. Bureau of Mines evaluates identified resources at individual mines and known mineralized areas by collecting data on current and past mining activities and through field examination of mines, prospects, claims, and mineralized areas. Identified resources are classified according to a system that is a modification of that described by McKelvey (1972) and U.S. Bureau of Mines and U.S. Geological Survey (1980). U.S. Geological Survey studies are designed to provide a scientific basis for assessing the potential for undiscovered mineral resources by determining geologic units and structures, possible environments of mineral deposition, presence of geochemical and geophysical anomalies, and applicable ore-deposit models. Goudarzi (1984) discussed mineral assessment methodology and terminology as they apply to these surveys. See "Appendixes" for the definition of levels of mineral resource potential and certainty of assessment and for the resource/reserve classification.

Location and Physiography

The Mill Creek Canyon Wilderness Study Area is approximately 9,780 acres in size, and its western end is 2 mi east of the city of Moab, Utah (fig. 1). The terrain is generally steep and rugged; elevations range from about 7,300 ft near Wilson Mesa to about 4,800 ft at the mouth of Mill Creek canyon. Access to the area is by U.S. Highway 191 on the southwest and the Sand Flats Road on the north and east. Access within the area is by four-wheel-drive vehicle on the Mill Creek canyon jeep trail (Barnes, 1986), by mountain bicycle, and by foot. The climate is semiarid; mean annual precipitation of 10 to 15 in. falls mostly during thunderstorms that cause flash floods.

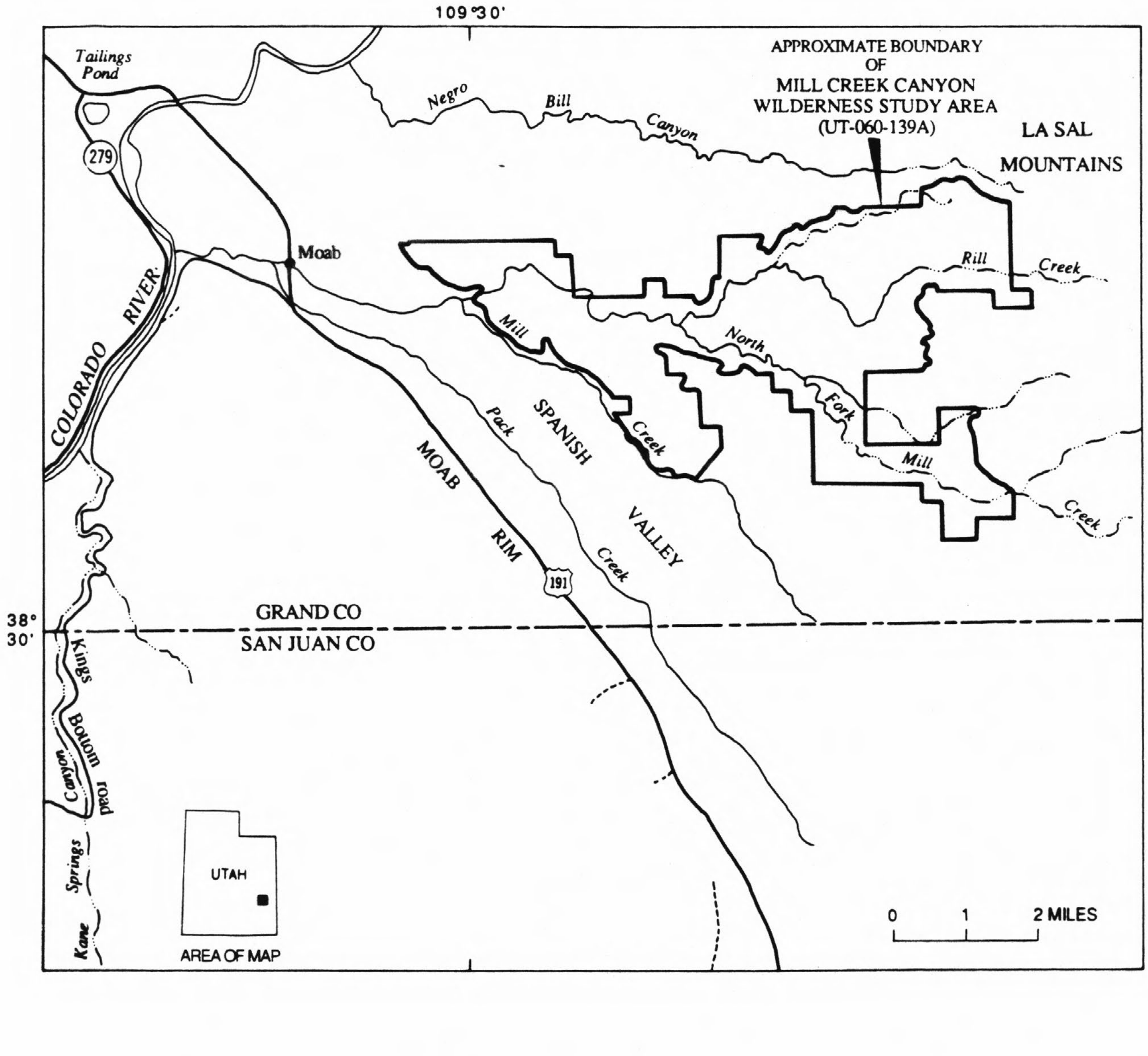

Figure 1. Index map showing location of Mill Creek Canyon Wilderness Study Area, Grand County, Utah.

