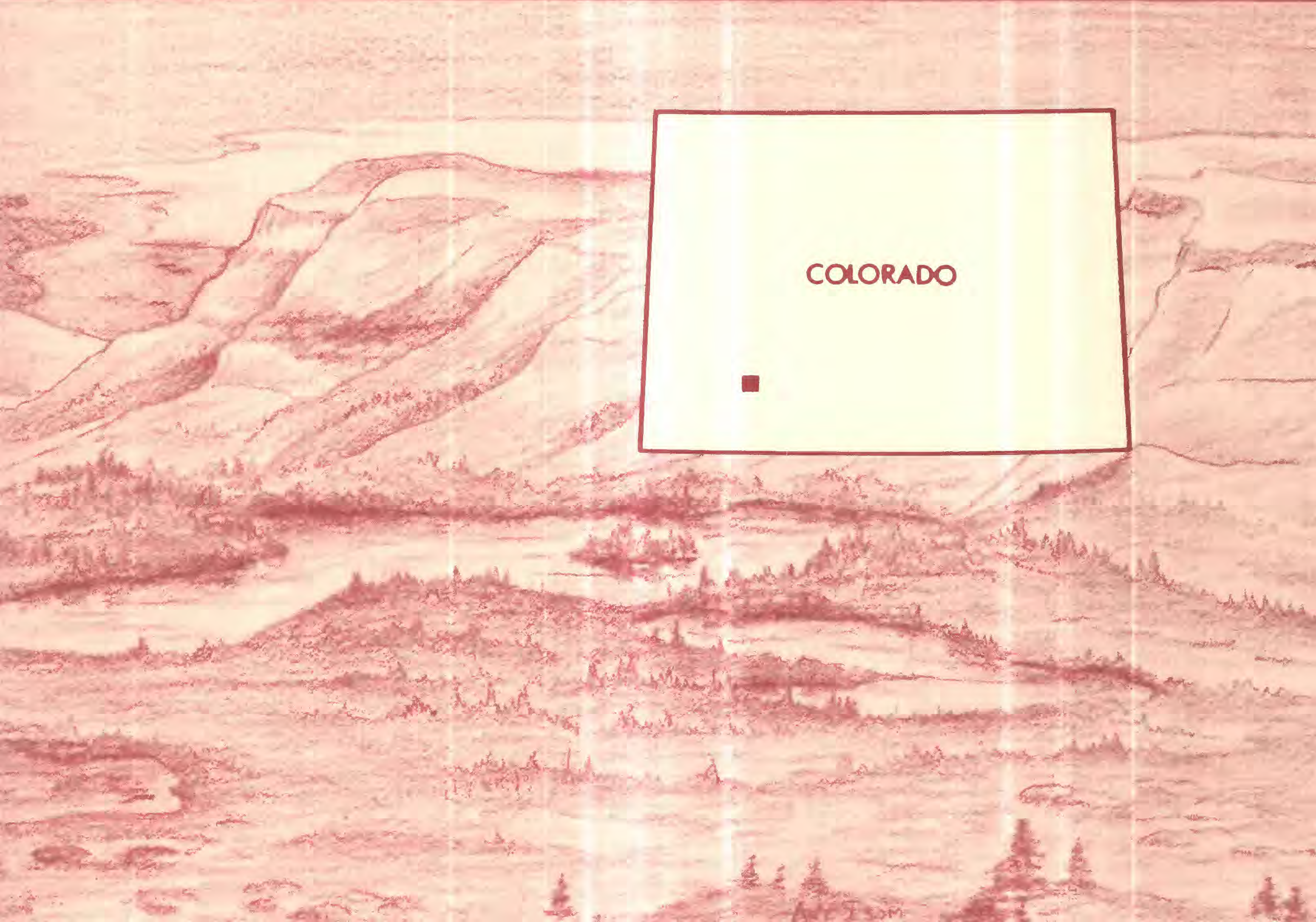
Mineral Resources of the Redcloud Peak and Handies Peak Wilderness Study Areas, Hinsdale County, Colorado

U.S. GEOLOGICAL SURVEY BULLETIN 1715–B



Chapter B

Mineral Resources of the Redcloud Peak and Handies Peak Wilderness Study Areas, Hinsdale County, Colorado

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U.S. GEOLOGICAL SURVEY BULLETIN 1715

MINERAL RESOURCES OF WILDERNESS STUDY AREAS—
SOUTHWESTERN COLORADO

DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY
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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 Redcloud Peak (CO–030–208) and Handies Peak (CO–030–241) Wilderness Study Areas, Hinsdale County, Colorado.

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Mineral Resources of the Redcloud Peak and Handies Peak Wilderness Study Areas, Hinsdale County, Colorado

By Richard F. Sanford, Richard I. Grauch, Ken Hon, Dana J. Bove, *and* V.J.S. Grauch
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SUMMARY

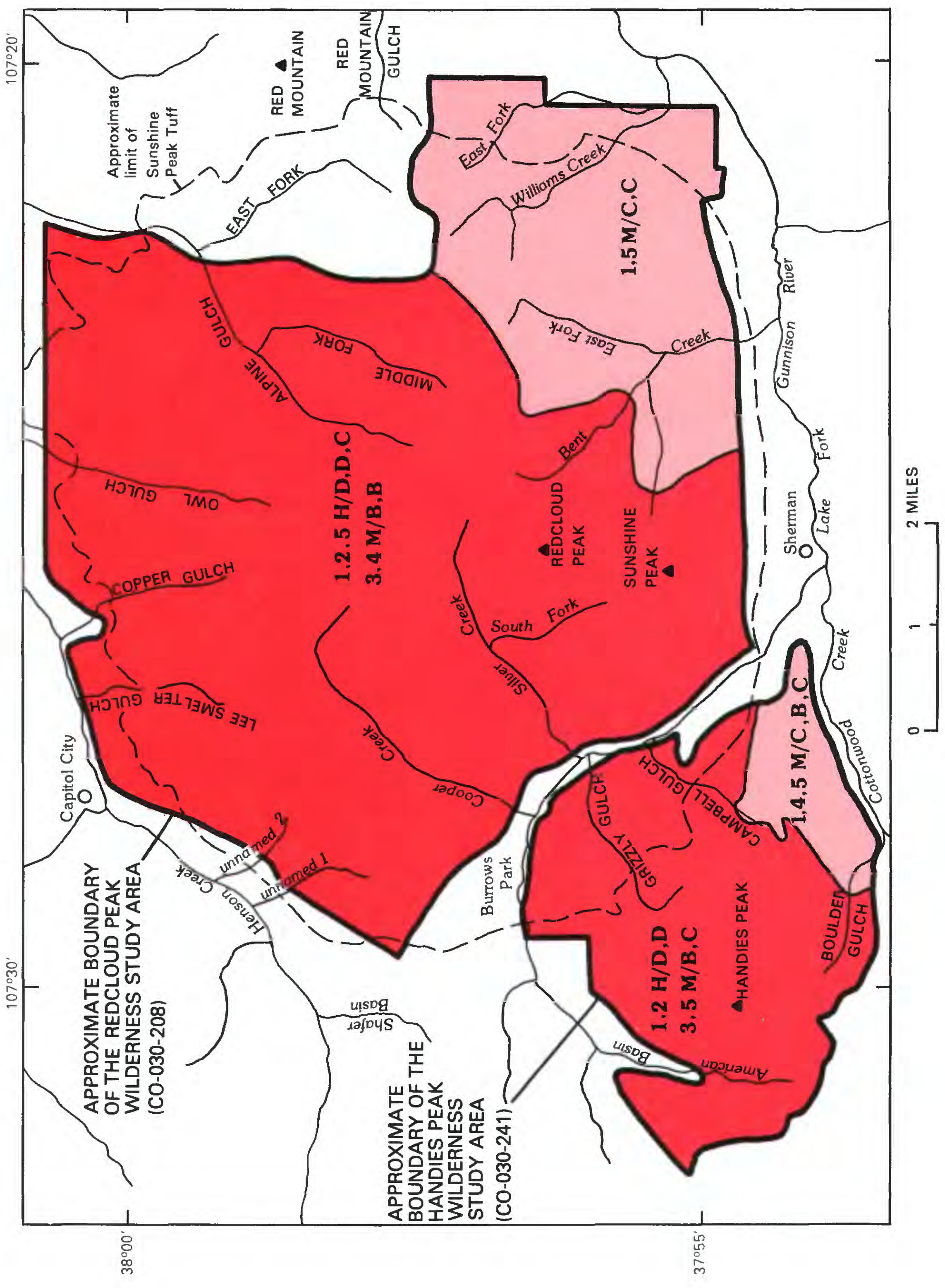
By Richard F. Sanford and Stanley L. Korzeb

Abstract

At the request of the U.S. Bureau of Land Management, 30,400 acres of the Redcloud Peak (CO–030–208) Wilderness Study Area and 7,885 acres of the Handies Peak (CO–030–241) Wilderness Study Area were studied. In this report the studied area(s) is (are) called the "wilderness study area(s)" or simply the "study area(s)." No identified mineral resources were found in the study areas; however, one vein containing silver, lead, and zinc resources just north of the Redcloud Peak Wilderness Study Area extends into that study area. Much of the study areas has high mineral resource potential for precious (silver and gold) and base (principally lead, zinc, and copper, but also antimony, barite, bismuth, cadmium, fluorspar, manganese, mercury, selenium, tellurium, and tungsten) metals in vein-type and breccia-pipe-type epithermal deposits; the rest of the study areas has moderate potential for these commodities in these two deposit types (fig. 1). Part of the Redcloud Peak study area has high potential for uranium in vein-type deposits; other parts of both study areas have moderate potential for this commodity. Parts of the Redcloud Peak study area have moderate potential for molybdenum and copper in quartz monzonite-associated porphyry deposits; part of the Handies Peak study area has moderate potential for molybdenum in granite-related porphyry deposits. Much of the study area has moderate potential for gold and silver in volcanic-hosted disseminated-type epithermal deposits. For all commodities and their deposit types previously mentioned, parts of both study areas also have low potential (not shown on fig. 1). The mineral resource potential for gold and silver in clastic-sediment-hosted disseminated-type deposits is low in those parts of both study areas underlain by the Henson Member of the Silverton Volcanics (not shown on fig. 1). The mineral and energy resource potential for aluminum in alunite deposits, uranium in disseminated deposits, and geothermal sources is low throughout both study areas. There is no energy resource potential for coal, oil, and natural gas.

Character and Setting

The Redcloud Peak and Handies Peak Wilderness Study Areas are in the western San Juan Mountains in Hinsdale County, Colo., between the Uncompahgre and Gunnison National Forests and 2 mi (miles) south of the Big Blue Wilderness Area (fig. 2). The study areas are accessible by gravel roads leading west and south from Lake City, Colo. The interiors of both areas can be reached only by foot trails and former jeep roads. Both areas are rugged, with steep-sided valleys and high ridges and peaks. Altitudes range from approximately 9,400 ft (feet) along major drainages to 14,034 ft in the Redcloud Peak Wilderness Study Area and 14,048 ft in the Handies Peak Wilderness Study Area.


107°20'
107°30'
38°00'
37°55'
Approximate limit of Sunshine Peak Tuff
RED MOUNTAIN
RED MOUNTAIN GULCH
EAST FORK
East Fork
Williams Creek
1,5 M/C,C
East Fork
Creek
Gunnison River
ALPINE GULCH
MIDDLE FORK
1,2,5 H/D,D,C
3,4 M/B,B
Bent
OWL GULCH
COPPER GULCH
REDCLOUD PEAK
SUNSHINE PEAK
Sherman
Lake Fork
South Fork
Silver Creek
LEE SMELTER GULCH
Cooper Creek
Capitol City
Creek
Cottonwood
1,4,5 M/C,B,C
CAMPBELL GULCH
GRIZZLY GULCH
Burrows Park
unnamed 2
unnamed 1
Henson Creek
BOULDER GULCH
HANDIES PEAK
1,2 H/D,D
3,5 M/B,C
American Basin
Shafer Basin
APPROXIMATE BOUNDARY OF THE REDCLOUD PEAK WILDERNESS STUDY AREA (CO-030-208)
APPROXIMATE BOUNDARY OF THE HANDIES PEAK WILDERNESS STUDY AREA (CO-030-241)
0 1 2 MILES

EXPLANATION OF GENERALIZED MINERAL AND ENERGY RESOURCE POTENTIAL

[See figures 8 through 12 for more detailed information on potentials for commodities 1 through 5, respectively. Those parts of both study areas that are underlain by the Henson Member of the Silverton Volcanics (pls. 1 and 2) have low potential for resources of gold and silver in clastic-sediment-hosted disseminated-type epithermal deposits, with certainty level B. Study areas have low potential for resources of (1) alunite, with certainty level D, (2) uranium in disseminated deposits, with certainty level C, and (3) geothermal energy sources, with certainty level B. Study areas have no potential for coal, oil, and natural gas, with certainty level D]

REDCLOUD PEAK WILDERNESS STUDY AREA

1,2,5 H/D,D,C 3,4 M/B,B	Geologic terrane having (1) high potential for commodities 1, 2, and 5, with certainty levels D, D, and C, respectively, and (2) moderate potential for commodities 3 and 4, with certainty level B
1,5 M/C,C	Geologic terrane having moderate potential for commodities 1 and 5, with certainty level C

HANDIES PEAK WILDERNESS STUDY AREA

1,2 H/D,D 3,5 M/B,C	Geologic terrane having (1) high potential for commodities 1 and 2, with certainty level D, and (2) moderate potential for commodities 3 and 5, with certainty levels B and C
1,4,5 M/C,B,C	Geologic terrane having moderate potential for commodities 1, 4, and 5, with certainty levels C, B, and C, respectively

Commodities—Ag, silver; Au, gold; Pb, lead; Zn, zinc; Cu, copper; Mo, molybdenum; Sb, antimony; Bi, bismuth; Cd, cadmium; Mn, manganese; Hg, mercury; Se, selenium; Te, tellurium; W, tungsten

1 Vein-type epithermal deposits (principally Ag, Au, Pb, Zn, and Cu, and minor Sb, barite, Bi, Cd, fluorspar, Mn, Hg, Se, Te, W)

2 Breccia-pipe-type epithermal deposits (principally Ag, Au, Pb, Zn, and Cu, and minor Sb, barite, Bi, Cd, fluorspar, Mn, Hg, Se, Te, W)

3 Volcanic-hosted disseminated-type epithermal deposits (Au, Ag)

4 Porphyry-type deposits (Mo and (or) Cu)

5 Vein uranium deposits

Certainty levels

B Data indicate geologic environment and suggest level of resource potential

C Data indicate geologic environment and resource potential, but do not establish activity of resource-forming processes

D Data clearly define geologic environment and level of resource potential, and indicate activity of resource-forming processes in all or part of study area

Figure 1. Summary map showing generalized mineral resource potential of the Redcloud Peak and Handies Peak Wilderness Study Areas, southwestern Colorado.

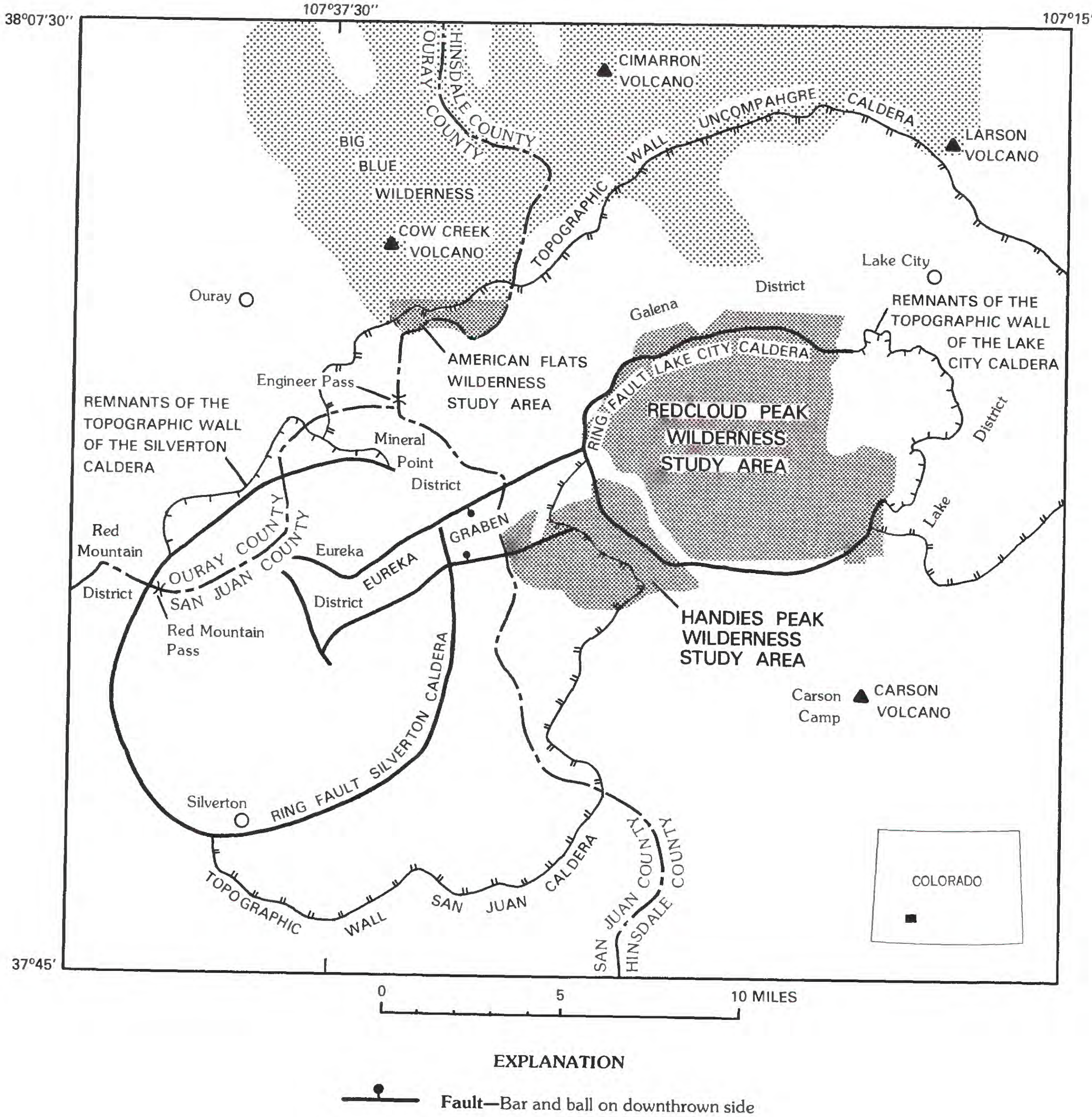


Figure 2. Index map showing location and generalized geologic setting of the Redcloud Peak and Handies Peak Wilderness Study Areas, southwestern Colorado. (Modified from Lipman, 1976a.)

The study areas are in the San Juan volcanic field, which consists largely of Oligocene and Miocene volcanic rocks resting on Mesozoic and Paleozoic sedimentary rocks and on Proterozoic granitic and metamorphic rocks (see geologic time chart in Appendix for relative geologic ages). In the vicinity of the study areas, most mineralization was associated with mid-Tertiary volcanic activity. During Oligocene time, from 33 to 30 Ma (million years ago), eruptions of large volcanoes created a plateau composed of lava flows and related rocks that covered at least 8,000 mi^2. Between 30 and 26 Ma, explosive eruptions blanketed the region with thick sheets of volcanic ash. As a result of collapse into the partly evacuated magma chambers, three large circular depressions (calderas) were created in the western San Juan region. Following collapse, the intrusion of another (resurgent) magma body domed and stretched the overlying layers forming a northeast-trending, down-dropped, fault-bounded regional structure called the Eureka graben. In early Miocene time, about 23 Ma, a similar sequence of events recurred in the eastern part of the earlier caldera complex. The Sunshine Peak Tuff was erupted, and the Lake City caldera subsided as a consequence of magma removal. Shortly after, the Lake City caldera was domed by emplacement of a variety of resurgent intrusions.

The wilderness study areas are in and adjacent to the Eureka graben in an area where Paleozoic and Mesozoic sedimentary rocks are absent and Oligocene volcanic rocks rest directly on Proterozoic granitic and metamorphic rocks. Many of the faults in the Eureka graben show evidence of mineralization, and in adjacent areas outside of the wilderness study areas these faults contain significant deposits of gold, silver, lead, zinc, and copper.

Identified Mineral Resources

The caldera complex in the western San Juan Mountains region is one of the major mining areas in the Western United States. Estimated metal production since the early 1880's has been about $8.5 billion at current prices (gold, $340/troy oz (ounce); silver, $6.80/troy oz). The wilderness study areas include parts of the Lake and Galena mining districts and are just east of the Eureka and Mineral Point mining districts (fig. 2). Combined metal production from the Lake and Galena districts has been about $200 million at current prices. The wilderness study areas have been explored for precious (gold and silver) and base (principally lead, copper, and zinc) metals, uranium, and molybdenum. A vein in the Pride of America mine, just north of the Redcloud Peak Wilderness Study Area, contains silver, lead, and zinc, and the same vein structure extends into the wilderness study area. However, no identified mineral resources were found in either wilderness study area.

Mineral and Energy Resource Potential

Large parts of the wilderness study areas have high mineral resource potential for undiscovered silver, gold, lead, zinc, and copper resources, with lesser amounts of associated antimony, barite, bismuth, cadmium, fluorspar, manganese, mercury, selenium, tellurium, and tungsten resources, in vein and breccia-pipe deposits (figs. 1, 8, 9). These areas have mineralized veins and (or) breccias (masses of angular broken rock), contain anomalously high concentrations of metallic and related elements in rock and stream-sediment samples, and have intensely altered host rocks exposed in favorable tectonic, structural, and lithologic settings. Moderate potential for these commodities in such deposits is in areas having a favorable geologic setting but few mineralized structures, an incomplete suite of anomalous indicator elements, and less altered host rocks. Areas of low mineral resource potential for these commodities in breccia-pipe deposits are characterized by favorable geologic setting but little specific evidence of mineralization or alteration. The wilderness study areas also have regions of moderate potential for undiscovered gold-silver resources in disseminated deposits hosted by permeable volcanic rocks adjacent to mineralized faults and fractures (figs. 1, 10). The remaining parts of the wilderness study areas have low mineral resource potential for undiscovered gold-silver resources in disseminated deposits hosted by volcanic rocks. Small areas, which are underlain by sedimentary rocks, have low potential for undiscovered gold-silver resources in sediment-hosted disseminated deposits.

Two areas within the Redcloud Peak Wilderness Study Area have moderate mineral resource potential for undiscovered molybdenum and copper in porphyry-type deposits in altered and mineralized intrusive rocks, and one area in the Handies Peak Wilderness Study Area has moderate potential for undiscovered molybdenum resources in such deposits (figs. 1, 11). The areas of moderate potential are defined by the proximity of weak porphyry-type mineralization in and adjacent to intrusive bodies, the distribution of altered rocks, and the presence of geochemical anomalies in rock and stream-sediment samples. The rest of the wilderness study areas has low mineral resource potential for undiscovered molybdenum and copper resources in such deposits.

The southwestern part of the Redcloud Peak Wilderness Study Area, in the vicinity of Silver Creek and Redcloud Peak, has high mineral resource potential for undiscovered uranium resources in vein deposits based on the presence of a uranium-gold-silver-bearing vein, intensely altered rocks, well-developed fractures, anomalous radioactivity, and anomalous uranium concentrations in stream-sediment samples (figs. 1, 12). Moderate potential for undiscovered uranium resources in this type of deposit extends over other parts of the Redcloud Peak Wilderness Study Area and parts of the Handies Peak Wilderness Study Area where similar conditions are present. Remaining parts of the wilderness study areas have low potential for undiscovered uranium resources in such deposits. The mineral resource potential for undiscovered uranium resources in disseminated deposits associated with high-silica rhyolites is low in both areas.

Although major deposits of alunite, a source of aluminum, occur 1 mi east of the Redcloud Peak Wilderness Study Area and elsewhere in the San Juan Mountains, the mineral resource potential for undiscovered alunite resources in the wilderness study areas is low. No evidence for currently active hot spring activity was found, and thus the energy resource potential for undiscovered geothermal sources is low. The geologic environment is unfavorable for deposits of coal, oil, and natural gas, so there is no energy resource potential for these commodities.

INTRODUCTION

By Richard F. Sanford and Stanley L. Korzeb

The Redcloud Peak (CO–030–208) and Handies Peak (CO–030–241) Wilderness Study Areas are in the western San Juan Mountains in Hinsdale County, Colo. The USGS (U.S. Geological Survey) and the USBM (U.S. Bureau of Mines) studied 30,400 acres of the Redcloud Peak Wilderness Study Area and 7,885 acres of the Handies Peak Wilderness Study Area. The study of this acreage was requested by the BLM (U.S. Bureau of Land Management). In this report, the studied area(s) is (are) called "wilderness study area(s)" or simply "study area(s)." The study areas are surrounded by non-wilderness public land administered by the BLM and by small parcels of private land. The BLM-administered and private lands are bounded by the Big Blue Wilderness Area (fig. 2) and the Uncompahgre National Forest on the north and west and by the Gunnison National Forest on the south and east. The wilderness study areas are accessible by jeep roads and foot trails that connect with two gravel roads from Lake City (pls. 1, 2), one extending west along Henson Creek and the other extending south and west along the Lake Fork Gunnison River. The study areas range in elevation from about 9,400 ft in the valleys of Henson Creek and the Lake Fork Gunnison River to 14,048 ft at the top of Handies Peak (fig. 1) in the Handies Peak Wilderness Study Area. Two other peaks above 14,000 ft are Redcloud (14,034 ft) and Sunshine (14,001 ft) Peaks (fig. 1), both in the Redcloud Peak Wilderness Study Area.

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

Investigations by the U.S. Bureau of Mines

Field investigations of the Redcloud Peak and Handies Peak Wilderness Study Areas were conducted by the USBM during July and August 1984; observations on prospecting, mining, and claim activity are as of that period. Prior to field work, an extensive review was made of county and BLM records for locations of patented and unpatented claims and Federal mineral leases in or near the wilderness study areas. Officials of the BLM, mine owners, claim owners, and local residents provided information regarding mining activity and mineral deposits. The USBM surveyed and studied the mines, prospects, and mineralized areas to appraise reserves and identified subeconomic resources.

Investigations by the U.S. Geological Survey

During the summers of 1984 and 1985, the USGS conducted geological, geophysical, and geochemical surveys of the wilderness study areas. The data have been integrated with other data gathered in ongoing studies of the Lake City caldera and its surroundings.

Acknowledgments.—We gratefully acknowledge the cooperation of the regional BLM and the regional USFS (U.S. Forest Service), particularly Terry Reed, Arden Anderson, John Sering, and Duane Harp, for their assistance during the course of this study. Norma Swanson, of Lake City, Colo., generously allowed us access to her extensive collection of unpublished mining reports. Many claim and mine owners permitted access to their property and provided unpublished data.

GEOLOGIC SETTING

By Ken Hon

Geology of the Western San Juan Volcanic Field

The Redcloud Peak and Handies Peak Wilderness Study Areas are located in the western part of the mid-Tertiary San Juan volcanic field of southwestern Colorado (fig. 2). The western San Juan Mountains were the site of periodic volcanic and hydrothermal activity from about 33 Ma until about 5 Ma (Lipman and others, 1970, 1973, 1976; Naeser and others, 1980).[1] Andesitic to dacitic lava flows and breccias were erupted approximately 33–30 Ma from several large stratovolcanoes in the area between Lake City and Silverton (fig. 2) (Lipman and others, 1973, 1976). Volcanic and volcaniclastic rocks related to these centers are as much as 5,000 ft thick in some places and were deposited unconformably upon Mesozoic and Paleozoic sedimentary rocks, and on Proterozoic metamorphic and igneous rocks. Near the Redcloud Peak and Handies Peak Wilderness Study Areas the underlying basement is composed entirely of Proterozoic rocks, because the sedimentary rocks were either not deposited or were removed by pre-volcanic erosion.

[1]Potassium-argon (K-Ar) ages determined from rocks of the San Juan volcanic field prior to 1976 were replaced by the recalculated ages presented by Hon and Mehnert (1983). Volcanic and intrusive rocks were named according to the IUGS (International Union of Geological Sciences) classifications given by Le Maitre (1984) and Streckeisen (1976).

About 30 Ma, andesitic volcanism gave way to eruption of huge volumes of ash-flow tuff, which was accompanied by subsidence of the source areas to form calderas (Steven and Lipman, 1976). In the vicinity of the Redcloud Peak and Handies Peak Wilderness Study Areas, the Uncompahgre and San Juan calderas collapsed contemporaneously during the eruption of the 29-Ma Sapinero Mesa Tuff (Lipman and others, 1973). Caving of oversteepened caldera walls enlarged the Uncompahgre and San Juan calderas so that only a narrow septum of Middle Proterozoic granite remained between them (Lipman, 1976a, b). The two calderas jointly resurged soon after their collapse and formed a broad elliptical dome that extends from Lake City to Silverton (fig. 2) (Lipman and others, 1973; Steven and Lipman, 1976). Distensional faulting along the crest of the dome produced a complex northeast-trending graben (the Eureka graben shown on fig. 2) with numerous inwardly dipping normal faults (Luedke and Burbank, 1968; Steven and Lipman, 1976). Postcollapse volcanic activity partly filled the moats of the calderas with andesitic to dacitic lava flows and related tuffaceous sediments (Silverton Volcanics), and several 25- to 28-Ma monzonitic stocks were intruded late in the development of the Uncompahgre caldera (Lipman, 1976a; Caskey, 1979; Slack, 1980).

Volcanic activity resumed in early Miocene time when the 23.1-Ma Sunshine Peak Tuff was erupted from the eastern part of the earlier caldera complex and caused the collapse of the Lake City caldera (Lipman and others, 1973; Hon and others, 1983). The Lake City caldera is nested within the Uncompahgre caldera and truncates many of the older structures associated with the Uncompahgre–San Juan caldera complex, including faults of the Eureka graben (Lipman, 1976a; Steven and Lipman, 1976). The silicic alkalic rocks related to the Lake City caldera are petrologically distinct from the calc-alkaline rocks formed during the earlier caldera sequences (Lipman and others, 1978; Hon, 1987). At about the same time (22–24 Ma), a series of quartz- and sanidine-bearing, dacitic to andesitic intrusions were emplaced along a northeasterly trend from Red Mountain Pass to Engineer Pass (fig. 2) (Lipman and others, 1976). Later, high-silica rhyolites were intruded largely along the same linear trend between 19 and 10 Ma, but these extended farther to the northeast toward Lake City (fig. 2) (Lipman, 1976a; Lipman and others, 1976; Maher, 1983).

Geology of the Redcloud Peak Wilderness Study Area

The Redcloud Peak Wilderness Study Area is mostly within the 23.1-Ma Lake City caldera (fig. 2, pl. 1), which collapsed in response to the eruption of the compositionally zoned Sunshine Peak Tuff. This ash-flow sheet consists of a high-silica rhyolitic lower member, a rhyolitic middle member, and a quartz trachytic upper member (pl. 1) (Hon and others, 1983; Hon, 1987). The three ash-flow members interfinger with a caldera-collapse breccia member produced by periodic landsliding of older rocks from the walls of the Lake City caldera. Most of the rocks exposed within the Redcloud Peak study area and in the eastern third of the Handies Peak study area are part of this caldera-fill sequence (pls. 1, 2) (Lipman, 1976a, b; Hon, 1987).

The contemporaneous collapse and infilling of the Lake City caldera by the Sunshine Peak Tuff was followed relatively rapidly by the eruption of the dacite lavas of Grassy Mountain along the southeastern quadrant of the ring fault. The subsequent emplacement of a large quartz syenite pluton and related rhyolitic intrusions into the north-central part of the caldera resurgently domed the caldera and tilted the earlier lavas (pl. 1) (Hon, 1987). Most of the resurgence apparently postdated the early phase of postcollapse volcanism, but occurred prior to the eruption of dacite lavas that cover the area north of Red Mountain (pl. 1). The final stages of igneous activity in the Lake City caldera were the intrusion of the dacite of Red Mountain and the quartz monzonite of Alpine Gulch, apparently from the same underlying magma chamber. Although the length of the entire caldera cycle is not resolvable by K-Ar dating (Hon, 1987; Mehnert and others, 1973), paleomagnetic data indicate that its duration was probably less than 300,000 years (Reynolds and others, 1986).

A few small areas of volcanic rocks, which are dominantly Uncompahgre caldera fill outside of the Lake City caldera, lie within the boundaries of the Redcloud Peak Wilderness Study Area (pl. 1). Monzonitic intrusions related to the Uncompahgre caldera are also present in the northwestern and southeastern corners of the study area (pl. 1) (Lipman, 1976a).

Structural activity within the Redcloud Peak Wilderness Study Area was closely related to volcanic processes, particularly to the formation of the Lake City caldera. Major episodes of faulting and doming within the study area are directly attributable to catastrophic ash-flow eruptions, followed by the emplacement of a large intrusive body.

The most prominent structure is the ring fault of the Lake City caldera, which is typically vertical or dips steeply inward toward the center of the caldera (pl. 1) (Lipman, 1976a). The ring fault bounds a deeply subsided block marked by the accumulation of more than 5,000 ft of Sunshine Peak Tuff. During resurgence of the Lake City caldera, differential upward movement occurred along the ring fault. The asymmetric emplacement of the resurgent quartz syenite intrusion within the north-central part of the caldera produced uplift of greater than 4,000 ft on the northern sector of the ring fault, and displacements gradually decrease in a counterclockwise direction along the ring fault. Stratigraphic relations also indicate the presence of a major fault in the drainage of Alpine Gulch. Maximum displacement of greater than 4,000 ft along this fault coincides with the area of greatest uplift on the ring fault and displacement diminishes rapidly toward the interior of the caldera (pl. 1) (Hon, 1987).

Faulting within the caldera is related to resurgent doming and the emplacement of quartz syenite intrusions into the caldera-fill sequence. The faults are concentrated above the quartz syenite intrusions and have a dominant northeast trend, suggesting that they represent the root zone of an extensional graben. The displacements on these faults are generally less than 200 ft, although some displacements of as much as 600 ft can be documented. Many of the faults are marked by quartz veins or fault breccias, but some have no outcrop expression and are reflected only by stratigraphic offsets (pl. 1) (Hon, 1987).