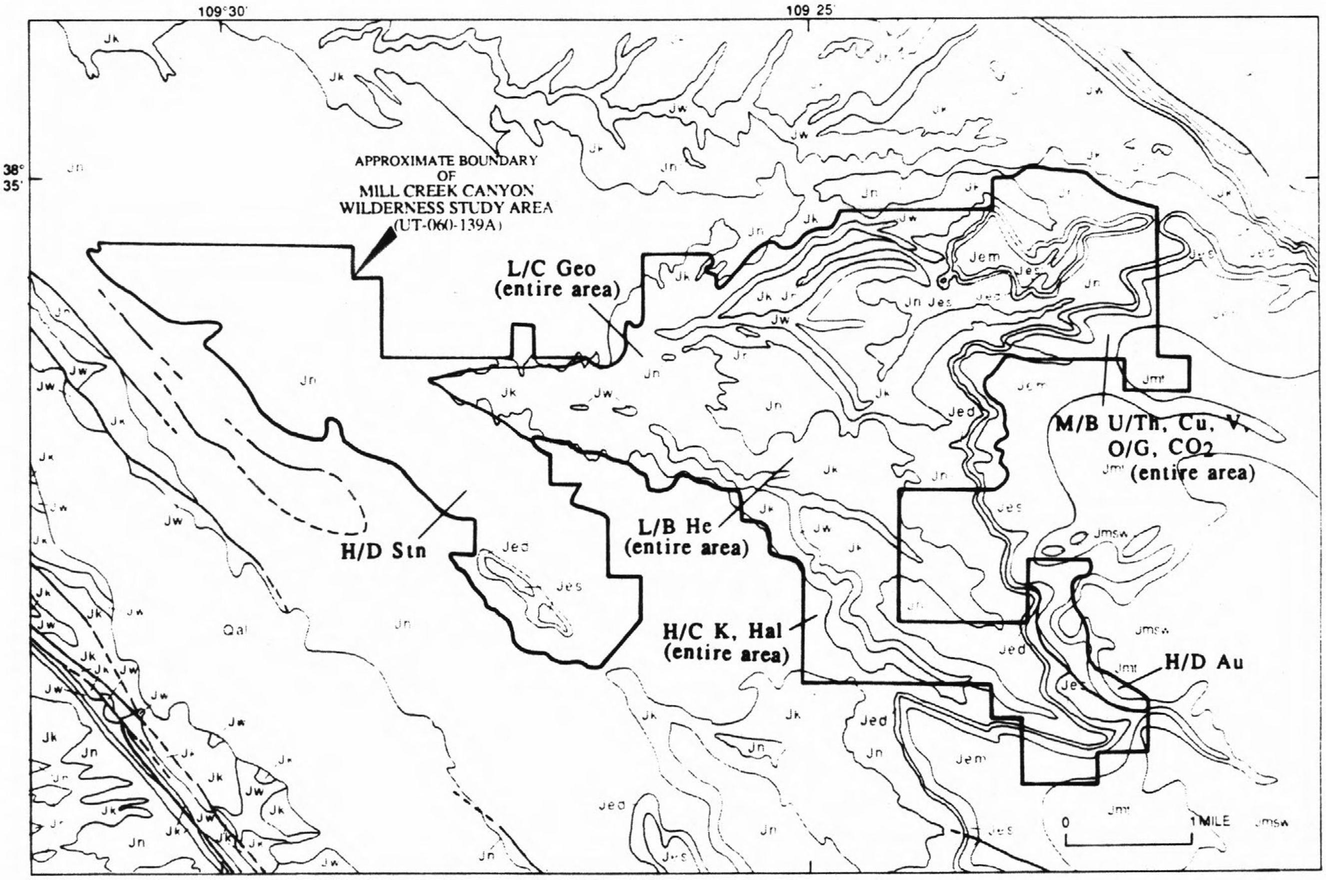

Figure 2. Mineral resource potential and generalized geology of Mill Creek Canyon Wilderness Study Area, Grand County, Utah. Geology modified from Baker (1933).

EXPLANATION

[box symbol]	Area having high mineral resource potential (H) for stone and (or) potash and halite, where indicated and moderate mineral resource potential (M) or low mineral resource potential (L) for commodities as indicated

Certainty of Assessment

B	Data only suggest level of potential
C	Data give good indication of level of potential
D	Data clearly define level of potential

Commodities

Au	Placer gold
CO_2	Carbon dioxide gas
Cu	Copper
Geo	Geothermal energy
Hal	Halite
He	Helium gas
K	Potash
O/G	Oil and gas
Stn	Building stone
U/Th	Uranium and thorium
V	Vanadium

DESCRIPTION OF MAP UNITS

Qal	Alluvium (Quaternary)--Alluvial fan deposits and stream deposits of gravel, sand, silt, and clay
Jmsw	Morrison Formation, Salt Wash Member (Upper Jurassic)--Massive, fine-grained sandstone
Jmt	Morrison Formation, Tidwell Member (Upper Jurassic)--Red shale and siltstone
Jem	Entrada Sandstone, Moab Tongue (Middle Jurassic)--Massive, white, medium-grained friable sandstone
Jes	Entrada Sandstone, Slick Rock Member (Middle Jurassic)--Massive, cross-bedded, banded, orange and white sandstone
Jed	Entrada Sandstone, Dewey Bridge Member (Middle Jurassic)--Red siltstone and shale
Jn	Navajo Sandstone (Lower Jurassic)--Fine- to medium-grained, cross-bedded quartz sandstone
Jk	Kayenta Formation (Lower Jurassic)--Sandstone with minor conglomerate, siltstone, limestone, and shale
Jw	Wingate Sandstone (Lower Jurassic)--Fine-grained, quartzose, cross-bedded calcareous sandstone
Pc	Cutler Formation, undivided (Lower Permian)--Cherty chalky limestone, siltstone, anhydrite, claystone, conglomerate, and massive, crossbedded arkosic sandstone interbedded with lenses of siltstone and sandy shale
[line symbol]	Contact--Dashed where approximately located
[line symbol]	Fault--Dashed where inferred

Figure 2. Continued

Vegetation on the mesas in the western parts of the study area consists of sagebrush and grasses; sagebrush (*Artemisia tridentata*) is the dominant species. The higher elevations to the east, including all ridges and canyons, are vegetated with a piñon-juniper climax community that consists of juniper (*Juniper utahensis*, *J. scopulorum* et spp.) and piñon pine (*Pinus edulis* et spp.). The zones between wooded areas support sparse grass, herbs, and small shrubs including Mormon tea (*Ephedra* sp.), sagebrush, blackbrush (*Coleogyne* sp. and *Ceanothus greggi*), and squawbrush (*Rhus trilobata*). Yucca (*Yucca* sp.) and cacti, including pricklypear (*Opuntia* sp.), are common.

Procedures

The U.S. Geological Survey conducted detailed field investigations of the Mill Creek Canyon Wilderness Study Area in the summer of 1988. This work included making a detailed geologic map at the scale of 1:24,000, collecting geochemical and petrologic samples, and examining outcrops for evidence of mineralization. The generalized geology of the study area (fig. 2) is modified from Baker (1933).

U.S. Bureau of Mines personnel reviewed literature concerning mining and geology of the region. In addition, U.S. Bureau of Land Management records were reviewed for mining claim information and oil and gas leases and lease applications.

In September 1988, two U.S. Bureau of Mines geologists spent 11 days conducting a field examination in and within 1 mi of the study area. Surface workings and selected outcrops were sampled. A total of 7 samples was collected during the field investigation; five samples (MCC 3-7) were collected inside the study area and two (MCC 1-2) were collected just outside the east boundary. One sandstone sample (MCC 3) was analyzed for characteristics necessary for its use as an industrial material. The remaining samples were analyzed by neutron activation for 34 elements including gold and silver. Bondar-Clegg and Company, Lakewood, Colo., conducted the analyses.

Previous Studies

Overview geologic reports of the region and of nearby areas include Hintze's (1980) geologic map of Utah, geologic maps of Arches National Park (Doelling, 1985; Lohman, 1975; Baars, 1983b), and geologic maps of Canyonlands National Park (Huntoon and others, 1982; Baars, 1983b). Other geologic reports on the region include those by McKnight (1940), Hemphill (1955), Baars (1983a), and Stokes (1969; 1987); geologic reports of local interest were published by Barnes (1978) and Vreeland (1976a, b). Reports on the stratigraphy include those by Stewart and others (1972a, b), Richmond (1962), and Padian (1989).

Geophysical studies in the area include those by Byerly and Joesting (1959), Case and Joesting, (1972), Case and others (1963), Joesting and others (1966), and Hildenbrand and Kucks (1983). Structural geology of the area was studied by Hunt (1958), Williams (1964), and Baars and Doelling (1987).

Mineral and energy resources papers on the area include those by Baker (1933), Baker and others (1952), Williams (1964), Baars (1966), Dolton and others (1981), Molenaar and others (1982), and Molenaar and Sandberg (1983). Nearby wilderness study areas for which mineral resources papers have been published include Lost Spring Canyon Wilderness Study Area 25 mi to the north (Soulliere and others, 1988; Gese, 1987), Negro Bill Canyon Wilderness Study Area just to the northeast (Bartsch-Winkler and others, 1990), and Behind The Rocks Wilderness Study Area 5 mi to the southwest across Spanish Valley (Patterson and others, 1988; Thompson, 1988).