Mineralization within the Redcloud Peak study area appears to have occurred mainly during the Lake City caldera cycle. Quartz veins occupy many of the mapped faults within the core of the caldera, and the intensity of the alteration associated with these mineralized structures is zoned about the resurgent intrusion (pl. 1) (Hon, 1987). Silver and lead-zinc-copper vein deposits north of the Lake City caldera, about 1–2 mi outside of the study area, are also postulated to be related to the emplacement of the resurgent intrusion (Slack, 1980). A few faults containing quartz veins cut or displace intracaldera intrusions, which indicates some mineralization occurred after the main caldera cycle (pl. 1). Small silicified and brecciated masses of rock containing fragments of or cutting Sunshine Peak Tuff are present in the northwestern part of the study area (pl. 1) (Hon, 1987). These breccias bear some resemblance to the silicified cap rock associated with breccia-pipe deposits near Engineer and Red Mountain Passes (fig. 2) (Burbank, 1941; Fisher and Leedy, 1973; Maher, 1983).

Both the quartz monzonite of Alpine Gulch and the dacite of Red Mountain, which lies just to the east of the study area, display characteristics of weak porphyry-type mineralization (pl. 1) (Bove, 1984; Hon, 1987). The quartz monzonite body is cut by rare graphic quartz-feldspar veinlets and magnetite veinlets; it is also closely associated with a zone of tourmaline breccias and fragmental dikes (pl. 1) (Hon, 1987). The dacite of Red Mountain is spatially and temporally associated with extensive hydrothermal breccias and 23.1-Ma alunite alteration (Mehnert and others, 1979; Bove, 1984). The intense advanced argillic alteration on Red Mountain grades downward into argillic and potassic zones that are weakly mineralized (Bove, 1984). Both of these plutons appear to have been intruded along the ring fault from the same underlying magma chamber late in the Lake City caldera cycle. No geologic evidence of porphyry-type disseminated mineral deposits was found associated with any of the resurgent quartz syenite or rhyolite intrusions within the core of the Lake City caldera (Hon, 1987). In the northwest corner of the study area, alteration and widely disseminated porphyry-type mineralization associated with monzonites in the Capitol City area (Steven and others, 1977; Slack, 1980) predate the Lake City caldera, as shown by masses of this altered rock locally within megabreccia of the Lake City caldera (Lipman and others, 1976).

Geology of the Handies Peak Wilderness Study Area

The Handies Peak Wilderness Study Area encompasses part of the San Juan caldera, as well as the southwestern edge of the Lake City caldera. The area between these two calderas is marked by faulted blocks of Proterozoic granite (pl. 2) (Lipman, 1976a), which represent the remnants of the septum dividing the San Juan and Uncompahgre calderas.

Rocks within the western part of the Handies Peak study area represent deep levels of the fill within the San Juan caldera and include thick sequences of the intracaldera Sapinero Mesa Tuff (Eureka Member) interfingered complexly with megabreccia (Picayune Megabreccia Member) (pl. 2) (Lipman, 1976a, b). In places this intracaldera ash-flow assemblage is capped by remnants of postcollapse lavas (andesite, dacite, and rhyolite) and interbedded sediments of the Silverton Volcanics, which were downfaulted within the Eureka graben (pl. 2) (Lipman, 1976a). A similar sequence of intracaldera ash-flow tuff (lower member of the Sunshine Peak Tuff) and interfingered caldera-collapse breccia occurs in the part of the Lake City caldera within the Handies Peak study area (pl. 2).

Only one intrusive body, a small dike southeast of Handies Peak (pl. 2), was mapped in this study area. The dike is a quartz- and sanidine-bearing dacite, similar to dacites dated between 22 and 24 Ma in the vicinity of Red Mountain and Engineer Passes (Lipman and others, 1976). Dikes of 17.5-Ma high-silica rhyolite are associated with mineralized pebble dikes 1 mi south of the study area (Hon, 1987); however, there is no indication that similar intrusions occur within the study area.

Northeast-trending faults of the Eureka graben dominate structure within the Handies Peak study area; however, on the south side of the study area a few faults trend northwest (pl. 2) (Lipman, 1976a). Most of the quartz veins in the study area lie within the Eureka graben and represent the extension of a vein system that is highly mineralized 5 mi southwest of the study area (Burbank and Luedke, 1969; Casadevall and Ohmoto, 1977). Although the faults were formed during resurgence of the Uncompahgre–San Juan caldera complex, mineralization did not occur until after the Lake City caldera cycle (Lipman and others, 1976). Some sections of the ring fault of the Lake City caldera also contain quartz veins that are younger than the caldera (pl. 2) (Hon, 1987).

APPRAISAL OF IDENTIFIED RESOURCES

By Stanley L. Korzeb

Methods of Evaluation

County and BLM records were reviewed for locations of patented and unpatented claims and Federal mineral leases and lease applications in or near the wilderness study areas. Field studies included examination of known mines, prospects, and mineralized areas. Officals of the BLM, mine owners, claim owners, and local residents provided information regarding mining activity and mineral deposits. Samples of 538 rocks were taken from sites within and near the wilderness study areas. Chip samples were taken across known or suspected mineralized or altered areas, and grab samples were taken from mine dumps. Samples from patented claims outside of the study areas were taken only if the mineralized structure extends into one of the study areas. All samples were fire assayed for gold and silver, and most were analyzed by atomic-emission spectrography for 40 elements. Additional analyses were made when other elements of interest were detected or suspected. Analytical results are available for public inspection at the U.S. Bureau of Mines, Intermountain Field Operations Center, Building 20, Denver Federal Center, Denver, CO 80225, and are reported in Korzeb (1986) and in Sanford and others (1987).

Four hundred feet of drill core from a site adjacent to the Handies Peak study area were described in detail. Sixteen polished sections were examined to determine the mineralogy and texture of the veins.

Mining History

The western San Juan Mountains contain numerous mining districts that have produced precious (silver and gold) and base (principally lead, copper, and zinc) metals worth about $8.5 billion at today's prices[2]. With some important exceptions, most of this production has been from vein-type epithermal deposits. Breccia-pipe-type epithermal deposits of the Red Mountain district, 12 mi west of the study areas near Red Mountain Pass (fig. 2), produced metals worth at least $164 million. Clastic-sediment disseminated-type epithermal deposits adjacent to veins had $20 million in reserves plus total production through 1971. The acid-sulfate-type deposits (included in breccia-pipe-type deposits) of Carson camp, 4 mi south of the Redcloud Peak study area, produced metals worth about $3 million. Although there has been no production of metals in the area from volcanic-hosted disseminated gold-silver deposits, from molybdenum-copper porphyry deposits, nor from vein uranium deposits, the USGS investigations show that the geologic setting is favorable for their occurrence. Mining has mostly been by underground methods. Open-pit mining, used elsewhere for disseminated gold-silver deposits and porphyry molybdenum-copper deposits, has not been used in the western San Juan Mountains as of 1987.

Parts of two mining districts (the Galena and Lake districts) are within the wilderness study areas, and two other districts (the Eureka and Mineral Point districts) are just west of the study areas in the vicinity of the Eureka graben and Engineer Pass (fig. 2). Most of the mines in these districts produced mainly silver, lead, copper, zinc, and minor amounts of gold. The individual silver-lead-copper-zinc deposits in the districts adjacent to the wilderness study areas range in production from very small to about $200 million from the Ute–Ulay mine (pl. 1). Gold exceeded silver in dollar amount of production in only three mines in these districts: (1) the Sunnyside mine in the Eureka district (total production value: more than $217 million), (2) the Golden Fleece mine in the Lake district south of Lake City (total production value: $23 million), and (3) the Golden Wonder mine in the Lake district south of Lake City (total production value: $740,000).

The Galena mining district is adjacent to and partly inside the northern boundary of the Redcloud Peak study area and extends from Engineer Pass to Lake City (fig. 2). Mining began after the discovery of the Ute–Ulay veins in 1871 (Irving and Bancroft, 1911, p. 13). The Ute–Ulay mine was active during 1871–1883 and 1887–1940's (Irving and Bancroft, 1911, p. 14; Burbank, 1947a, p. 440). In 1984, a flotation mill at the Ute–Ulay mine in Henson Creek processed gold-telluride ore from the Golden Wonder mine in the Lake district.

The Pride of America mine (pl. 1) in the Galena district produced silver-lead-zinc-copper ore intermittently between 1954 and 1969, during which time the ore assayed 10 troy oz of silver per ton, 10–17 percent combined lead and zinc, and 1 percent copper. The ore was shipped to the Ute–Ulay mine and to Silverton for milling (Sanford and others, 1986). Since then, the mine has been inactive (as of early 1987).

Total production from the Galena district in 1943, entirely from the Ute–Ulay mine, was 34 oz of gold, 9,329 oz of silver, 5 tons of copper, 191 tons of lead, and 16.5 tons of zinc (Burbank, 1947a, p. 440). From

[2]Production figures are calculated at current prices, using $340/oz for gold and $6.80/oz for silver where separate figures are available. Where only total value of production figures are available and production was mostly pre-1933, the current production value was computed by multiplying the pre-1933 production by the ratio of the current price of gold ($340/oz) to the pre-1933 price of gold ($20.67). Sources of production data are: Sunnyside mine, Casadevall and Ohomoto (1977); Golden Fleece mine, Irving and Bancroft (1911); Golden Wonder mine, Slack (1976); Ute–Ulay mine, Irving and Bancroft (1911), Burbank (1947a), p. 440; San Juan Mountains, Burbank and Luedke (1968); Red Mountain district, Burbank (1947b), p. 430; Clastic-sediment disseminated-type epithermal deposits, Mayor and Fisher (1972); Carson camp, Larsen (1911).

1946 to 1958, combined production for the Lake and Galena districts was 190 oz of gold, 36,696 oz of silver, 24 tons of copper, 846 tons of lead, and 186 tons of zinc (Del Rio, 1960, p. 157).

The Lake district is mostly outside the eastern and southern boundary of the Redcloud Peak study area and outside the northern boundary of the Handies Peak study area. The extreme western part of this district is referred to as Burrows Park (fig. 1). With the discovery of the Golden Fleece vein in 1874, the Lake district was established (Irving and Bancroft, 1911, p. 13). This vein had produced $1,400,000 (current value: $23 million) of ore as of 1911 (Irving and Bancroft, 1911, p. 14). The Bon Homme mine (pl. 2) in Burrows Park had produced $2,265 (current value: $37,260) of ore by 1911 (Irving and Bancroft, 1911, p. 17).

In 1984, mineral activity in the two study areas was limited to claim staking. One hundred thirty one patented claims and 509 unpatented claims are within an area including the study areas and a 1-mi-wide strip around their borders. Of the 131 patented claims, 8 are in the Redcloud Peak Wilderness Study Area and 15 are in the Handies Peak Wilderness Study Area. A claim owner was planning to core drill a patented claim near Cooper Creek (fig. 1) in the Redcloud Peak Wilderness Study Area in 1985. A block of unpatented claims in the Redcloud Peak Wilderness Study Area was staked for uranium in 1979, but no mining for uranium or anything else was done.

Appraisal of Sites Examined

Veins in the two study areas are exposed only in surface cuts, outcrops, and short adits. Samples from the veins contain anomalous concentrations of many elements, but no identified resources were found. Although no mineral resources are exposed at the surface, the USGS studies suggest that some may be present at depth in the veins.

Redcloud Peak Wilderness Study Area

Three mines in the Galena district are adjacent to the Redcloud Peak Wilderness Study Area: the Pride of America, Four Aces, and Ute–Ulay mines (pl. 1). The Pride of America mine (Korzeb, 1986; Sanford and others, 1986) is just outside the northern boundary of the study area and in 1984 was owned by Ada–Mar Mines, Inc., Grand Junction, Colo. A jeep road extending from the main road in Henson Creek Valley provides access to the mine. From this mine, a west-striking vein and a north-striking vein trend into the Redcloud Peak Wilderness Study Area. The veins exposed in the mine consist of brecciated and silicified tuff; white quartz and clay in pods, seams, and stringers; and sulfide minerals. The most abundant sulfide minerals are galena, sphalerite, and pyrite in seams, stringers, pods, and disseminated grains. Chalcopyrite, silver-bearing tetrahedrite, and native silver occur in minor amounts. These two veins have high contents of arsenic, barium, copper, lead, silver, and zinc.

In the north-trending vein at the Pride of America mine, anomalous concentrations are reported (Korzeb, 1986) for arsenic (0.014–0.084 percent), barium (0.006–0.06 percent), copper (0.073–1.3 percent), lead (1.3–18 percent), silver (0.9–78.2 oz per ton), and zinc (0.22–44 percent). Assay grades for elements of potential economic interest average 17.4 oz silver per ton, 6.0 percent lead, and 9.85 percent zinc. In the west-trending vein of the Pride of America mine, grades are: arsenic (0.0021–0.031 percent), barium (0.01–0.1 percent), copper (0.018–0.82 percent), lead (0.012–14.5 percent), silver (0.2–29.9 oz per ton), and zinc (0.017–12.2 percent). The average grade of the vein is 6.9 oz silver per ton, 4.7 percent lead, and 1.7 percent zinc.

The Four Aces mine (Korzeb, 1986) is 600 ft north of the northern boundary of the Redcloud Peak Wilderness Study Area. Stanley Guy, Grand Junction, Colo., owned the Four Aces mine in 1984. A jeep road extending from the main road along Henson Creek provides access to the mine. The Four Aces mine is on the same west-trending vein mined in the Pride of America mine but is 200 ft higher in elevation. The vein is composed of brecciated and silicified tuff; white quartz in stringers, pods, and veinlets; disseminated pyrite; and traces of disseminated galena, sphalerite, and chalcopyrite. Sulfide mineral content is lower at this higher exposure of the vein than in the Pride of America mine.

In the Four Aces mine, anomalously high concentrations of arsenic, barium, lead, silver, and zinc were found in the west-trending vein. Average assay grades for the vein are: arsenic 0.005 percent, barium 0.007 percent, lead 0.13 percent, silver 0.3 oz per ton, and zinc 0.10 percent.

The Ute–Ulay mine (Slack, 1976, 1980), about ½ mi north of the Redcloud Peak study area, was owned in 1984 by LKA International, Inc., Seattle, Wash. Access is from the main road along Henson Creek. This mine has accounted for most of the silver, lead, and zinc produced in the Galena mining district.

The Redcloud Peak Wilderness Study Area has approximately 100 quartz veins of which about 30 are more than 2,000 ft long; some are as much as 1 mi long and extend 1,000 ft vertically (Hon, 1987). These veins consist of brecciated and silicified tuff; stringers, pods, lenses, and seams of white quartz; disseminated pyrite; and traces of galena, chalcopyrite, sphalerite, tetrahedrite, and rhodochrosite. Anomalous amounts of arsenic, barium, lead, silver, and zinc have been found in the veins in the study area. Tetrahedrite, colusite, and telluride minerals have been found in the Sweethome vein (pl. 1) (Korzeb, 1986; R.F. Sanford and A.M. Kramer, unpub. data); semseyite (lead-antimony sulfosalt) has been found in the vicinity of Cooper Creek (fig. 1, pl. 1) (Korzeb, 1986); and tetrahedrite, tennantite, colusite, thorite, and monazite have been found at the Champion mine (R.F. Sanford and A.M. Kramer, unpub. data).

The widest parts of the exposed veins have the highest sulfide mineral content and the highest assay values. The highest values for arsenic, barium, lead, silver, and zinc were found in prospects in the vicinity of Cooper Creek, in the ring fracture near the western boundary of the study area, and in the Sweethome vein.

Handies Peak Wilderness Study Area

In the Handies Peak Wilderness Study Area, there are nearly 50 veins of which about 12 are longer than 2,000 ft and several are longer than 1 mi (Hon, 1987). The veins are composed of brecciated and silicified tuff; pods, stringers, and seams of white quartz; and disseminated grains, pods, seams, and veinlets of pyrite, galena, sphalerite, and chalcopyrite (Korzeb, 1986).

Anomalously high arsenic, barium, copper, lead, silver, and zinc concentrations were found in surface and underground samples of veins in the Handies Peak study area. On the west side of American Basin (fig. 1), one vein is as much as 40 ft thick. At this location, sulfide minerals are more abundant, and analytical values are higher than in samples of the vein where it is less than 10 ft wide. In samples from the 40-ft-wide section of the vein, maximum grades are 2.2 oz silver per ton and 14.3 percent lead compared to 1.0 oz silver per ton and 0.17 percent lead for vein widths of less than 10 ft (Korzeb, 1986).

Mineralogy and geochemistry of the exposed veins in the Handies Peak study area are similar to those of veins in the Pride of America, Four Aces, and Ute–Ulay mines (Korzeb, 1986). No mineral resources were identified at the surface in the study area, but USGS studies show that resources similar to those in formerly producing mines may exist at depth in these veins. Highest grades of mineral resources are most likely to be found where veins exceed 10 ft in thickness and where high values of arsenic, barium, copper, lead, silver, and zinc are found. The Fannie vein in the Bon Homme mine (pl. 2), near the northern boundary of the Handies Peak study area, has had limited production of silver, copper, lead, and zinc; according to the USGS study, additional undiscovered resources of these elements might be found elsewhere in this vein within the wilderness study area.

Geochemical and mineralogical evidence for a porphyry molybdenum deposit was found in a drill hole east of the Handies Peak study area (pl. 2). A 421-ft-long angle hole (−45°) drilled by MAPCO (USBM, unpub. records) adjacent to the southeast corner of the study area intersected approximately 300 ft of Proterozoic granite. The drill core shows alteration, mineralogy, and geochemical concentrations similar to those of porphyry molybdenum deposits at Climax, Colo. (Korzeb, 1986). Pyrite and fluorite are associated with porphyry molybdenum deposits of the Climax type (White and others, 1981, p. 270–271); both were found in quartz veins in the drill core. Propylitically altered rock intersected by the MAPCO drill hole is recognized by the presence of chlorite, epidote, calcite, clay, and sericite and is commonly found in the host rock above Climax-type ore bodies (White and others, 1981, p. 302–303). Veins of massive white quartz containing fluorite and molybdenite also were intersected. Analytical results showed anomalous molybdenum, niobium, strontium, thorium, and uranium concentrations in the quartz veins and adjacent altered rocks. Analytical results of two samples from the quartz veins (provided to USBM by Charles Dustin, Lake City, Colo.) are: molybdenum 0.0002–0.05 percent, niobium 0.002 percent, strontium 0.009 percent, thorium 0.0055 percent, and uranium 0.0003–0.0007 percent. These analytical values are not ore grade and are not diagnostic because only two samples were analyzed, but they do indicate mineralization like that commonly associated with porphyry molybdenum deposits.

ASSESSMENT OF POTENTIAL FOR UNDISCOVERED RESOURCES

Geochemistry

By Richard F. Sanford and Richard I. Grauch

Analytical Methods

Several different analytical techniques were used by the USGS to analyze samples of veins, altered host rocks, and stream sediments in and around the wilderness study areas. The two main analytical techniques used were direct-current arc emission spectroscopy (Myers and others, 1961; Grimes and Marranzino, 1968) and inductively coupled argon plasma atomic emission spectroscopy (Crock and others, 1983). Many other specialized techniques were employed for individual elements. Sample preparation and analytical techniques are described in detail in Sanford and Seeley (1987) and Sanford and others (1987). Of the USGS samples, 412 were from veins and altered host rocks. Twenty-five stream-sediment samples were analyzed by the USGS in order to confirm geochemical anomalies defined by data from 317 stream-sediment samples analyzed by Barringer Research, Inc., for the BLM (Weiland and others, 1980). This data set, hereafter referred to as the BLM data, is a subset of samples from the Lake City–Silverton region. USBM data include 554 samples from prospected veins and mine dumps (S.L. Korzeb, USBM files, Denver; Korzeb, 1986; Sanford and others, 1987). These data were considered along with the USGS and BLM data in the following analysis of the geochemistry.

Analyses of an element were considered anomalous if they exceeded the concentration in 95 percent of the samples of typical host rocks (Sanford and others, 1987). Elements having concentrations more than two orders of magnitude above the minimum anomalous concentration were classified as highly anomalous.

Results of Analyses of Rock Samples

The following elements occur in anomalous concentrations and are important for evaluating the mineral resource potential in the study areas: gold, silver, antimony, arsenic, barium, beryllium, bismuth, boron, copper, indium, iron, lead, manganese, mercury, molybdenum, niobium, phosphorous, rare-earth elements, scandium, strontium, sulfur, tellurium, thallium, thorium, tin, tungsten, uranium, vanadium, and zinc. The complete analytical data are reported in Sanford and others (1987).

The wilderness study areas are extensively mineralized. Virtually all sampled veins show anomalous concentrations of several of the above elements. For example, figure 3 shows the distribution of samples with anomalous gold, silver, or molybdenum concentrations.

Many elements commonly occur together in anomalous amounts; silver, copper, lead, zinc, arsenic, molybdenum, and antimony, for example, form broad anomalies that extend across much of the wilderness study areas as illustrated by the area of anomalous silver concentrations shown on figure 3. This suite of elements is typical of mineralized veins and altered rocks throughout the highly mineralized western San Juan Mountains. For comparison, abundances of these elements in the wilderness study areas are closely similar to those in breccia-pipe deposits of the Red Mountain district near Red Mountain Pass (fig. 2) (Fisher and Leedy, 1973) and the breccia-pipe deposit on Engineer Pass (fig. 2) (Maher, 1983) as shown in table 1. Only the southeast corner of the Redcloud Peak Wilderness Study Area and a narrow strip along the southeast margin of the Handies Peak Wilderness Study Area have no anomalies, which reflects a combination of few samples in areas of poor exposure, difficult access, and an apparent scarcity of veins.

Anomalous gold concentrations are found in scattered localities throughout the northern part of the Redcloud Peak Wilderness Study Area (fig. 3). The Silver Creek–Burrows Park area (fig. 3) is locally anomalous in gold. The Handies Peak Wilderness Study Area has numerous scattered mineral occurrences, especially in the American Basin–Handies Peak area (fig. 3).

Molybdenum concentrations are anomalous in virtually all sampled veins; hence figure 3 shows only molybdenum occurrences that exceed 235 ppm (parts per million). Highly anomalous molybdenum concentrations (as much as 1,000 ppm) are in veins of the Galena and Lake districts northeast of the Redcloud Peak Wilderness Study Area (fig. 2), and the molybdenum there is locally associated with lithium. The contiguous Alpine Gulch area in the Redcloud Peak Wilderness Study Area (fig. 1) also contains very high molybdenum concentrations. Veins on the north and west margins of the Redcloud Peak Wilderness Study Area are also highly anomalous in molybdenum. Very high concentrations also occur in the Handies Peak Wilderness Study Area between American Basin and the Black Wonder mine (fig. 3, pl. 1). Highest concentrations of molybdenum are in the upper parts of Grizzly Gulch, Campbell Creek, and Boulder Gulch drainages (fig. 3). In the Handies Peak area, molybdenum is associated with thallium and barium.

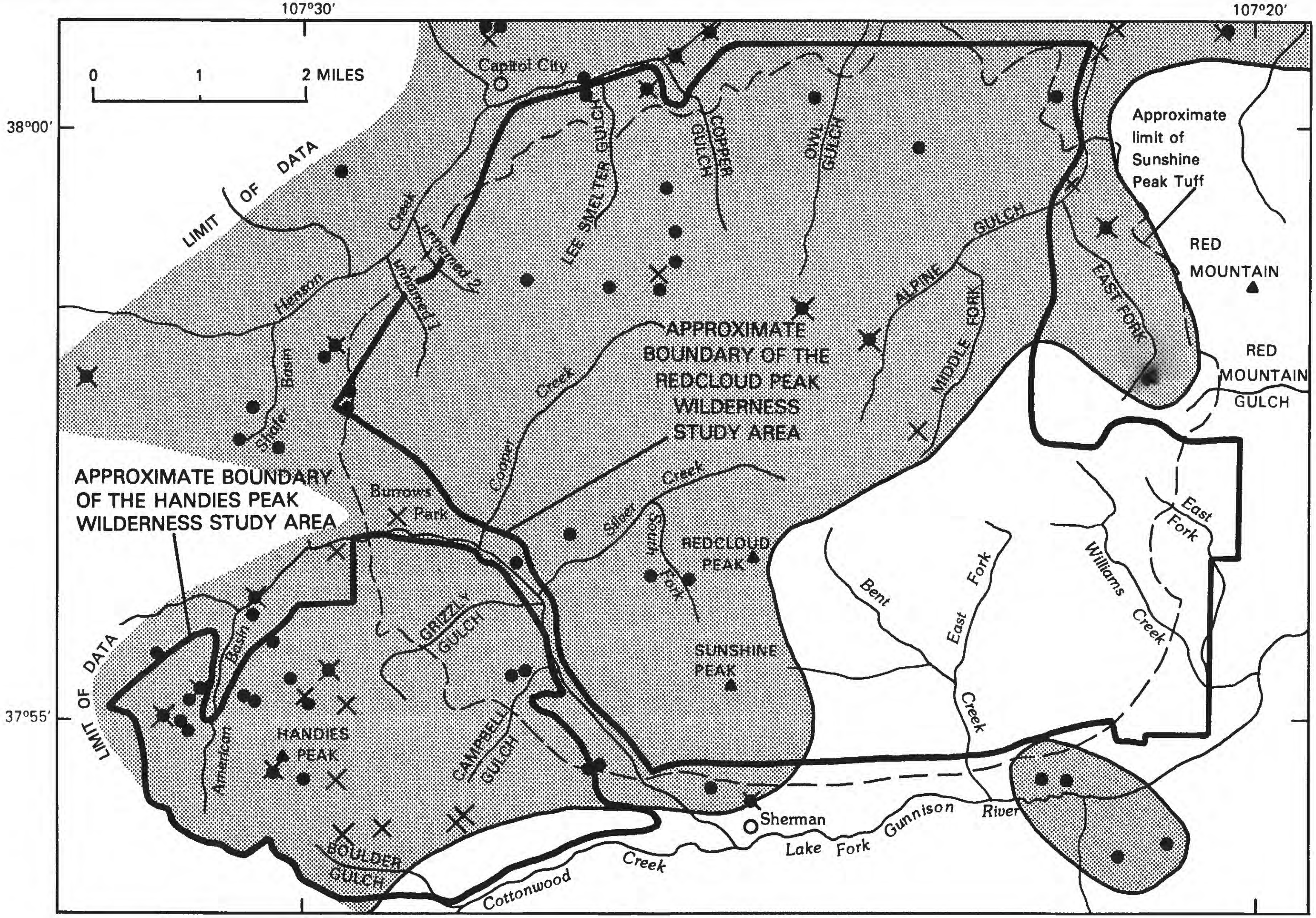
Tungsten and boron concentrations are anomalous in two mineralized samples associated with the quartz monzonite of Alpine Gulch (pl. 1) (Hon, 1987). Tungsten is high in a hematite vein; boron is high in the tourmaline breccia. Because the detection limit (50 ppm) for tungsten is so high above what is typical of the host rocks (2 ppm) (Sanford, 1987), the extent of tungsten anomalies cannot be determined. However, the sample containing 150 ppm is significant because it is about 75 times background.

The elements beryllium, indium, manganese, and tin are closely associated and, according to USGS data (Sanford and others, 1987), are in anomalous concentrations in veins of Burrows Park, upper Cooper Creek, Silver Creek, and Alpine Gulch in the Redcloud Peak Wilderness Study Area and in a vein northeast of Handies Peak in the Handies Peak Wilderness Study Area. USBM data (S.L. Korzeb, USBM files, Denver; Sanford and others, 1987) show a much wider distribution of beryllium over most of the wilderness study areas. High-silica rhyolites north of the Lake City caldera are also strongly anomalous in beryllium (Sanford and others, 1987).

Thorium, rare-earth elements, and phosphorous occur together in veinlets of the Champion mine in Burrows Park (fig. 1, pl. 1) and in a silicified breccia on the northwest margin of the Lake City caldera. A few other locations in the Lake City caldera as well as the high-silica rhyolites north of the Lake City caldera also exhibit anomalous concentrations of one or more of these elements (Sanford and others, 1987).

Results of Analyses of Stream-Sediment Samples

Statistical analysis, including multivariate factor analysis, of the BLM stream-sediment data indicate that the major drainages of both wilderness study areas traverse zones of anomalous metal content. Elemental concentrations are considered anomalous if they are within or above the 90th percentile of the probability distribution. For example, base-metal (copper, lead, and zinc) occurrences are indicated in the areas of American Basin, Shafer Basin, lower Lee Smelter Gulch, and Owl Gulch (fig. 4, table 2). These results are in general agreement with spatially limited investigations conducted by the U.S. Department of Energy (Theis and others, 1981).



EXPLANATION

- Area of samples with anomalous silver (>0.1 ppm)
- ● Sample with anomalous gold (>0.1 ppm)
- × Sample with highly anomalous molybdenum (>235 ppm)

Figure 3. Summary map of rock geochemistry of the Redcloud Peak and Handies Peak Wilderness Study Areas and vicinity. Anomalies in base metals (including lead, zinc, copper, and bismuth) and other elements (such as antimony, arsenic, barium, mercury, and tellurium) that characterize epithermal deposits cover the same general area as anomalous silver. (Data from Sanford and others, 1987.)

Table 1. Comparison of trace-element concentrations in rock samples, Ouray–Silverton–Lake City area, San Juan Mountains, Colorado

[Values in ppm (parts per million); upper value, maximum; lower value, average. Leaders (--), no data]

	Redcloud Peak Wilderness Study Area (Sanford and others, 1987)	Handies Peak Wilderness Study Area (Sanford and others, 1987)	Engineer Pass (Maher, 1983)	Red Mountain District (Fisher and Leedy, 1973)
Ag	500	200	120	200
	30	36	34.1	--
As	5,800	>2,200	790	4,000
	280	360	112	--
Au	15	12	11	3.0
	1.4	2.2	0.68	--
Bi	7,900	100	--	300
	230	25	--	--
Cu	43,000	22,000	--	4,000
	2,000	1,500	--	--
Mn	>84,000	3,000	--	3,000
	3,200	260	--	--
Mo	1,000	1,000	150	--
	53	140	1.98	--
Pb	>91,000	>59,000	16,000	8,300
	3,200	2,900	1,640	--
Sb	>500	>1,000	430	1,000
	51	55	103	--
Zn	>100,000	>120,000	--	1,200
	8,800	4,200	--	--

Absolute tin concentrations of the BLM sample set are suspect because of the digestion method used prior to chemical analysis (Weiland and others, 1980). However, the USGS data (Sanford and others, 1987) confirm the tin anomalies defined by the BLM data. Precious metals (gold and silver) cannot be adequately evaluated with these data because no gold analyses are available, and silver is reported only where it is present in concentrations of 5 ppm or more. However, pathfinder elements, such as arsenic, can be used as indicators of precious metals. Anomalous concentrations of beryllium and manganese were found only in stream drainages underlain by the lower member of the Sunshine Peak Tuff (table 2).

Visual examination of the heavy-mineral fraction of the USGS stream-sediment samples indicates that barite, fluorite, zircon, apatite, pyrite, and anatase are nearly ubiquitous in the central part of the Redcloud Peak Wilderness Study Area. Topaz was tentatively identified in two samples, one from the upper Cooper Creek drainage and one from the upper Silver Creek drainage (fig. 1, pl. 1).

Geophysics

By V.J.S. Grauch and Richard I. Grauch

Gravity Survey and Results

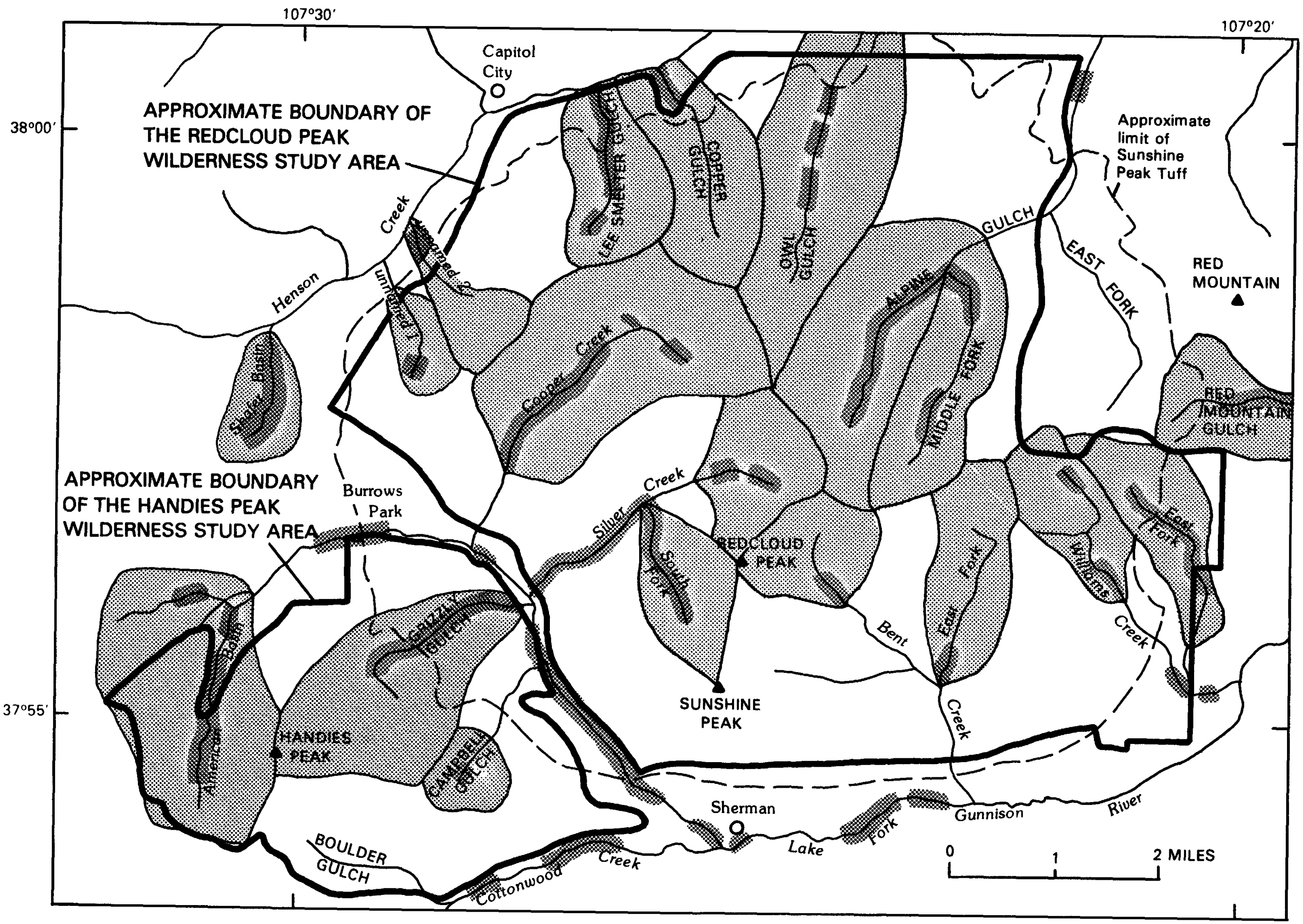
Gravity data for the Handies Peak and Redcloud Peak Wilderness Study Areas were acquired from Grauch and Campbell (1985) and the Department of Defense data bank (NOAA National Geophysical Data Center). Grauch and Campbell (1985) described the data reduction procedure. A complete Bouguer anomaly map for the study areas and surrounding region is shown on figure 5. The reduction density for this map is 2.40 g/cm^3, reflecting the density of the ash-flow tuff within the Lake City caldera, where most of the gravity measurements were collected. Anomalies (closed contours) on this map indicate areas where the density of rocks deviate from 2.40 g/cm^3.