Land-use management reports that pertain to the study area include the Resource Management Plan (U.S. Bureau of Land Management, 1985a) and its final environmental impact statement (U.S. Bureau of Land Management, 1983) as well as the statewide wilderness report (draft) (U.S. Bureau of Land Management, 1985b).

Acknowledgments

The authors greatly appreciate the cooperation of Peter Christensen, Lynn Jackson, Brent Northrup, Terry McParland, David Minor, Max Day, and Russell Van Koch of the U.S. Bureau of Land Management who gave support and use of their facilities. Fran Barnes provided information on local field conditions and access. Christine Turner-Peterson helped by discussing uranium resources. Information supplied by Philip Gramlich of Moab concerning gold occurrences in alluvium along the east boundary of the study area is greatly appreciated.

APPRAISAL OF IDENTIFIED RESOURCES

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Mining History

No signs of mining activity were found in the Mill Creek Canyon Wilderness Study Area; two small pits are adjacent to the east boundary. The nearest mining district is about 7 mi northeast of the study area in the La Sal Mountains. Lode mining claims extend into the western part of the study area. Placer claims along Mill Creek cover a large part of the study area (Lane, 1989).

Appraisal of Sites Examined

Gold was detected in six samples from detrital material that consists of alluvial gravels and eolian sand and silt along the east edge of the Mill Creek Canyon Wilderness Study Area. Sample MCC 1 contains 675 parts per billion (ppb) gold (0.020 ounces per short ton, oz/st) and sample MCC 4 contains 575 ppb gold (0.017 oz/st). The other samples contain between 14 and 86 ppb gold. These gravels are only present along the east edge of the study area, and significant concentrations of gold are not likely to be present elsewhere (Lane, 1989). The gold-bearing gravels are between 6 in. and 30 ft thick (Philip Gramlich, oral commun., 1988) and extend about 1,000 ft between the east boundary and the canyon rim. Detailed measurements of the thickness of the gravels by trenching or drilling would be required to determine if gold resources are present. Eolian sand deposits are abundant in the study area (Richmond, 1962) but are not considered economic because similar deposits occur closer to possible markets.

A sandstone sample (MCC 3) collected in the study area was determined to be protoquartzite (containing 75-95 percent silica, SiO_2). This sandstone is not suitable as glass sand because the SiO_2 content is too low and the amounts of iron (FeO_2) and aluminum (Al_2O_3) oxides are too high (Lane, 1989). Glass sand generally requires an SiO_2 content of at least 93 to 99 percent, an FeO_2 content of 0.06 percent or less, and an Al_2O_3 content between 0.1 and 0.5 percent (Bates, 1960; Coope and Harben, 1977). Sand to be used as foundry sand requires an SiO_2 content of at least 88 percent (Coope and Harben, 1977).

Sandstone in the Mill Creek Canyon Wilderness Study Area may be suitable for use as foundry, fracturing, or filtering sand; however, characteristics for these uses vary. The sandstone is unlikely to be developed because similar deposits occur nearer to possible markets.

Energy Resources

The study area is in a terrane rated as having medium potential for the occurrence of oil and gas (Molenaar and Sandberg, 1983). Oil and gas leases cover a very small part of the study area. The region was investigated thoroughly for uranium occurrences during the uranium boom of the 1950's; no uranium occurrences were found. No geothermal activity is known in the wilderness study area.

Conclusions

No mineral resources were identified in the Mill Creek Canyon Wilderness Study Area. Analysis of the samples collected in and near the study area show gold in detrital material in the eastern part. Additional field work including possible trenching or drilling is needed to determine if a resource exists.

Eolian sand and sandstone occur in the study area and may be suitable as foundry, fracturing, or filtering sand. It is unlikely these will be developed because similar deposits are readily available elsewhere nearer possible markets.

Oil and gas leases cover only a very small part of the study area. No geothermal resources are known to exist in the study area.

ASSESSMENT OF MINERAL RESOURCE POTENTIAL

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Geology

The Mill Creek Canyon Wilderness Study Area is within the Paradox Basin fold and fault belt of the Colorado Plateau physiographic province. It is underlain by the northeastern limb of the Moab Valley-Spanish Valley salt anticline that collapsed when the upper part of the salt core was dissolved and removed by groundwater (Baars and Doelling, 1987). The rock units exposed within the study area consist mainly of subhorizontal beds of Jurassic sandstone and minor amounts of shale and siltstone (fig. 2). Sedimentary rock units as old as Cambrianmay underlie the area at depth. The Precambrian basement beneath the study area is probably about 7,000 ft below sea level.

Stratigraphy

Although no rock units older than Early Jurassic crop out within the study area, older subhorizontal rocks crop out in the general region and (or) underlie the study area at depth. The oldest of these rocks are Precambrian igneous and metamorphic basement rocks. The oldest strata overlying the basement rocks consist of Cambrian quartzite and shale, Devonian limestone, dolomite, siltstone, shale, and sandstone, and Mississippian limestone and dolomite. The Cambrian rocks consist of the Ignacio Quartzite and Ophir Shale. The Devonian rocks consist of the Aneth and Elbert Formations and the Ouray Limestone (Gustafson, 1981). The Aneth is a dark-gray siltstone that includes lighter-colored dolomites and is as thick as 200 ft. The Elbert consists of a basal sandstone and an upper dolomite, green and red shale, and sandstone; the combined thickness is as much as 600 ft. The Ouray is a massive limestone and dolomite that has some thin green shale and is as thick as 150 ft. The Lower Mississippian Leadville Limestone is a light-colored limestone and dolomite that is as thick as 1,000 ft where Late Mississippian to Early Pennsylvanian erosion has left it intact (Gustafson, 1981).

The oldest of the post-Mississippian rocks, the Paradox Member of the Middle and Upper Pennsylvanian Hermosa Formation, is exposed near the study area (fig. 2). The Paradox Member consists of salts, anhydrite, and gypsum interbedded with black shales (Baars, 1983b). It ranges in thickness from 0 to 10,000 ft. This unit is being mined for potash by solution methods down river from Moab.

Permian rocks in the region are represented by the Cutler Formation (Lower Permian) and equivalent units; uranium has been mined from units within the Cutler. The Elephant Canyon Formation (equivalent to the lower part of the Cutler) consists of gray, cherty, chalky limestone, blue-gray siltstone, and thin beds of anhydrite. It ranges in thickness from 400 to 1,500 ft. The Cutler Formation contains the Halgaito Tongue, Cedar Mesa Sandstone Member, Organ Rock Shale Member, and White Rim Sandstone Member. The Halgaito consists of reddish-brown and purple arkosic sandstone, red siltstone, claystone, and conglomerate and ranges in thickness from 400 to 700 ft. The Cedar Mesa Sandstone Member consists of white to pale-reddish-brown, massive, crossbedded sandstone interbedded with lenses of red, gray, green, and brown sandstones. It ranges in thickness from 200 to 1,200 ft. The Organ Rock Shale Member consists of reddish-brown siltstone and sandy shale and ranges in thickness from 250 to 400 ft. The White Rim Sandstone Member consists of light-gray to yellowish-gray, fine-grained, crossbedded sandstone as thick as 250 ft. It forms overhanging cliffs in Canyonlands National Park southwest of the study area (Baars, 1983b).