Several Bouguer anomalies indicate subsurface intrusions. The broad high (H1) (fig. 5) covering the northwestern part of the Lake City caldera generally coincides

Table 2. Distribution of anomalous elements and oxides in stream-sediment samples, Redcloud Peak and Handies Peak Wilderness Study Areas, southwestern Colorado

[X, more than 1 anomalous sample in the drainage; (X), a single anomalous sample in the drainage. See fig. 4 for locations of drainage basins. Data from Weiland and others (1980); 317 samples from data set were used, sample numbers are: 1112-1172, 1241-1280, 1283, 1287, 1295-1302, 1307-1309, 1329- 1332, 2012, 2030-2031, 2038-2052, 2107-2111, 2120-2133, 2136-2160, 2202-2232, 2239-2269, 2280-2301, 2308-2318, 3000-3021]

Drainage basin	Principal geologic unit drained	Anomalous elements and oxides															
		Fe_2O_3	Cr	Co	Ni	K_2O	U	Sn	Be	MnO_2	Mo	Cu	Pb	Zn	As	Ag	Ba
Lake Fork Gunnison River:																	
American Basin area	Picayune Megabreccia Member of Sapinero Mesa Tuff.		X								X	X	X	(X)	X		X
Between Burrows Park and Sherman.	Lower member of Sunshine Peak Tuff-	X			(X)		X		X	(X)	X	X	(X)	X			
East of Sherman	Proterozoic granite----------------					X	X										
Grizzly Gulch:																	
Upper	Proterozoic granite----------------				X			(X)					X		X		
Lower	Lower member of Sunshine Peak Tuff-	X		(X)	X			(X)							X		X
Campbell Creek:																	
Upper	Proterozoic granite----------------			(X)													
Lower	Lower member of Sunshine Peak Tuff-					X											X
Boulder Gulch	Silverton Volcanics (andesite and sandstone).	(X)															
Cottonwood Creek	Proterozoic granite----------------	X	(X)				X				(X)	X					X
Unnamed #1	Lower member of Sunshine Peak Tuff-		(X)														
Unnamed #2	Lower member of Sunshine Peak Tuff-					X				X	X		(X)				
Smelter Gulch:																	
Upper	Lower member of Sunshine Peak Tuff-				(X)					X	X						
Lower	Eureka Member of Sapinero Mesa Tuff	X	(X)	(X)	(X)						X	X	X			(X)	
Copper Gulch:																	
Upper	Lower member of Sunshine Peak Tuff-			X	(X)												
Lower	Eureka Member of Sapinero Mesa Tuff				(X)						X						
Owl Gulch	Lower member of Sunshine Peak Tuff-		(X)	(X)			(X)				(X)	X	(X)				
Alpine Gulch	Lower member of Sunshine Peak Tuff-			X		X		X	X	X	X			X		(X)	(X)
Alpine Gulch Middle Fork	Lower member of Sunshine Peak Tuff-			X					X		X			X			
Alpine Gulch East Fork	Lower member of Sunshine Peak Tuff-	X															
Williams Creek:																	
Upper	Upper member of Sunshine Peak Tuff-	X				X	(X)	(X)									
Lower	Silverton Volcanics (dacite)-------	X		(X)				X									(X)
Williams Creek East Fork:																	
Upper	Upper member of Sunshine Peak Tuff-							X									
Lower	Dacite of Grassy Mountain and Silverton Volcanics.			(X)				X									
Bent Creek:																	
Upper	Lower member of Sunshine Peak Tuff-					X			X	(X)	X						
Lower	Middle and upper members of Sunshine Peak Tuff.					X	(X)										
Silver Creek	Lower member of Sunshine Peak Tuff-				(X)		X	X	X	X	X			X		(X)	(X)
Silver Creek South Fork	Lower member of Sunshine Peak Tuff-				(X)		X	X	X	X		(X)	(X)	X	X		(X)
Cooper Creek:																	
Upper	Lower member of Sunshine Peak Tuff-	X	(X)				X	X	(X)				(X)				
Lower	Lower member of Sunshine Peak Tuff-						X	X					(X)				
Shafer Basin	Eureka Member of Sapinero Mesa Tuff					X					X	X	X	X	X		
Red Mountain Gulch	Dacite of Grassy Mountain----------	X	(X)	X		X			(X)	X				X		X	(X)
Minimum concentration considered anomalous (90 percent of samples contain less than this amount; ppm unless noted otherwise)-----			8.6%	30	41	17	4.8%	17	159	6.3	0.3%	8	47.5	85	382	48	5



EXPLANATION

Areas containing anomalous values— See table 2 for specific anomalous elements and oxides. Fe_2O_3 and K_2O not included here

Generalized drainage basins of first-order streams whose samples had anomalous values

Figure 4. Summary map of stream-sediment geochemistry of the Redcloud Peak and Handies Peak Wilderness Study Areas and vicinity. (Data from Weiland and others, 1980.)

with a broad aeromagnetic high and with outcrops of quartz syenite. H1 probably reflects the resurgent intrusion under the caldera. The gravity and magnetic models of Grauch (1985) suggest that H5 is caused by a southern, deeper extension of the intrusion. The models also suggest that the crescent-shaped high centered on Red Mountain (H2) is produced by a deep intrusive body that is more magnetic and denser than the resurgent intrusion. This body may have fed the Red Mountain dacite dome just east of the Redcloud Peak Wilderness Study Area.

The large-magnitude, local high anomaly between Silver Creek and Cooper Creek (H3) has no corresponding aeromagnetic or surface expression, but may indicate a small dense intrusion that has lost its magnetic minerals through hydrothermal alteration. Preliminary gravity modeling with simple geometric shapes constrain estimates of the density and shape of the causative body. The body is probably fairly close to the surface (within the first hundred feet) and does not extend laterally much more than ¾ mi in any direction. The body also extends to great depth and is denser than 2.67 g/cm^3. These constraints suggest that H3 represents a body of intermediate or mafic composition that locally intruded the Sunshine Peak Tuff. Its location within an area of extensive hydrothermal alteration may explain the lack of an associated aeromagnetic anomaly.

The low along Alpine Gulch (L1) coincides with a major tear fault (pl. 1). L1 is probably caused by low-density material that is spatially associated with the fault. The quartz monzonite of Alpine Gulch at the mouth of Alpine Gulch crops out only on the west side of this tear fault. The aeromagnetic data (High Life Helicopters/QEB, 1981) confirm that the quartz monzonite occurs only on the west side, even at depth, and in fact may continue just below the surface about a mile to the northwest.

Anomalies located in or near the Handies Peak Wilderness Study Area are the lows in Burrows Park (L2), along Grizzly Gulch (L3), and straddling the edges of the two study areas (L4), and a high (H4) centered around Handies Peak. L2 and L3 may be due to fracturing and alteration typical of the Eureka graben (fig. 2). The low at L4 suggests a local area of low-density rock, and coincides with an area of hydrothermally altered rock that was inferred from electrical studies (Pierce and Hoover, 1985). Hydrothermal solutions at shallow depth may have altered the minerals of the rocks in this area to lower density minerals. The aeromagnetic map (fig. 6) shows a negative anomaly (L2) coinciding with gravity anomaly L3 and bordering L4. This aeromagnetic low also suggests an area that has lost its magnetic minerals through hydrothermal alteration (Grauch, in press).

The high gravity anomaly centered around Handies Peak (H4) is poorly constrained. It may be caused by an underlying intrusion. The steep sides of this anomaly suggest a shallow source, although there is no surface evidence for a shallow intrusion in this area. The high anomaly more likely indicates that the material making up Handies Peak is somewhat denser than the reduction density of 2.40 g/cm^3.

Aeromagnetic Survey and Results

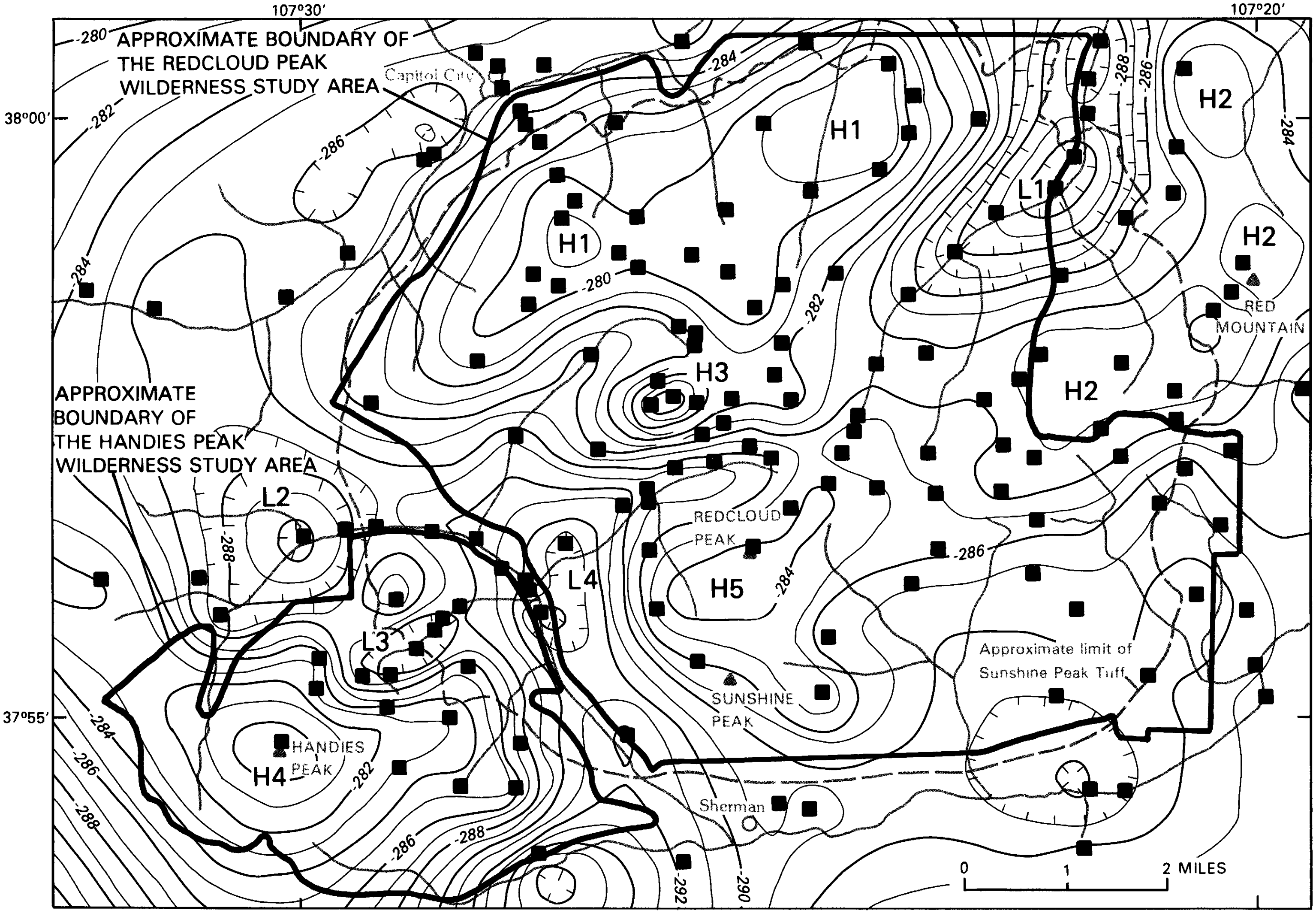
Detailed aeromagnetic data over the Redcloud Peak and Handies Peak Wilderness Study Areas (High Life Helicopters/QEB, 1981) have been evaluated elsewhere (Grauch, in press). In addition, regional aeromagnetic data (U.S. Geological Survey, 1972) and another detailed survey (High Life Helicopters/QEB, 1983) were available but were not evaluated during this investigation. The 1983 High Life survey shows the same features as the 1981 High Life survey and covers a similar area. A total intensity aeromagnetic anomaly map for the study areas and vicinity is shown on figure 6.

The aeromagnetic data over the study areas reflect mostly rocks exposed at the surface, such as at anomalies L1, H1, H2, and H3 on figure 6 (Grauch, in press). Aeromagnetic anomalies H4 and H5 confirm the presence of the quartz syenite resurgent intrusion, expressed as gravity anomaly H1, and the intrusion centered under Red Mountain, expressed as gravity anomaly H2. In addition, a steep-sided, local aeromagnetic anomaly (H6), which has no gravity counterpart, occurs over alluvium 2.5 mi west of Grassy Mountain, crossing the contacts between ash flows of the lower and middle and the middle and upper members of the Sunshine Peak Tuff (pl. 1) (Hon, 1987). The source of the anomaly must be strongly magnetic and very shallow (under the alluvium or within it), but there is nothing anomalous at the surface. The absence of an associated gravity anomaly suggests that the magnetic source is not an intrusion.

A broad, low aeromagnetic anomaly (L2 on fig. 6) coincides with gravity anomaly L3 and borders on L4 (fig. 5). As discussed in the previous section, this area may have experienced extensive hydrothermal alteration at shallow depths.

Aeroradiometric Survey and Results

Aeroradiometric data covering both the Redcloud Peak and Handies Peak Wilderness Study Areas were collected by High Life Helicopters, Inc. (High Life Helicopters/QEB, 1981). The data are in general agreement with those obtained by two earlier surveys (Western Geophysical Company of America, 1979; GeoMetrics, Inc., 1979). These latter two surveys were not evaluated as part of this study. Interpretation of the High Life Helicopters, Inc., data by Pitkin and Duval (1982) suggests that within the wilderness study areas the chemistry of the exposed rocks is accurately reflected by the airborne measurement of eU (equivalent uranium), eTh (equivalent thorium), and K (potassium). Highly anomalous concentrations of these elements were not recognized within the study areas.



EXPLANATION

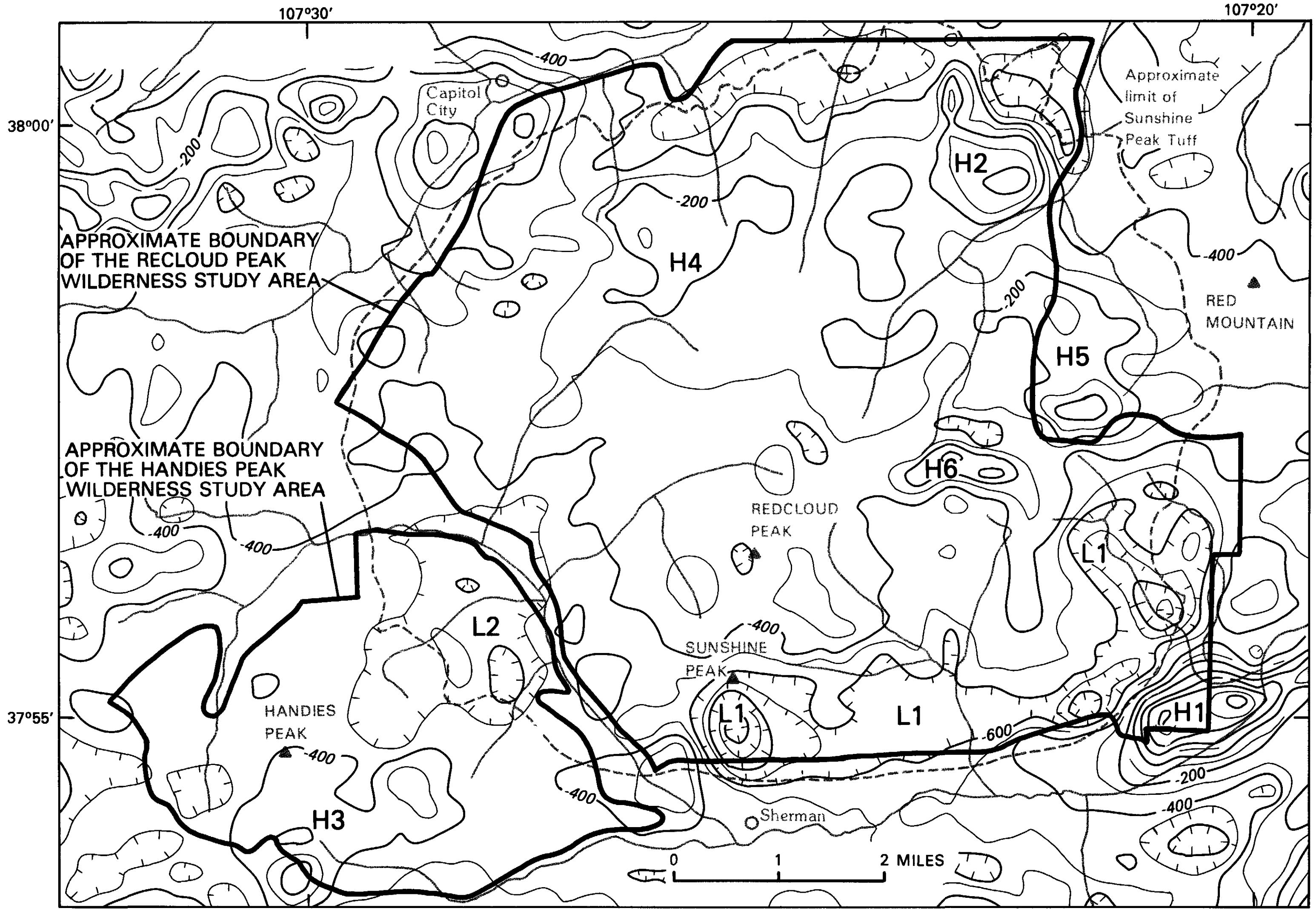
-288 **Gravity contours**--Contour interval 1 milligal. Hachures indicate closed lows

■ **Gravity station**

H4 **Gravity high**--Referred to in text

L2 **Gravity low**--Referred to in text

Figure 5. Complete Bouguer gravity anomaly map of the Redcloud Peak and Handies Peak Wilderness Study Areas. Reduction density = 2.40 g/cm^3.



EXPLANATION

-400 **Aeromagnetic contours**--Contour interval 100 gammas. Hachures indicate closed lows

H3 **Aeromagnetic high**--Referred to in text

L2 **Aeromagnetic low**--Referred to in text

Figure 6. Total intensity aeromagnetic anomaly map of the Redcloud Peak and Handies Peak Wilderness Study Areas. The survey was draped an average of 400 ft above ground with north-south flight lines spaced 1/3 mi apart (High Life Helicopters/QEB, 1981).

Rhyolite intrusions immediately north of the Redcloud Peak Wilderness Study Area, which are associated with minor uranium deposits, have slightly elevated (>0.5) eU/eTh ratios. Several small areas within both study areas have ratios greater than 0.5; however, they do not correspond to mapped rhyolite intrusions and are interpreted in a later section on resource potential for uranium as due to uranium enrichment related to potential vein-type deposits.

Electrical Survey and Results

Pierce and Hoover (1985) conducted an audiomagnetotelluric traverse across both of the study areas (fig. 7) and a telluric traverse through Burrows Park just north of the Handies Peak Wilderness Study Area. Both techniques are designed to measure variations in resistivity of rocks in the near surface and deeper subsurface. Areas of low resistivity may indicate altered rock and (or) water-saturated, conductive material. Three areas of anomalously low resistivity were defined within the study areas. The ring fault of the Lake City caldera marks a deep zone of very low resistivity, which Pierce and Hoover (1985) interpreted as a zone of alteration and possible mineralization. This area generally coincides with gravity and aeromagnetic lows, L4 on figure 5 and L2 on figure 6. In addition, a steeply dipping resistivity gradient occurs near Silver Creek, and a gently east-dipping resistivity gradient occurs between Middle Fork Alpine Gulch and East Fork Alpine Gulch. Pierce and Hoover (1985) interpreted both of these anomalies as manifestations of contact zones between the resurgent intrusion of the Lake City caldera and the Sunshine Peak Tuff.

Mineral and Energy Resource Potential

Epithermal Precious-Metal (Silver and Gold) and Base-Metal (Principally Lead, Zinc, and Copper) Deposits

By Richard F. Sanford

Criteria for Recognition of Epithermal Deposits

Epithermal ore deposits are those formed by precipitation of metals from hydrothermal solutions at moderate temperatures (200–300 °C) and relatively shallow depth (a few hundred to several thousand feet). The hydrothermal solution was originally meteoric water, which percolated downward through fractures and pore spaces in the rocks and was then heated, presumably by deep-seated igneous intrusions. As the temperature of the water increased, the water reacted with and leached metals from the enclosing rocks. Where this solute-laden fluid rose by convection through fractures and pore spaces toward the surface, it cooled and (or) mixed with dilute surface water causing the metals to drop out as sulfides, sulfosalts, and other valuable minerals.

The commodities of epithermal deposits are principally gold, silver, lead, copper, and zinc. Other commodities in this type of deposit include antimony, bismuth, cadmium, manganese, mercury, selenium, tellurium, tungsten, barite, and fluorspar. Anomalous associated elements that are primarily useful as exploration guides include, in addition, arsenic, barium, molybdenum, niobium, thallium, and tin (Fisher and Leedy, 1973; Ashley, 1982; Berger, 1982; Silberman, 1982; Bonham, 1984, 1986; Tooker, 1985).

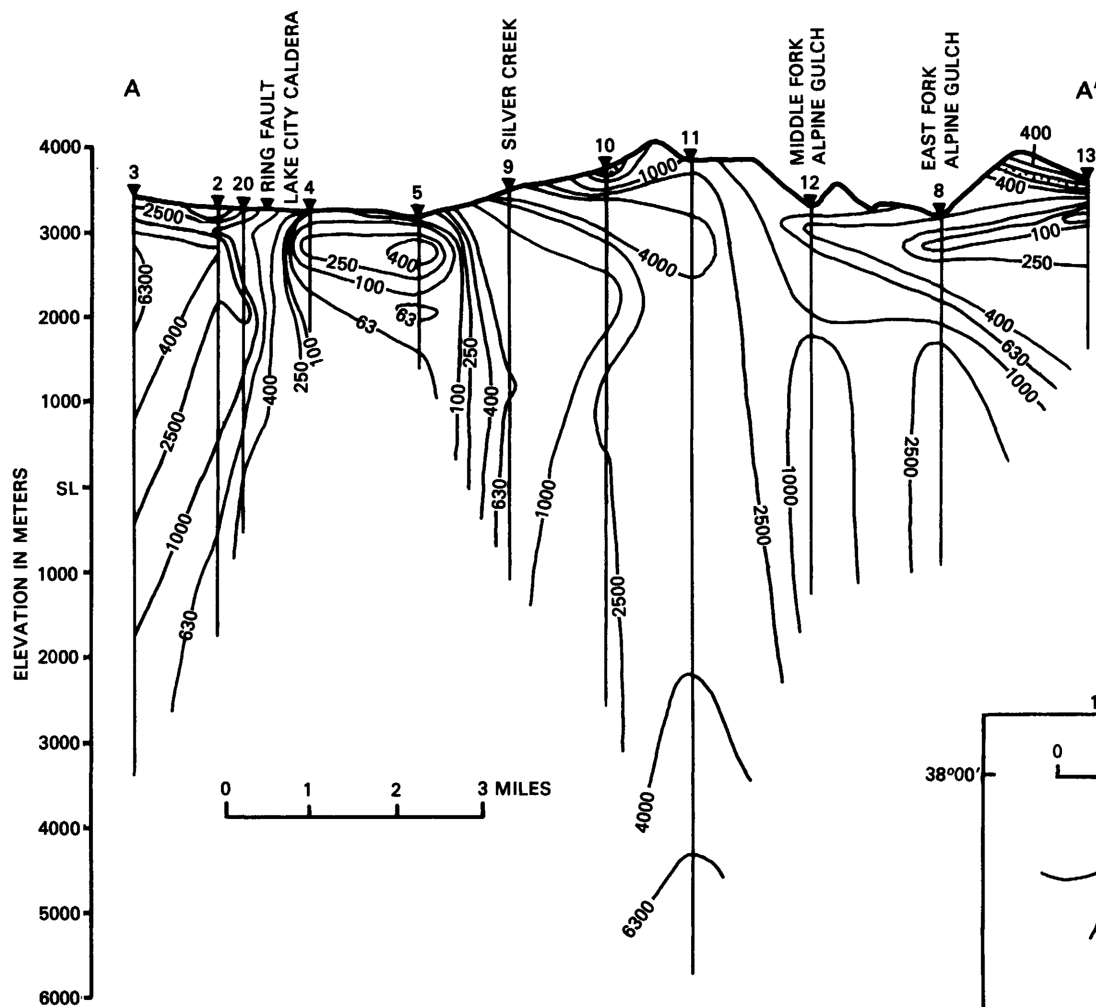
The common tectonic setting for epithermal deposits is a stable continental craton covered by a thick volcanic pile of rhyodacitic to rhyolitic flows and tuffs (Barton and others, 1982).

Structures favorable for the occurrence of epithermal deposits in volcanic terrane are usually faults, fractures, and cavities that have formed during multiple generations of fracturing associated with caldera collapse, resurgent doming, and graben formation (Berger, 1982; Hayba and others, 1985; Heald and others, 1987). Multiple episodes of fracturing and brecciation favor the circulation of hydrothermal fluids. Major faults that bound graben structures and collapse calderas are particularly favorable for large deposits, although important deposits, notably those at the Ute–Ulay mine, are hosted by relatively small isolated structures. In the western San Juan Mountains, the most favorable formations are the San Juan Formation, the Silverton Volcanics, and the Eureka and Picayune Megabreccia Members of the Sapinero Mesa Tuff (Bejnar, 1958).

Alteration around epithermal deposits includes propylitic, silicic, sericitic, argillic, and advanced argillic types. Regional propylitization of host rocks is virtually ubiquitous in mineralized areas.

The study areas are favorable for the occurrence of four types of epithermal deposits: vein, breccia-pipe, volcanic-hosted disseminated, and clastic-sediment disseminated.

Previous work shows that the historically most important epithermal deposits in the San Juan Mountains region are those in veins. The Idarado–Camp Bird (Moehlman, 1936; Hildebrand, 1957), Sunnyside (Burbank and Luedke, 1968; Casadevall and Ohmoto, 1977), and Creede (Steven and Ratté, 1965; Steven and Eaton, 1975; Barton and others, 1982) deposits in the San Juan Mountains are examples of this type. Veins are formerly open fractures and faults that have since been filled by hydrothermally deposited minerals. They are typically steeply dipping to vertical and are orders of magnitude longer than they are wide. Individual veins are typically a few feet wide and as much as several miles long. At depth, they extend to hundreds or thousands of feet. Ore occurs as pods or lenses separated by barren waste material such as quartz. Because of this variability within veins, it is important to recognize that seemingly barren



EXPLANATION

(400) **Audio-magnetotelluric contours** -- Contours in ohmmeters. Hachures indicate decreasing values

2 ▼ **Audio-magnetotelluric station**

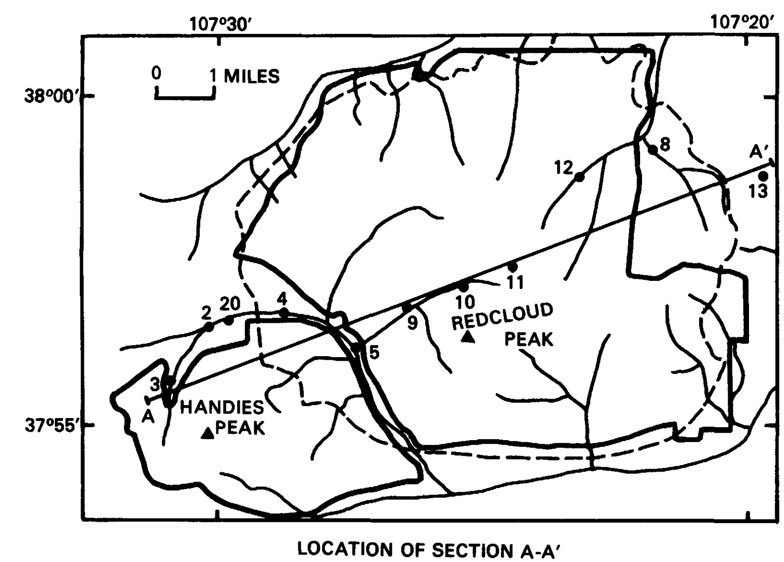


Figure 7. Audio-magnetotelluric cross section through the Redcloud Peak and Handies Peak Wilderness Study Areas. Vertical exaggeration 1.6:1. (Modified from Pierce and Hoover, 1985.)

veins at the surface may be rich in ore at depth, and, conversely, rich veins at the surface may be barren at depth. Vein-type deposits typically exhibit potassium-feldspar "flooding" and sericitization adjacent to the veins and sericitic to argillic caps above the ore (Barton and others, 1982).

The second type of epithermal deposit is a breccia-pipe deposit. The Red Mountain district between Silverton and Ouray (Ransome, 1901) contains many deposits of this type. Other examples near the study area are the Engineer Pass deposit (Maher, 1983), the Golden Wonder mine (Billings and Kalliokoski, 1982; Kalliokoski and Billings, 1982), and the Carson camp deposits (Larsen, 1911). Breccia pipes are roughly cylindrical in shape, equidimensional in plan, and tens to hundreds of feet in diameter. Surface expression of pipe-like bodies ranges from very prominent silica caps having varicolored red, orange, and yellow alteration halos to subtle ring-shaped fractures and brecciated zones with little hydrothermal alteration. Breccia-pipe deposits are generally smaller and have higher grades than vein-type deposits. Typically, the ore fills the interstices of fault and hydrothermal breccias. Acid dissolution typically has enlarged the cavities and locally provided additional space for mineral deposition. Such deposits are commonly leached in the center with surrounding zones of intense silicification and advanced argillic alteration. They tend to be concentrated along the ring faults of calderas (Hayba and others, 1985; Heald and others, 1987).

The third type of epithermal deposits is disseminated deposits in volcanic rocks. Round Mountain in Nevada (Berger and Tingley, 1980; Sander and Mills, 1984) typifies this type of deposit. Precious metals (gold and silver) are usually the only mineral commodities. In these deposits, a large volume of volcanic rock has been mineralized either in an extensive network of small veinlets or in the primary pore spaces of a permeable nonwelded tuff. Ore bodies vary in size from minor deposits adjacent to veins to major deposits covering square miles. Locally, stockworks in the hanging walls of veins are more productive than the veins. Some districts show several structural types of epithermal deposits (for example, veins, stockworks, and replacements) that are controlled by local differences in the host rocks. Thus, areas having known deposits of precious metals in veins in volcanic rocks are favorable for the occurrence of disseminated deposits.

Disseminated deposits in clastic rocks are the fourth type of epithermal deposits considered here. The Bachelor Mountain deposit at Creede, Colo. (Smith, 1981; Rice, 1984) is one example. Ore minerals were deposited in primary and secondary pore spaces in permeable volcaniclastic sandstones. Sediment-hosted ore bodies occur as disseminations in small bodies adjacent to veins as at the Idarado mine (Mayor and Fisher, 1972), in larger bodies where veins in volcanic rocks terminate against lacustrine volcaniclastic sediments as at Creede (Smith, 1981; Rice, 1984), and as large bodies covering square miles in volcaniclastic sediments as at Sulfur and Hasbrouck Peak, Nev. (Silberman, 1982). Permeable host rocks and adjacent mineralized veins are considered as favorable indicators for the occurrence of this type of deposit.

Evaluation of Mineral Resource Potential for Epithermal Deposits—General Statement

The study areas have regions of high mineral resource potential and regions of moderate potential for principally silver, gold, lead, zinc, and copper in epithermal deposits, with certainty levels ranging from B to D. The Redcloud Peak and Handies Peak Wilderness Study Areas are in Tertiary volcanic terrane that is highly fractured and faulted as a result of repeated episodes of caldera collapse and graben formation. Such a setting favors the formation of all types of epithermal deposits. Mapping (Hon, 1987; this report) and geophysical data (Grauch, 1985) indicate that large intrusions capable of driving convective hydrothermal circulation underlie the Redcloud Peak Wilderness Study Area, although similar clear evidence for intrusions in the Handies Peak Wilderness Study Area is lacking. Geophysical data also suggest several areas of intense fracturing and alteration in both areas. The wilderness study areas lie in or adjacent to the highly mineralized San Juan–Uncompahgre caldera complex, which includes the Eureka graben.

Almost all of the Redcloud Peak and Handies Peak Wilderness Study Areas has anomalous concentrations of virtually all the elements associated with epithermal deposits elsewhere in similar volcanic environments. These geochemical anomalies are favorable indicators for the occurrence of all the types of epithermal deposits discussed here.

Regional propylitic alteration is widespread especially in the lower two members of the Sunshine Peak Tuff (Hon, 1987), in the lower part of the Eureka Member of the Sapinero Mesa Tuff (Lipman, 1976a), and in the Proterozoic rocks closest to the ring fault of the Lake City caldera and to the Eureka graben (Larson and Taylor, 1986). Quartz-sericite-pyrite alteration, corresponding to hematite- and limonite-altered areas on plate 1, occurs around the resurgent intrusion in the Lake City caldera and in most rocks adjacent to veins in the two study areas (Hon, 1987). Similar alteration has affected rocks in the Capitol City area (Slack, 1976; Steven and others, 1977). Oxygen-isotope data also indicate hydrothermal alteration in the study areas (Larson, 1983; Larson and Taylor, 1986). Electrical studies suggest that much intensely altered rock is associated with the ring fault in the Burrows Park area (pl. 1, fig. 7) (Pierce and Hoover, 1985). The widespread and locally intense alteration in the study areas is a favorable indicator for all varieties of epithermal deposits.