Triassic rocks are exposed nearby but are present only at depth beneath the study area and consist of the Moenkopi Formation (Lower and Middle? Triassic) and the Chinle Formation (Upper Triassic) (O'Sullivan and MacLachlan, 1975). The Moenkopi Formation includes the Hoskinnini Member, an unnamed lower slope-forming member, the Sinbad Limestone Member, a ledge-forming member, and an upper slope-forming member. The Moenkopi generally consists of reddish-brown, evenly bedded, ripple-marked, cross-laminated siltstone and fine-grained sandstone. It ranges in thickness from 200 to 500 ft. The Chinle Formation locally includes the Moss Back Member, Petrified Forest Member, Owl Rock Member, and Church Rock Member. The Chinle Formation generally consists of variegated red, purple, green, and yellow bentonitic-clay-rich sandstone and siltstone. Uranium has been mined from this formation.

The oldest rocks exposed at the surface within the study area are Jurassic in age and are about 900 ft thick. The oldest Jurassic units are in the Lower Jurassic Glen Canyon Group (Pipiringos and O'Sullivan, 1978), which includes the Wingate Sandstone, the Kayenta Formation, and the Navajo Sandstone. The Wingate is a reddish-brown, massive, cross-bedded, fine-grained, well-sorted sandstone that ranges in thickness from 30 to 435 ft. The uppermost part of the Wingate Sandstone is exposed in creek bottoms in the central part of the study area. This unit appears to be particularly resistant to erosion, so that its gentle westward dip tends to determine the gradient of the lower reaches of the creeks. Above the Wingate is the Kayenta Formation, which consists of reddish-brown to lavender, fine- to medium-grained sandstone with minor amounts of conglomerate, siltstone, limestone, and shale. It ranges in thickness from 200 to 260 ft. Padian (1989) reported fossils of the dinosaur Scelidosaurus (Jurassic) in the Kayenta from northern Arizona. The Kayenta is overlain by the Navajo Sandstone, a buff to pale-orange, well-sorted, fine- to medium-grained, cross-bedded sandstone that is about 300 ft thick. This unit is quarried for flagstone just west of the study area near Moab.

Overlying the Glen Canyon Group is the Entrada Sandstone (Middle Jurassic) that ranges in thickness from 225 to 350 ft and contains three members: the Dewey Bridge Member, Slick Rock Member, and Moab Tongue. The Dewey Bridge Member is a red siltstone and shale; the Slick Rock Member is a salmon to white, fine-grained, cross-bedded, sandstone; and the Moab Tongue is a massive, white, medium-grained, friable sandstone.

Unconformably overlying the Entrada Sandstone is the Upper Jurassic Morrison Formation, which locally has three members. Only the lower two, the Tidwell and Salt Wash Members, are present in the study area. The Tidwell Member consists of reddish-brown, thin-bedded, ripple-laminated, muddy sandstone and siltstone that ranges in thickness from 20 to 90 ft. The Salt Wash Member is a massive fine-grained sandstone, but only a thin remnant of it remains on top of the plateaus in the eastern part of the study area. Uranium has been mined from the Salt Wash Member elsewhere, but no uranium was detected in this unit within the study area. Younger strata are not present in the study area due to erosion.

Quaternary deposits in the area consist of alluvium and talus. Along streams these sediments are poorly sorted mixtures of clay, silt, sand, and gravel. On the plateaus in the eastern part of the study area, they include talus, alluvial fans, and fluvial deposits. Stream deposits on the east side of the study area were eroded from granitic rocks in the La Sal Mountains to the east and include local gold placers.

Structure

The Precambrian basement in the region of the study area was transected by northwest-trending faults and rifts about 1,700 Ma. Cambrian through Mississippian strata were deposited in low-lying parts of the region. In Pennsylvanian time, the Uncompahgre Highland was uplifted east of the study area, and the adjacent Paradox basin held a sea into which sediments including salt were deposited. Accumulating clastic overburden from the east caused the salt to flow against the basement structures and upward along the basement fault blocks to form salt anticlines (Elston and others, 1962). Subsequent diapirism caused the salt to rise as much as 10,000 ft. The overlying strata collapsed when 3,000 to 6,000 ft of the evaporites were dissolved and removed by the action of groundwater (Baars and Stevenson, 1981). Moab Valley and Spanish Valley were formed by the collapse of the Moab Valley-Spanish Valley salt anticline, and Castle Valley was formed by the collapse of the Castle Valley salt anticline.

Geochemistry

Methods and Background

A reconnaissance geochemical survey was conducted in Mill Creek Canyon Wilderness Study Area during May 1988 to aid in the mineral resource assessment. Minus-80-mesh stream sediments, heavy-mineral panned concentrates derived from stream sediments, and rocks were selected as sample media. Stream-sediment samples represent a composite of rock and soil exposed in the drainage basin upstream. Their analysis provides information that helps identify those basins containing unusually high concentrations of elements that may be related to mineral occurrences. Chemical analysis of heavy minerals concentrated from stream sediments provides information about the chemistry of certain high-density, resistant minerals eroded from rocks exposed in the drainage basin upstream. The removal of most of the rock-forming silicates, clays, and organic material allows determination of some elements in the concentrate that are often not detectable in bulk stream sediments by the analytic methods available. Some of these elements can be constituents of minerals related to ore-forming processes.

Four rock samples were collected to provide information on geochemical background concentrations and to check for possible mineralization. Visibly altered and mineralized samples that might disclose suites of elements associated with mineralization were not found.

Bulk stream-sediment and heavy-mineral-concentrate samples were collected from active alluvium from 19 first- or second-order ephemeral streams within drainage basins ranging from 0.2 to 2.0 mi^2 in area. Sample-collection sites were selected in Mill Creek, North Fork of Mill Creek, Rill Creek, Burkholder Draw, and their tributary streams.

Sample Analysis

Stream-sediment, heavy-mineral-concentrate, and rock samples were all analyzed using a semiquantitative emission spectrographic method (Grimes and Marranzino, 1968) for the following 37 elements: antimony, arsenic, barium, beryllium, bismuth, boron, cadmium, calcium, chromium, cobalt, copper, gallium, germanium, gold, iron, lanthanum, lead, magnesium, manganese, molybdenum, nickel, niobium, palladium, phosphorous, platinum, scandium, silver, sodium, strontium, thorium, tin, titanium, tungsten, vanadium, yttrium, zinc, and zirconium.. In addition, stream-sediment and rock samples were analyzed for antimony, arsenic, bismuth, cadmium, gold, thorium, uranium, and zinc by specific chemical and instrumental methods (Centanni and others, 1956; Thompson and others, 1968; Motooka and Grimes, 1976; O'Leary and Meier, 1986; Crock and others, 1987). Analytical data, locations of sample-collection sites, analysis method references, detection limits, and a detailed description of the sampling and analytical techniques are given in a report by Bullock and others (1990).