Vein-Type Epithermal Deposits

Both study areas contain regions of high and moderate mineral resource potential for silver, gold, lead, zinc, copper, and smaller amounts of antimony, barite, bismuth, cadmium, fluorspar, manganese, mercury, selenium, tellurium, and tungsten in vein-type epithermal deposits, with certainty levels D and C, respectively. Deposits likely to be found probably would be medium to small in size relative to other deposits in the western San Juan Mountains. The general tectonic, structural, and geochemical characteristics of the Redcloud Peak and Handies Peak Wilderness Study Areas are similar to those of known mineralized areas nearby. For example, the Sunnyside mine in the Eureka graben lies on a major fault whose extension lies just to the north of the Handies Peak Wilderness Study Area (Luedke and Burbank, 1987). Many related, parallel, northeast-trending faults that bound the southern part of the Eureka graben pass through the Handies Peak Wilderness Study Area, and also are mineralized both outside and inside the Handies Peak Wilderness Study Area, suggesting that similar deposits might be found. Most likely, such deposits would be small, but large deposits like the Sunnyside are possible. In the Lake City caldera, however, the hydrothermal circulation was separate from that in the Eureka graben, as shown by Sanford and Ludwig (1985) using lead-isotope data. These lead-isotope data also suggest that rocks of the San Juan Formation, a favorable host for ore deposits, may underlie parts of the Redcloud Peak study area. Based on known occurrences in the Lake City caldera, undiscovered deposits in the Redcloud Peak Wilderness Study Area are probably small and scattered, but larger deposits may exist at depth if the San Juan Formation is present.

Although mineralized faults and fractures are numerous in the study areas, they tend to be shorter and narrower and to intersect each other less commonly than those in the most productive mining areas of the western San Juan Mountains. Thus, the hydrothermal circulation in the study areas was probably more limited and local in extent. These factors suggest that any deposits at depth in the study areas might be smaller than the giant deposits of the western San Juan Mountains, such as the Sunnyside, Idarado, and Camp Bird mines.

Most of the rocks exposed in the study areas are favorable for vein-type deposits based on the compilation by Bejnar (1958). The San Juan Formation, which is not exposed on the surface but which may exist widely at depth in the study areas, is the most favorable unit. The Silverton Volcanics, the intracaldera members of the Sapinero Mesa Tuff, and the Proterozoic granite of Cataract Canyon, which crop out primarily in the Handies Peak Wilderness Study Area (Lipman, 1976a; Hon, 1987) (pl. 2), are moderately favorable. The Sunshine Peak Tuff, underlying large parts of both study areas, is lithologically similar to the intracaldera members of the Sapinera Mesa Tuff and is considered by analogy to be moderately favorable as a host rock.

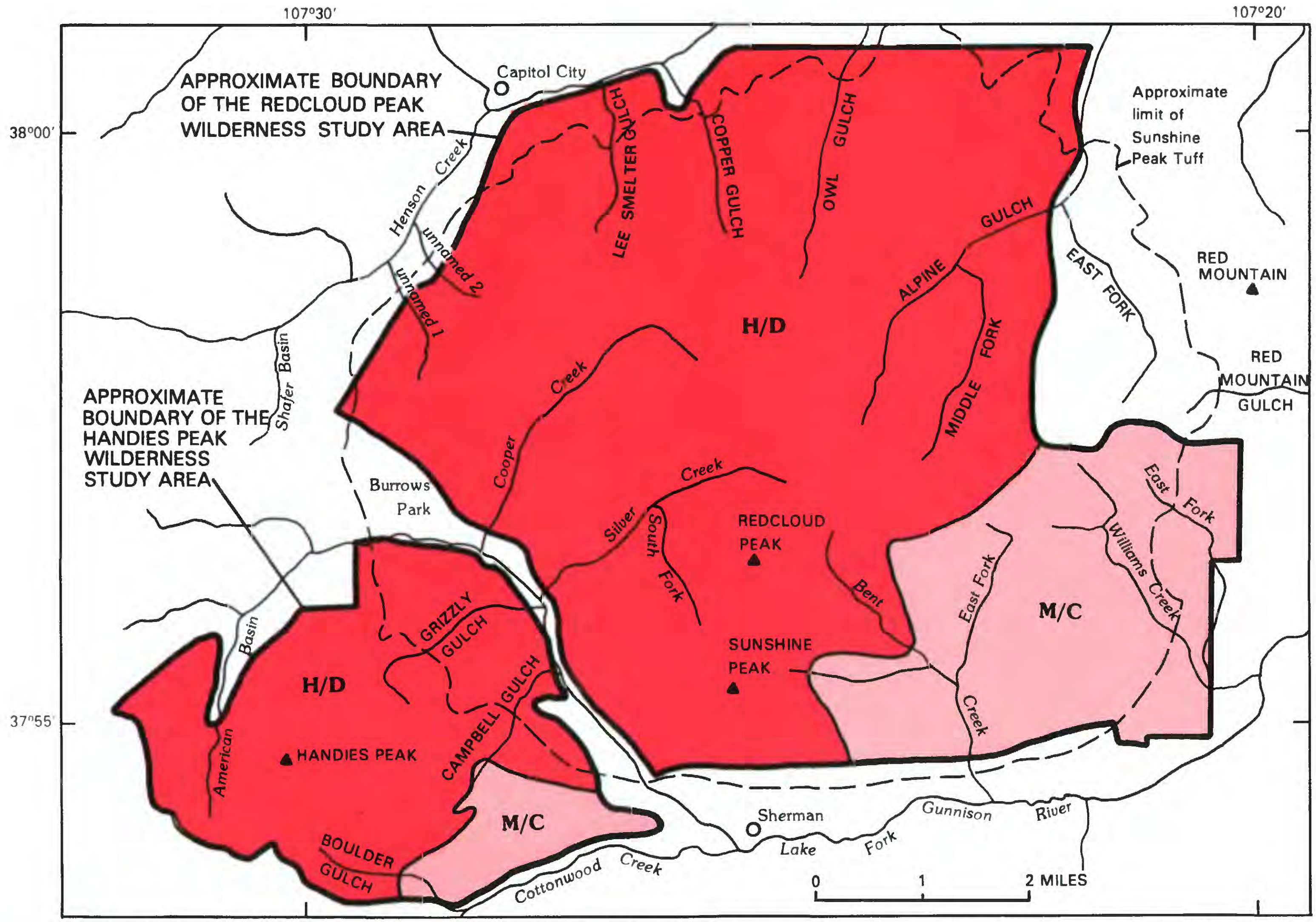
The potential for resources of silver, gold, lead, zinc, copper, and minor antimony, barite, bismuth, cadmium, fluorspar, manganese, mercury, selenium, tellurium, and tungsten in vein-type deposits (fig. 8) is high and clearly defined (certainty level D) over most of the Redcloud Peak and Handies Peak Wilderness Study Areas, and moderate and less well defined (certainty level C) over the remaining areas. Previously, Irving and Bancroft (1911), Burbank (1947a, p. 439 and 443), and Kelley (1946) also concluded that the potential for undiscovered vein-type deposits is high.

Breccia-Pipe-Type Epithermal Deposits

Several areas within the Redcloud Peak Wilderness Study Area and one area in the Handies Peak Wilderness Study Area have high potential for resources of silver, gold, lead, zinc, copper, and smaller amounts of antimony, barite, bismuth, cadmium, fluorspar, manganese, mercury, selenium, tellurium, and tungsten in breccia-pipe deposits (fig. 9). Silicified breccia was found at four locations in the Redcloud Peak Wilderness Study Area (pl. 1, fig. 9) (Hon, 1987). These breccias are in broad varicolored zones of hematite- and limonite-stained, silicified, and sericitized rock (Lee, 1986; Hon, 1987), and in areas of anomalous concentrations of uranium (Grauch, this report) and of base and precious metals, beryllium, indium, manganese, and tin (Sanford and others, 1987). In addition to these specific favorable indicators, the general setting in a caldera with resurgent intrusions is also favorable. Therefore, the areas having the most intensely altered and brecciated rock have high mineral resource potential for silver, gold, lead, zinc, copper, and minor antimony, barite, bismuth, cadmium, fluorspar, manganese, mercury, selenium, tellurium, and tungsten in breccia-pipe deposits (certainty level D). A moderate rating (certainty level D) for these same commodities is given to the surrounding terrane that lacks breccias and is less altered, but that may have buried deposits based on the presence of generally favorable terrane and evidence of mineralization (fig. 9). Areas of generally favorable terrane but little evidence of mineralization or alteration are assigned a low mineral resource potential (certainty level D) for the previously mentioned commodities.

Volcanic-Hosted Disseminated-Type Epithermal Deposits

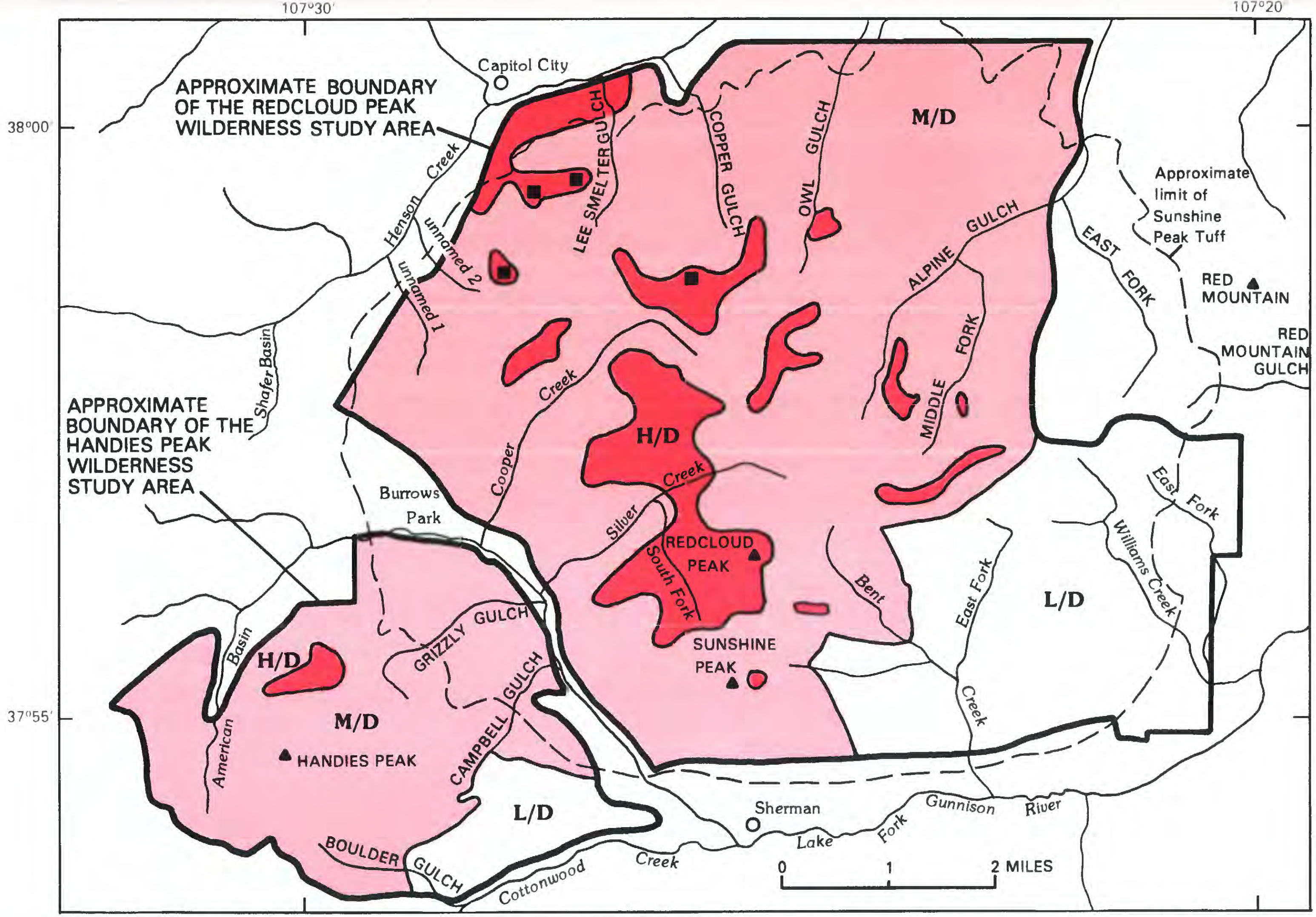
Large parts of the study areas have moderate mineral resource potential for gold and silver in volcanic-hosted disseminated epithermal deposits. The Eureka Member of the Sapinero Mesa Tuff and the Sunshine Peak Tuff tend to break in a network of small cracks rather than in large fractures (Burbank, 1941, p.250; Kelley,



EXPLANATION OF MINERAL RESOURCE POTENTIAL FOR SILVER, GOLD, LEAD, ZINC, COPPER, AND ASSOCIATED COMMODITIES IN VEIN-TYPE EPITHERMAL DEPOSITS

H/D	Geologic terrane having high mineral resource potential, with certainty level D
M/C	Geologic terrane having moderate mineral resource potential, with certainty level C

Figure 8. Mineral resource potential for silver, gold, lead, zinc, copper, and minor antimony, barite, bismuth, cadmium, fluorspar, manganese, mercury, selenium, tellurium, and tungsten in vein-type epithermal deposits, Redcloud Peak and Handies Peak Wilderness Study Areas.



EXPLANATION OF MINERAL RESOURCE POTENTIAL FOR SILVER, GOLD, LEAD, ZINC, COPPER, AND ASSOCIATED COMMODITIES IN BRECCIA-PIPE-TYPE EPITHERMAL DEPOSITS

H/D — Geologic terrane having high mineral resource potential, with certainty level D

M/D — Geologic terrane having moderate mineral resource potential, with certainty level D

L/D — Geologic terrane having low mineral resource potential, with certainty level D

■ — Silicified breccia

Figure 9. Mineral resource potential for silver, gold, lead, zinc, copper, and minor antimony, barite, bismuth, cadmium, fluorspar, manganese, mercury, selenium, tellurium, and tungsten in breccia-pipe-type epithermal deposits, Redcloud Peak and Handies Peak Wilderness Study Areas.

1946, p. 318ff; Lipman, 1976a), and therefore are less favorable for large mineralized fissure veins but more favorable for disseminated-type deposits. Consequently, there is a moderate mineral resource potential for gold and silver in volcanic-hosted disseminated deposits in areas underlain by the Eureka Member and the Sunshine Peak Tuff, but the certainty level is speculative (B) (fig. 10). Such deposits most likely would be small and adjacent to veins. Remaining areas have low mineral resource potential for gold and silver in this type of deposit (certainty level B).

Clastic-Sediment Disseminated-Type Epithermal Deposits

The parts of the study areas underlain by volcaniclastic sedimentary rocks (Henson Member of the Silverton Volcanics, pls. 1, 2) have a low mineral resource potential for gold and silver in disseminated deposits in clastic sedimentary rocks. Volcaniclastic lacustrine sedimentary rocks of the Henson Member of the Silverton Volcanics crop out in the southern part of the Handies Peak Wilderness Study Area and in a small area in the northern part of the Redcloud Peak Wilderness Study Area (pls. 1, 2). This unit is about 30–40 ft thick and covers about 1.5 sq mi in the Handies Peak Wilderness Study Area. At several places, these rocks are cut or bounded by mineralized faults that may have provided access for mineralizing solutions into the sedimentary rocks. The rock type and setting are similar to that of sediment-hosted mineral deposits elsewhere. However, the permeability of these rocks is low, and, if mineralization was much later than deposition of the sediments (Lipman and others, 1976), the hydrothermal circulation may have been severely restricted. We have no geochemical data from Henson Member sedimentary rocks in order to measure the extent of mineralization, if any, in this unit, so the indications for this type of deposit are incomplete. Thus, the potential is low (certainty level B) for gold and silver in this type of deposit in areas underlain by the Henson Member.

Porphyry-Type Molybdenum and (or) Copper Deposits

By Dana J. Bove

Porphyry-type molybdenum and copper deposits are characterized by disseminated and stockwork veinlet mineral concentrations in host rocks of variable composition that have been hydrothermally altered in a pattern roughly concentric to a source intrusion (Lowell and Guilbert, 1970). Genetic models of these deposits emphasize an important relation to near-surface, commonly porphyritic intrusive rocks and suggest that all porphyry-type deposits had a similar origin. Molybdenum porphyry deposits are spatially and genetically associated with intrusions ranging in composition from high-silica granite to quartz monzonite. The two main types of molybdenum porphyry deposits are (1) granite and (2) granodiorite or quartz monzonite—based on the chemical composition of the ore-related magmatic system (Mutschler and others, 1981).

Like the granodiorite molybdenum porphyries, copper porphyry deposits are genetically and spatially related to small, shallow-level intrusions that range from granodiorite to quartz monzonite in composition.