Results and Interpretation

Anomalous values, defined as being above the upper limit of normal background values, were determined for each element by inspection of the analytical data rather than by statistical techniques. A small number of samples (14 stream sediments and heavy-mineral concentrates and 4 rocks) were collected, and many elements had only a few measurable occurrences. For some elements (silver, gold, molybdenum, tin, tungsten) any occurrence above the detection limit would be considered anomalous.

The Jurassic sedimentary rocks exposed in the study area are barren, and the geochemical survey did not disclose any near-surface metallic mineralization. Only two heavy-mineral-concentrate samples contain anomalous concentrations of elements; both are from sites outside the wilderness study area. The concentrate from site NB035 contains 100 parts per million (ppm) gold. This site is at the head of the North Fork of Mill Creek and the site of a recent gold-placer operation. It is approximately 0.5 miles east of the wilderness study area in the Manti-La Sal National Forest. A second concentrate contains minor amounts of copper (70 ppm) and lead (1,000 ppm). This site, NB037, is at the head of a tributary to Burkholder Draw and east of the road on Wilson Mesa. No stream-sediment or rock samples from within the study area contain anomalous concentrations of elements.

Geophysical Studies

By combining data from deep drill holes and depth estimates from aeromagnetic data, a map was prepared that shows schematic contours of the Precambrian basement in the region including the Mill Creek Canyon Wilderness Study Area (fig. 3; Bartsch-Winkler and others, 1990, fig. 4; Case and Joesting, 1972). Southwest of the Moab Valley-Spanish Valley anticline, drill holes bottomed in Mississippian to Cambrian strata at depths ranging from 1,515 to 2,520 ft below sea level; a drill hole in the Spanish Valley salt anticline bottomed in Mississippian rocks at 3,523 ft below sea level. A drill hole just north of the study area bottomed in Devonian rocks at 5,882 ft below sea level, and a drill hole on the northeast flank of Castle Valley salt anticline penetrated about 3,000 ft of evaporites and bottomed in Cambrian strata at 6,905 ft below sea level.

Because the deep Mississippian to Cambrian stratigraphy is relatively well known from many drill holes to the south and west, it is possible to estimate the elevation of the Precambrian surface. Thickness of Mississippian to Cambrian strata in the Lisbon Valley area, 30 mi southeast of the study area, ranges from 1,675 to 1,855 ft. The Precambrian surface dips northwestward in the region at depths of 3,000 to 10,000 ft below sea level (fig. 3). In the study area, the Precambrian basement is probably about 7,000 ft below sea level.

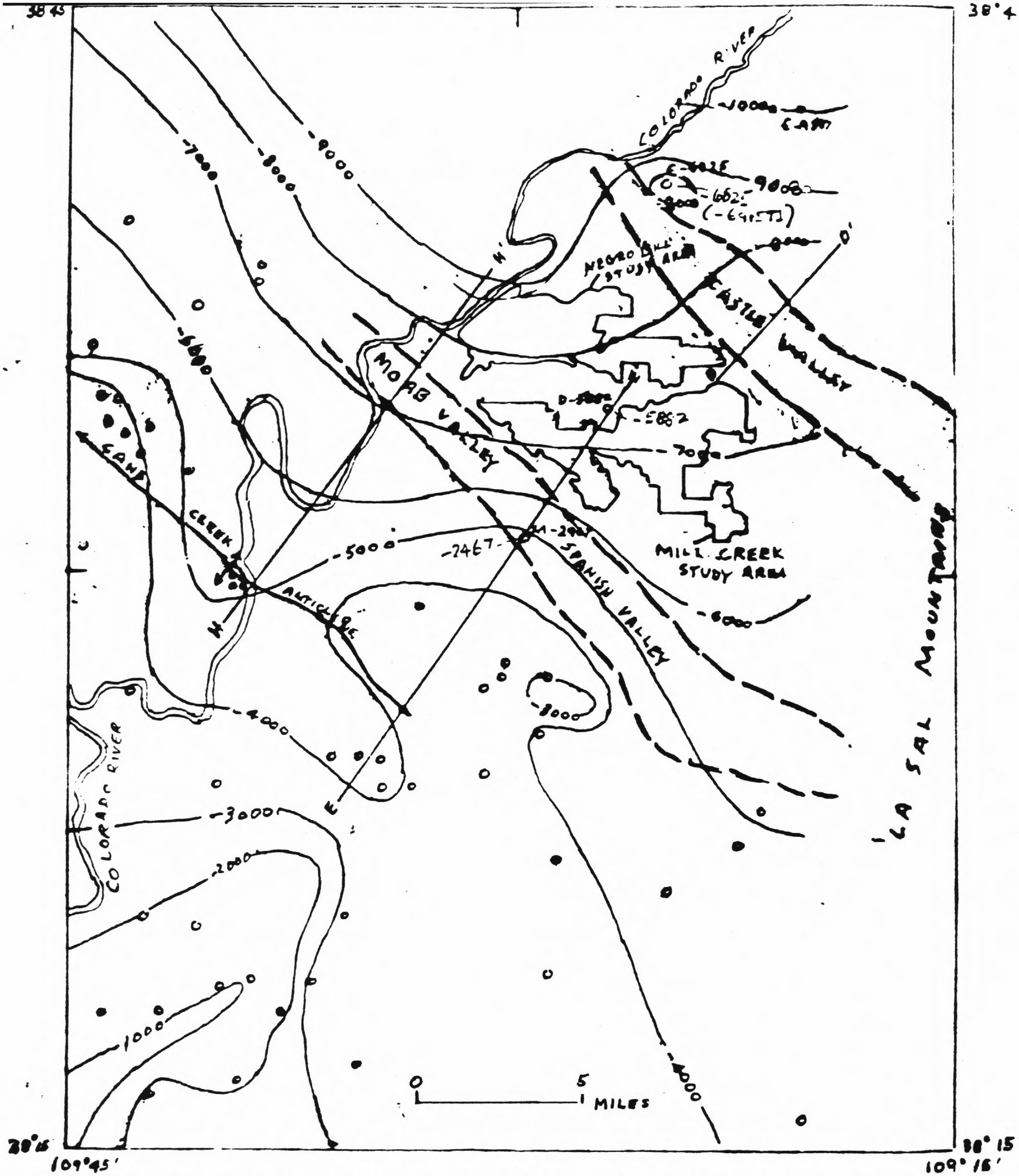

Figure 3. Schematic contours on Precambrian surface in vicinity of Mill Creek Canyon Wilderness Study Area, Utah. Circles indicate drill holes that bottomed in Pennsylvanian or older rocks (Case and Joesting, 1972). Numbered circles indicate bottom depth of holes and age of rocks at bottom: Ꞓ, Cambrian; M, Mississippian; D, Devonian. Contour interval 1,000 ft, datum is mean sea level. Heavy dashed lines show approximate boundaries of salt anticlines. *E-E'* is line of section for fig. 6; *D-D'* and *H-H'* are lines of section for gravity models in Case and Joesting (1973) and Bartsch-Winkler and others (1990).

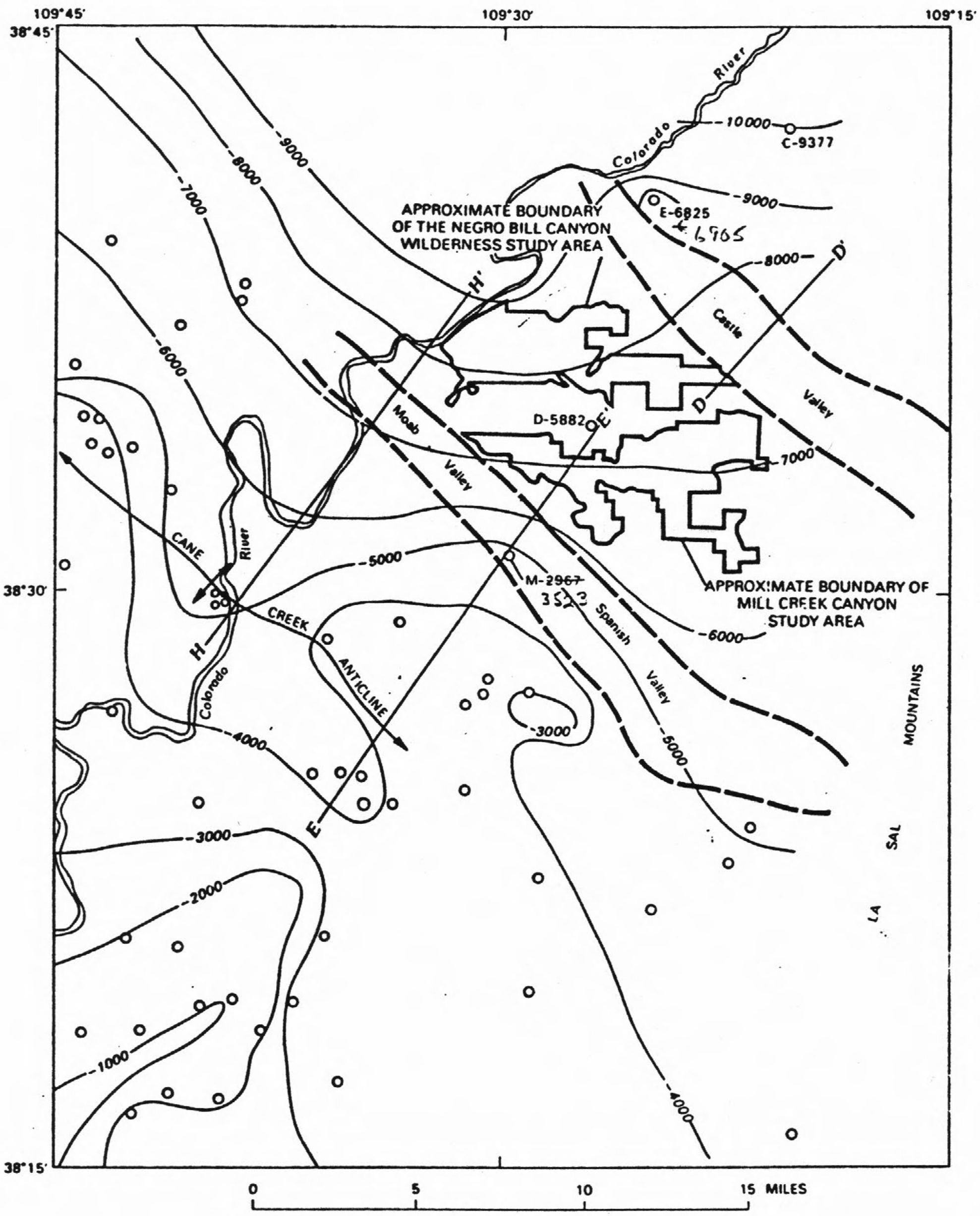

Figure 4. Residual total-intensity aeromagnetic map of vicinity including Mill Creek Canyon Wilderness Study Area, Utah. Contour interval 10 gammas. Hachures indicate closed areas of lower magnetic intensity. Original magnetic data were continued mathematically upward to elevation of 12,500 ft. From Hildenbrand and Kucks (1983) and Patterson and others (1988).

The well on the southwest flank of Spanish Valley penetrated about 5,800 ft of the Paradox Member of the Pennsylvanian Hermosa Formation, presumably evaporites with some shale and limestone, above Mississippian strata.

Aeromagnetic Data

Aeromagnetic surveys over the Mill Creek Canyon Wilderness Study Area and vicinity were flown at two different flight elevations: the eastern part was flown at an elevation of about 12,500 ft, flightline spacing about 1 mi (Case and others, 1963). The western part was flown at an elevation of about 8,500 ft, flightline spacing about 1 mi (Joesting and others, 1966). Four flightlines cross the study area. Subsequently, the magnetic data in the western part were continued mathematically upward to 12,500 ft, and a map was prepared (fig. 4; Hildenbrand and Kucks, 1983).

Anomalies on the original map, flown at 8,500 ft, diminish somewhat in amplitude when continued upward to 12,500 ft, but they retain their shapes. Comparison of figures 3 and 4 shows the intrabasement (Precambrian) origin for most of the magnetic anomalies of the region. High-amplitude, steep-gradient anomalies in the eastern part of figure 4 are produced by the Late Cretaceous-early Tertiary laccolithic intrusions of the La Sal Mountains. No sources of magnetic anomalies in the Phanerozoic sedimentary sequence have been identified.

The magnetic field is relatively smooth over the study area itself: contours show a south-plunging positive nose over the central part of the study area and negative re-entrants over the eastern and western parts of the area. Values increase northward by 20 to 30 gammas across the study area. These magnetic features are probably related to a much larger closed magnetic high about 12 to 15 mi northeast of the study area. This high is most likely produced by a very deep (10,000 ft below sea level, or more) magnetic body within the Precambrian basement.

Gravity Data

Few gravity stations were established in the study area, but stations north and south of the area provide control on the regional gravity anomaly field and trends of anomalies across the study area (fig. 5). The gravity data were reduced assuming a reduction density of 2.5 grams per cubic centimeter (g/cm^3); terrain corrections were calculated to a distance of 4.1 mi or farther. Details are provided in reports by Case and others (1963), Joesting and others (1966), and Hildenbrand and Kucks (1983). Gravity anomalies are regarded as accurate to about 2 milligals (mGal) with respect to the local base network.

The southwest side of the study area parallels the edge of relative negative anomalies over the northeastern part of the Spanish Valley salt anticline; the eastern part of the study area coincides with part of a positive gravity nose between the northwest-trending lows over the Castle Valley and Moab Valley-Spanish Valley salt anticlines. Two-dimensional gravity models were previously constructed along two lines near the study area: one line 2 mi northwest of the study area crosses the Moab Valley salt anticline, and the other starts at the north edge of the study area and crosses the Castle Valley salt anticline (Bartsch-Winkler and others, 1990, fig. 6; Case and Joesting, 1972). The salt core of the Moab Valley salt anticline has a vertical amplitude of about 9,000 ft on the model, assuming a mean density contrast of minus 0.35 g cm^{-3} between the salt and the adjacent strata. Subsequent drill data suggest that the amplitude varies from about 6,000 to 8,000 ft. The amplitude of the salt core of Castle Valley anticline is about 8,000 ft, assuming a density contrast of minus 0.3 g cm^{-3}.

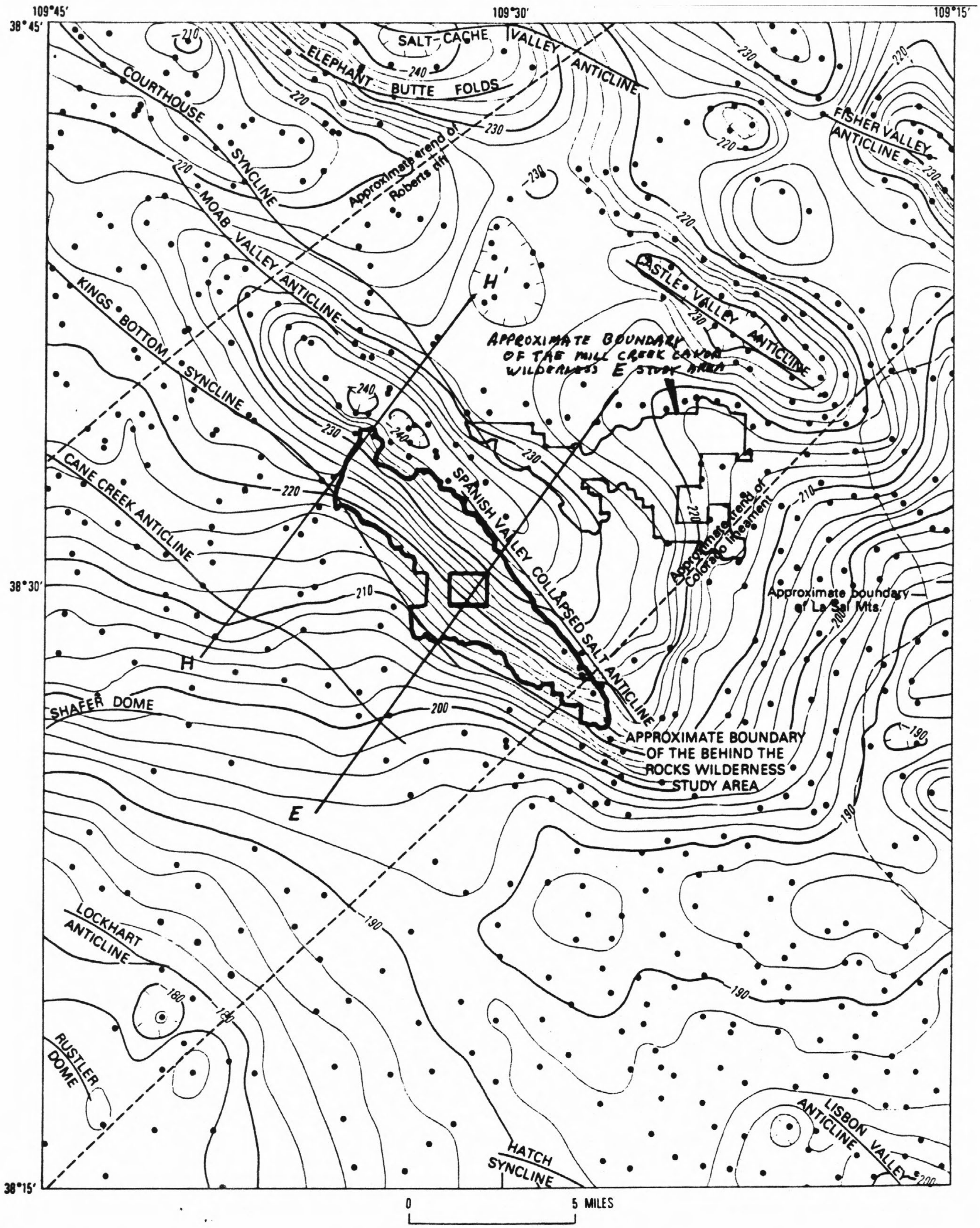

Figure 5. Bouguer anomaly map of region including Mill Creek Canyon Wilderness Study Area, Utah. Contour interval 2 milligals. Hachures show closed areas of lower gravity values. Dots indicate locations of gravity stations. Some surficial structural features are shown. Modified from Hildenbrand and Kucks (1983) and Patterson and others (1988).

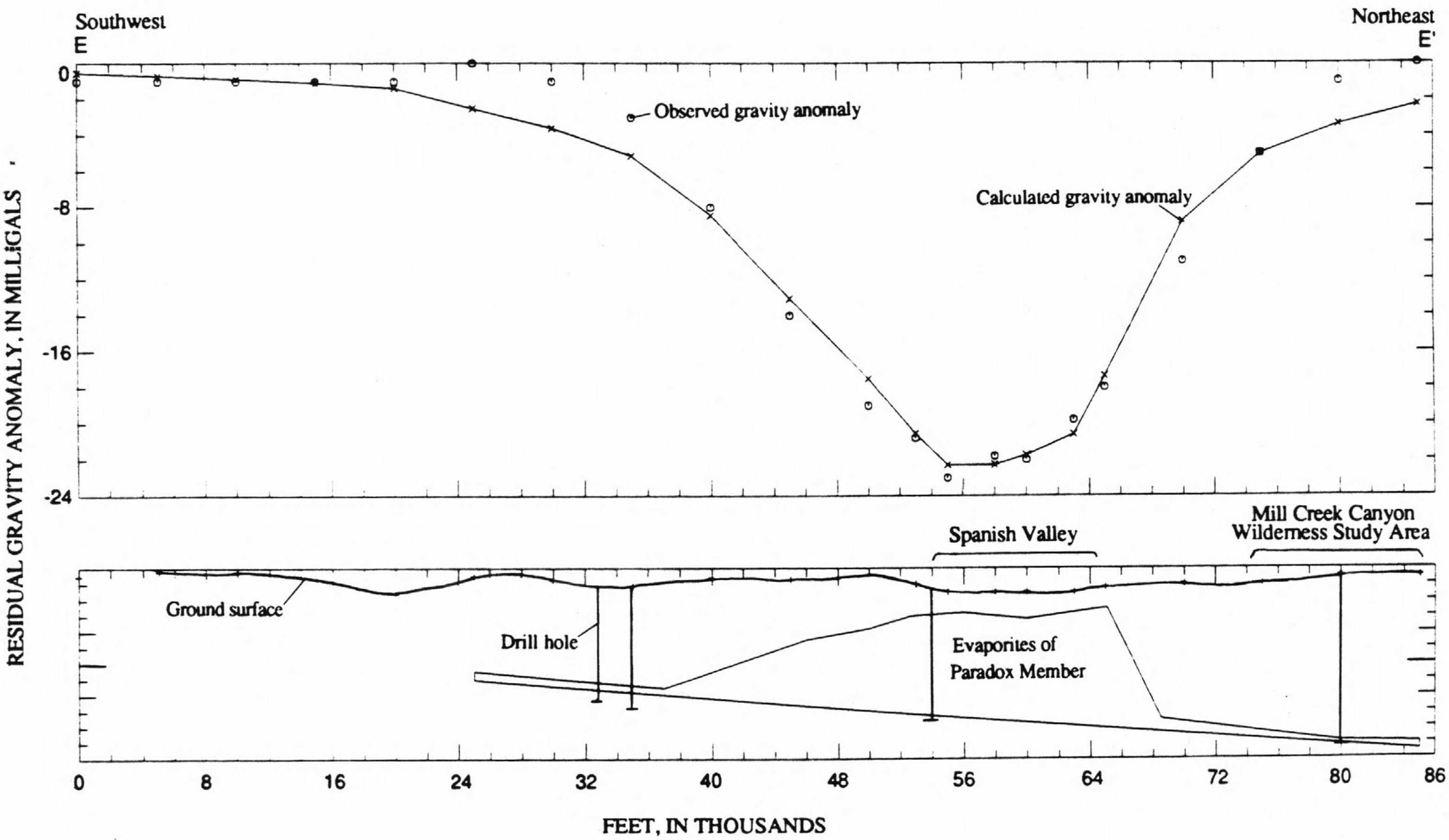

Figure 6. Schematic gravity model and section across Spanish Valley and Mill Creek Canyon Wilderness Study Area, Utah. Model along line *E-E'* of figure 3; +, point of surface at which gravity anomaly was calculated. Drill holes projected to line *E-E'*. Gravity effects of salt were not calculated at southwest end of section.

A schematic gravity model across the Spanish Valley salt anticline has been constructed using the available drill holes as a partial control on salt thickness (fig. 6). Because only a few gravity stations were established near the line of section, anomaly values were taken from the contour maps. The following assumptions were made in construction of the model: the evaporite sequence has a mean density contrast of minus 0.35 g cm^{-3}; the base of the evaporite sequence is planar (an unlikely assumption because drilling and geophysical data for large pre-salt structures for other salt anticlines of the Paradox basin do not indicate planar bases); and the residual anomalies were produced by subtracting a planar regional field from the Bouguer anomaly field. Some larger discrepancies between the residual anomalies and the calculated anomalies, southwest of Spanish Valley and at the northeast end of the section, may be due to presalt structures, to intrabasement density contrasts, or to variations in density contrasts within the salt itself or within the overlying sedimentary sequence. Note, however, that these differences are generally less than 2 mGal, the probable error in the residual Bouguer anomalies.

From the combined drill-hole and gravity data, it appears that the Spanish Valley salt anticline is asymmetrical, having a steeper northeastern flank. The geophysical data and interpretations, especially the gravity data, are pertinent to evaluation of the potential resources for potash and oil and gas of the study area; however, they provide little information about near-surface metallic mineral deposits.

Assessment of Mineral Resource Potential

Potash and halite are present in the Paradox Member of the Hermosa Formation. This member is present at a depth of more than 8,000 ft (fig. 6) within the study area. Solution mining of potash from this unit is presently underway at the Cane Creek mine, down river from Moab (Nigbor, 1982). At that site, however, the water necessary for such mining is abundant. Finding a water supply for such an operation within the study area may present a problem. There is, nonetheless, high mineral resource potential, certainty level C, for potash and halite in the entire study area. Gypsum and bentonite are also produced from the Paradox but only where the unit can be mined by direct access rather than by solution mining.

The Navajo Sandstone is presently being quarried for flagstone for building materials in the lower reaches of Mill Creek outside the study area (Terry McParland, U.S. Bureau of Land Management, Moab District Office Geologist, oral commun., 1988). The resource potential is high, certainty level D, for flagstone in low-lying areas underlain by the Navajo within the study area.

Gold is present in placer claims east of the study area on Wilson Mesa and is in gravel deposits derived from granitic terrane of the La Sal Mountains 4 mi to the east. In Pleistocene time, the host streams crossed parts of what is now Wilson Mesa within the study area. The top of Wilson Mesa, therefore, has high resource potential, certainty level D, for small placer deposits of gold.

Uranium is mined in nearby areas from the Cutler, Chinle, and Morrison Formations. Part of the Morrison is present in the upper part of the plateaus in the eastern part of the study area, and the other two units are present at depth beneath the study area. No uranium was reported from the limited drill data in and near the study area, and no uranium or thorium was detected in geochemical samples from the surface streams in the study area or from testing with a scintillometer during field mapping. However, it is possible that uranium- and (or) thorium-bearing zones within the three units may be present below the surface. Zones from which uranium is mined typically have also produced vanadium from vanadium silicates and copper from chalcopyrite, bornite, and chalcocite. Therefore, the entire study area has moderate mineral resource potential, certainty level C, for uranium, thorium, copper, and vanadium.

Oil is produced in the region from the Middle and Upper Pennsylvanian Paradox Member of the Hermosa Formation and from the Lower Mississippian Leadville Limestone, both of which are known to be present at depth beneath the study area. No oil and gas is known to be present beneath the study area, but leases cover part of it. The same porous rocks that could contain oil and gas could also contain carbon dioxide gas and, less likely, helium gas. A well in Lisbon Valley contains trace amounts of helium, and other wells there contain moderate amounts of carbon dioxide gas. Due to the underlying strata and to the proximity to those wells, the resource potential of the entire study area is moderate, certainty level B, for oil and gas and for carbon dioxide gas and is low, certainty level B, for helium gas.

No evidence of the presence of other metals related to deposition, structure, or intrusions was observed. No geothermal springs or wells were observed or are known to be present in the study area, and no evidence of geothermal activity was seen. The National Oceanic and Atmospheric Administration (1980) reported that the regional heat flow over the area is low. The entire study area has low resource potential, certainty level B, for geothermal energy.

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APPENDIXES

DEFINITION OF LEVELS OF MINERAL RESOURCE POTENTIAL AND CERTAINTY OF ASSESSMENT

LEVELS OF RESOURCE POTENTIAL

H **HIGH** mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate a high degree of likelihood for resource accumulation, where data support mineral-deposit models indicating presence of resources, and where evidence indicates that mineral concentration has taken place. Assignment of high resource potential to an area requires some positive knowledge that mineral-forming processes have been active in at least part of the area.

M **MODERATE** mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate reasonable likelihood for resource accumulation, and (or) where an application of mineral-deposit models indicates favorable ground for the specified type(s) of deposits.

L **LOW** mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics define a geologic environment in which the existence of resources is permissive. This broad category embraces areas with dispersed but insignificantly mineralized rock, as well as areas with little or no indication of having been mineralized.

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

U **UNKNOWN** mineral resource potential is assigned to areas where information is inadequate to assign a low, moderate, or high level of resource potential.

LEVELS OF CERTAINTY

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

LEVEL OF RESOURCE POTENTIAL ↑

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 →

Abstracted with minor modifications from:

Taylor, R.B., and Steven, T.A., 1983, Definition of mineral resource potential: Economic Geology, v. 78, no. 6, p. 1268-1270.
Taylor, R.B., Stoneman, R.J., and Marsh, S.P., 1984, An assessment of the mineral resource potential of the San Isabel National Forest, south-central Colorado: U.S. Geological Survey Bulletin 1638, p. 40-42.
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RESOURCE/RESERVE CLASSIFICATION

	IDENTIFIED RESOURCES			UNDISCOVERED RESOURCES	
	Demonstrated		Inferred	Probability Range	
	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, V.E., 1972, Mineral resource estimates and public policy: American Scientist, v. 60, p. 32-40; and U.S. Bureau of Mines and U.S. Geological Survey, 1980, Principles of a resource/reserve classification for minerals: U.S. Geological Survey Circular 831, p. 5.

GEOLOGIC TIME CHART

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

EON	ERA	PERIOD		EPOCH	AGE ESTIMATES OF BOUNDARIES IN MILLION YEARS (Ma)
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	[1]~570
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 Ma also called Precambrian, a time term without specific rank.
[2]Informal time term without specific rank.