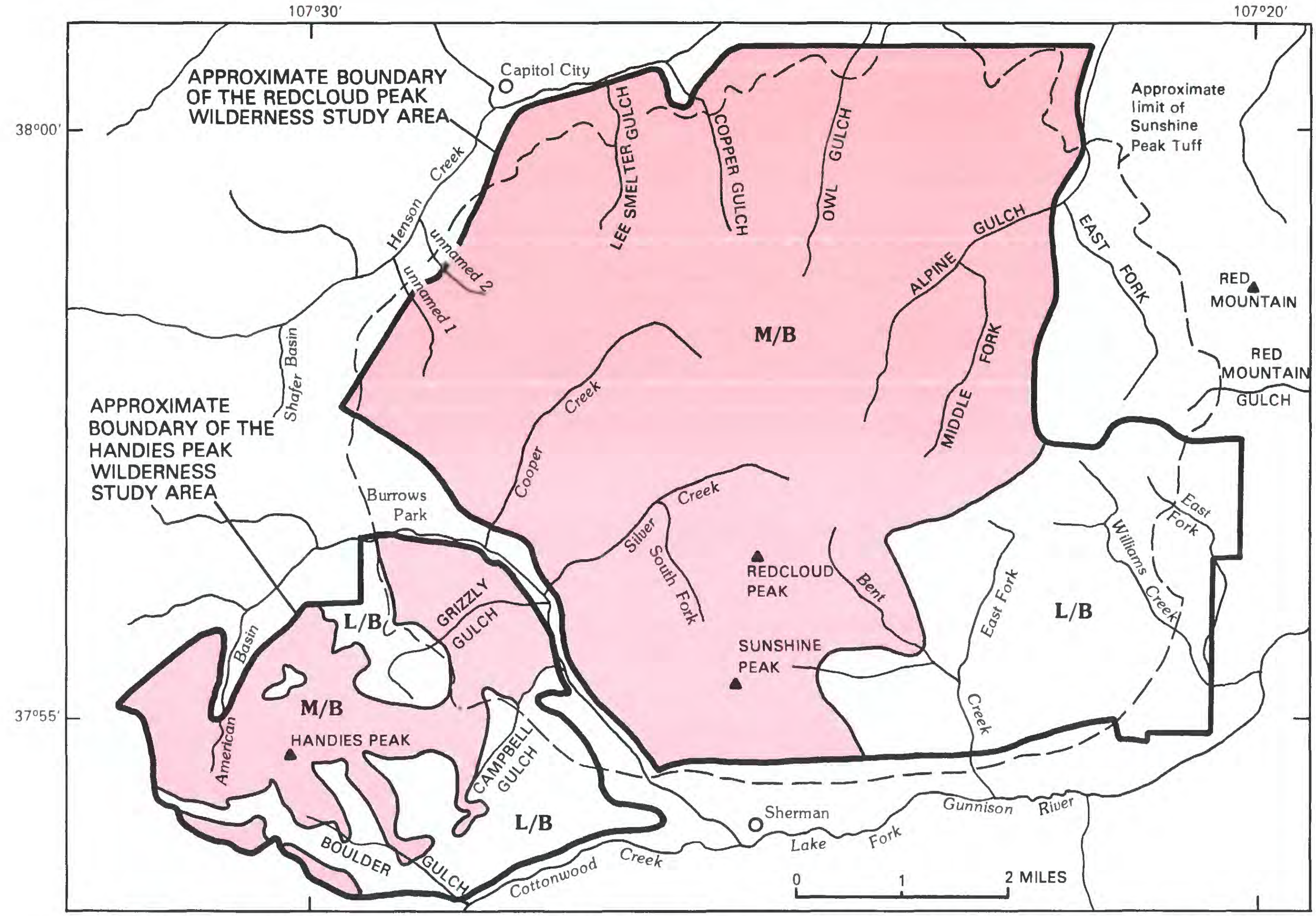
Mineral Resource Potential for Porphyry-Type Deposits in the Redcloud Peak Wilderness Study Area

The Capitol City and lower Alpine Gulch areas, within the Redcloud Peak Wilderness Study Area, have moderate mineral resource potential for molybdenum and copper in porphyry-type deposits, with certainty levels C and B, respectively (fig. 11, pl. 1).

Widespread hydrothermal alteration in the Capitol City area is spatially associated with several bodies of Oligocene quartz monzonite intrusions. One of these small intrusions crops out in the Redcloud Peak Wilderness Study Area just south of Capitol City (pl. 1). Veins that are also spatially associated with the quartz monzonite intrusions contain quartz, galena, sphalerite, chalcopyrite, pyrite, tetrahedrite, and barite (Irving and Bancroft, 1911; Steven and others, 1977; Slack, 1980; R.F. Sanford, unpub. data). In addition, these veins contain elevated concentrations of antimony, arsenic, bismuth, cadmium, and molybdenum (Fischer and others, 1968; Sanford and others, 1987).

Alteration in the Capitol City area is generally zoned with respect to the quartz monzonite intrusions (Slack, 1976). Nearest the intrusions, alteration is characterized by a quartz-clay-pyrite zone that grades outward into widespread propylitic alteration. In some areas, however, alteration does not correspond spatially to intrusive rock outcrops, suggesting the presence of concealed intrusions at shallow depths. Aeromagnetic studies (High Life Helicopters/QEB, 1981; Grauch, in press) and paleomagnetic data (R.L. Reynolds, unpub. data) indicate that a larger northeast-trending pluton underlies the small quartz monzonite outcrops in this vicinity.

Samples of altered rock immediately west of Capitol City are anomalous in gold, silver, arsenic, copper, lead, molybdenum, and zinc; additional samples from an altered area just south of Capitol City near the study area boundary contain anomalous concentrations of silver, antimony, arsenic, and molybdenum (fig. 3) (Steven and others, 1977). The most common metallic mineral associated with the alteration is pyrite, whose abundance ranges from 1 to 10 percent and averages from 1 to 3 percent of the rock by volume (Slack, 1976). In addition to pyrite, abundant microscopic grains of disseminated chalcopyrite occur in the Capitol City quartz monzonite intrusion (Slack, 1976).

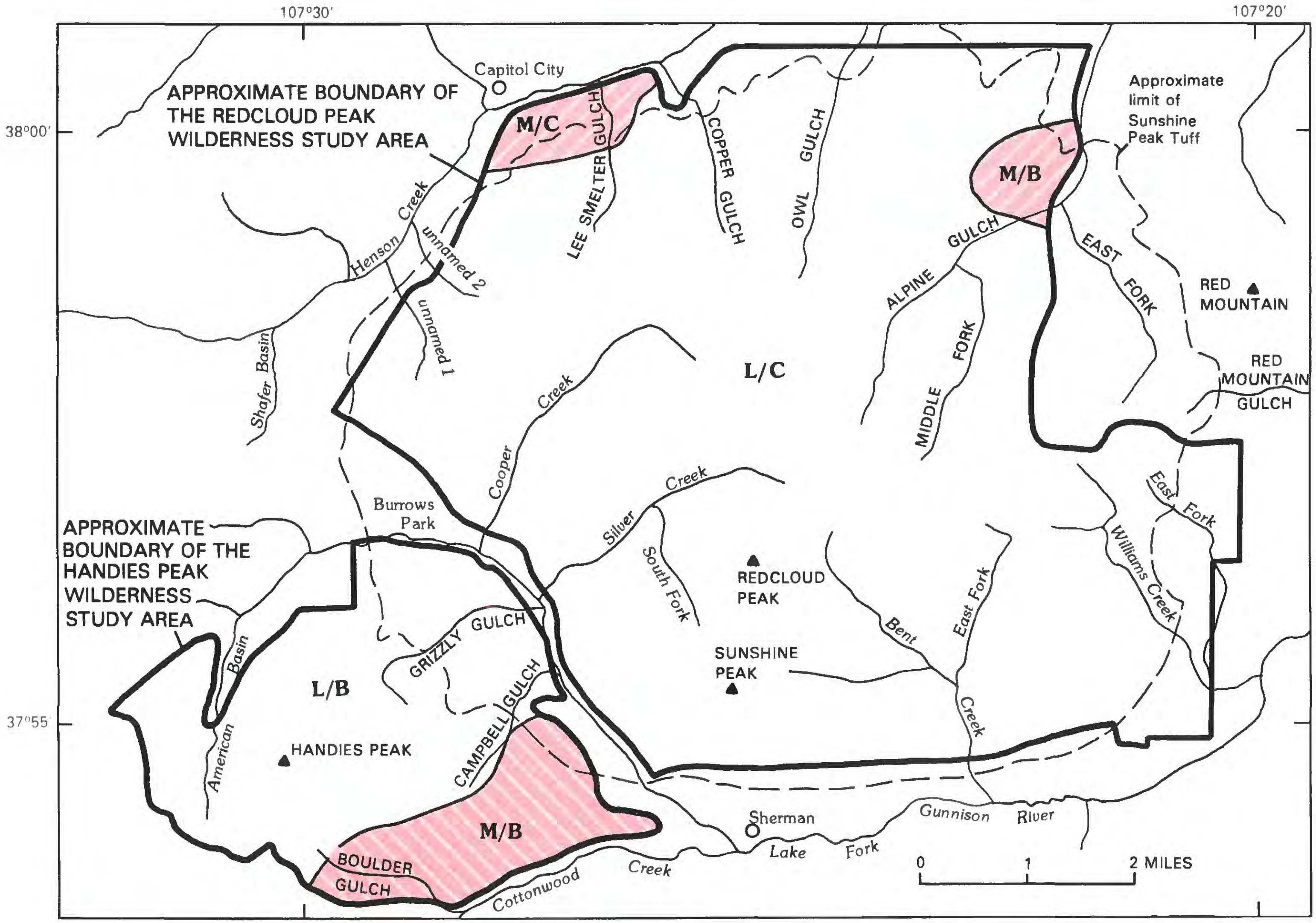


EXPLANATION OF MINERAL RESOURCE POTENTIAL FOR GOLD AND SILVER IN VOLCANIC-HOSTED DISSEMINATED-TYPE EPITHERMAL DEPOSITS

M/B — Geologic terrane having moderate mineral resource potential, with certainty level B

L/B — Geologic terrane having low mineral resource potential, with certainty level B

Figure 10. Mineral resource potential for gold and silver in volcanic-hosted disseminated-type epithermal deposits, Redcloud Peak and Handies Peak Wilderness Study Areas.



EXPLANATION OF MINERAL RESOURCE POTENTIAL FOR MOLYBDENUM AND (OR) COPPER IN PORPHYRY-TYPE DEPOSITS

M/B,C	Geologic terrane having moderate mineral resource potential for molybdenum and copper, with certainty levels B or C
M/B	Geologic terrane having moderate mineral resource potential for molybdenum, with certainty level B
L/B,C	Geologic terrane having low mineral resource potential for molybdenum and copper, with certainty levels B or C

Figure 11. Mineral resource potential for molybdenum and (or) copper in porphyry-type deposits, Redcloud Peak and Handies Peak Wilderness Study Areas.

Other important considerations include the presence of pyroxene within the quartz monzonite intrusions (which is typically absent in productive copper porphyry intrusions) and the observation that many quartz monzonite intrusions that are weakly mineralized at the surface show no evidence of mineralization at depth as shown by exploratory drilling (A.A. Bookstrom, oral commun., 1986).

The other area favorable for porphyry-type molybdenum-copper deposit mineralization (fig. 11) in the Redcloud Peak study area is in lower Alpine Gulch, where a Miocene quartz monzonite intrusion crops out west of the lower part of the gulch (pl. 1) (Hon, 1987). The intrusive rocks are similar texturally, petrographically, and chemically to the weakly mineralized, molybdenum porphyry-related intrusions at Red Mountain approximately 2 mi to the southeast.

Favorable features associated with the quartz monzonite of Alpine Gulch include fragmental dikes, tourmaline breccias, monomineralic veinlets of magnetite, veinlets of microperthitic quartz and potassium feldspar, and quartz veins containing pyrite, hematite, sphalerite, galena, and chalcopyrite (Hon, 1987).

Unfavorable features of the area include a lack of anomalous concentrations in stream-sediment samples of elements that indicate porphyry-type mineralization, relatively weak alteration of the intrusion, and no evidence of an alteration halo peripheral to the intrusion.

Despite characteristics favorable for the occurrence of a porphyry-type deposit in lower Alpine Gulch, the absence of a geochemical signature and the weak alteration suggest a moderate mineral resource potential, with certainty level B (fig. 11, pl. 1).

In the remainder of the Redcloud Peak Wilderness Study Area, beryllium, molybdenum, and tin are anomalously high in stream-sediment samples but do not necessarily reflect the presence of molybdenum porphyry resources. These geochemical anomalies can be explained by high concentrations of beryllium and molybdenum in the lower member of the Sunshine Peak Tuff (Ken Hon, unpub. data), as well as by typically anomalous molybdenum and tin in veins in the western San Juan Mountains (Fischer and others, 1968; Hildebrand, 1957).

However, the general geologic setting of the Redcloud Peak Wilderness Study Area (Hon, 1987) is typical of terrane in which porphyry-related deposits occur. Therefore, the entire study area, exclusive of the Alpine Gulch and Capitol City areas, has a low potential for molybdenum and copper in porphyry-type deposits, with certainty level C (fig. 11, pl. 1).

Mineral Resource Potential for Porphyry-Type Deposits in the Handies Peak Wilderness Study Area

Two localities just outside the Handies Peak Wilderness Study Area have geologic and (or) geochemical characteristics of molybdenum porphyry systems. One site, about 1 mi south of the study area, contains 17.5-Ma high-silica rhyolite dikes with associated mineralized pebble dikes and sparse molybdenum anomalies (Hon, 1987). Another favorable area occurs near the ring fault of the Lake City caldera just east of the study area. The exploratory drill hole at this locality encountered zones of brecciated and propylitized Proterozoic granite with quartz veins and quartz-healed breccias containing disseminated pyrite and traces of chalcopyrite, galena, molybdenite, and fluorite (Korzeb, 1986; this report). No associated intrusions have been seen at this locality.

Veins within the study area are commonly anomalous in molybdenum (as much as 1,000 ppm) (Sanford and others, 1987). Many of these veins contain the same elemental and mineralogic suite as gold-silver-lead-zinc-copper veins elsewhere in the Lake City area. Furthermore, high molybdenum contents also occur in many epithermal veins sampled in the western San Juan Mountains (Fischer and others, 1968; Sanford and others, 1987).

Similarly anomalous tin in vein and stream-sediment samples reflects the mineralogy of veins in the study area. Although commonly used as an indicator of porphyry-type deposits, tin is not a reliable indicator in this area because of its known occurrence in epithermal veins. Also tin is not associated here with other porphyry-type indicator elements.

Alteration indicative of a porphyry system is also absent within the study area. With the exception of the relatively large zone of fault-localized alteration northeast of Handies Peak, alteration is minimal and is fault associated.

Because two sites in close proximity to the Handies Peak Wilderness Study Area show characteristics of molybdenum-porphyry systems, a contiguous zone having a moderate mineral resource potential, with certainty level B, is outlined in the southeastern part of the study area (fig. 11, pl. 2). Considering that elevated molybdenum concentrations are common in veins of the western San Juan Mountains, the presence of anomalous vein-related molybdenum is probably not a definitive indicator of porphyry-molybdenum resource potential. The lack of porphyry-type intrusions and widespread hydrothermal alteration, combined with the absence of specific areas with key geochemical anomalies, were the major criteria for delineating an area of low potential for molybdenum and copper porphyry-type deposits, with certainty level B, in the remainder of the Handies Peak Wilderness Study Area.

Alunite (Aluminum) Deposits

By Dana J. Bove

With the development of recent metallurgical processing methods, alunite ($KAl_3(SO_4)_2$) is now regarded as a possible nonbauxite source of aluminum (Hall, 1978). Although the Tertiary volcanic setting of the Redcloud Peak and Handies Peaks Wilderness Study Areas is typical of the geologic terrane in which alunite deposits occur, the study areas lack extensive areas of alunitized rock, and thus the mineral resource potential for alunite is low, with certainty level D (fig. 1). An alunite deposit on Red Mountain (pl. 1), just east of the Redcloud Peak Wilderness Study Area, contains approximately 80 million short tons of alunite and is one of the largest alunite deposits in the United States. Bleached iron-oxide-stained altered areas are abundant in the Redcloud Peak and more rarely in the Handies Peak Wilderness Study Areas, however, they are less prominent and less extensive than the area of altered rock around Red Mountain (pls. 1, 2). Also, many of these altered areas are fault related, with silicified or quartz-healed central zones grading laterally into argillic (quartz, clay, pyrite) and propylitic (carbonates, epidote, quartz, chlorite) alteration assemblages. In contrast, quartz-alunite alteration at the nearby Red Mountain deposit is homogeneously distributed throughout large volumes of altered rock (Bove, 1984). No alunite was observed during field investigations or in laboratory tests of the 80 samples collected from altered areas shown on plates 1 and 2.

Uranium Deposits

By Richard I. Grauch

Uranium deposits within volcanic environments occur in several different settings (Steven and others, 1981; Goodell, 1985). Those of interest for the Redcloud Peak and Handies Peak Wilderness Study Areas are fracture systems that have undergone hydrothermal mineralization and areas within and marginal to rhyolitic intrusions containing disseminated deposits.

Mineral Resource Potential for Vein Uranium Deposits

An area encompassing the Silver Creek drainage in the southern part of the Redcloud Peak Wilderness Study Area (fig. 12, pl. 1) has a high mineral resource potential for uranium in veins, with certainty level C. This area contains an exposed mineralized (uraninite-gold-silver-bearing) vein, intensely altered rock, well-developed fractures, anomalous radioactivity, and stream-sediment samples with anomalous uranium contents (fig. 12). In addition, both the Redcloud Peak and Handies Peak Wilderness Study Areas have areas of moderate potential for uranium in veins, with certainty level C (fig. 12, pls. 1, 2). Uranium deposits in these areas are likely to be high grade (as shown by selected samples containing in excess of 1 percent uranium) but small in tonnage (as shown by the lack of uranium production from similar veins outside of the wilderness study areas, R.I. Grauch, unpub. data). Remaining areas have low potential for uranium in veins, with certainty level C (fig. 12).

Mineral Resource Potential for Disseminated Uranium Deposits

The Redcloud Peak and Handies Peak Wilderness Study Areas have a low mineral resource potential for disseminated uranium deposits, with certainty level C. The presence of only minor high-silica rhyolite intrusions, the lack of widespread altered rocks containing sericite and clay, the absence of a strong radiometric signature, and the general lack of porous host rocks are the basis for this evaluation.

Energy Sources other than Uranium

By Richard F. Sanford

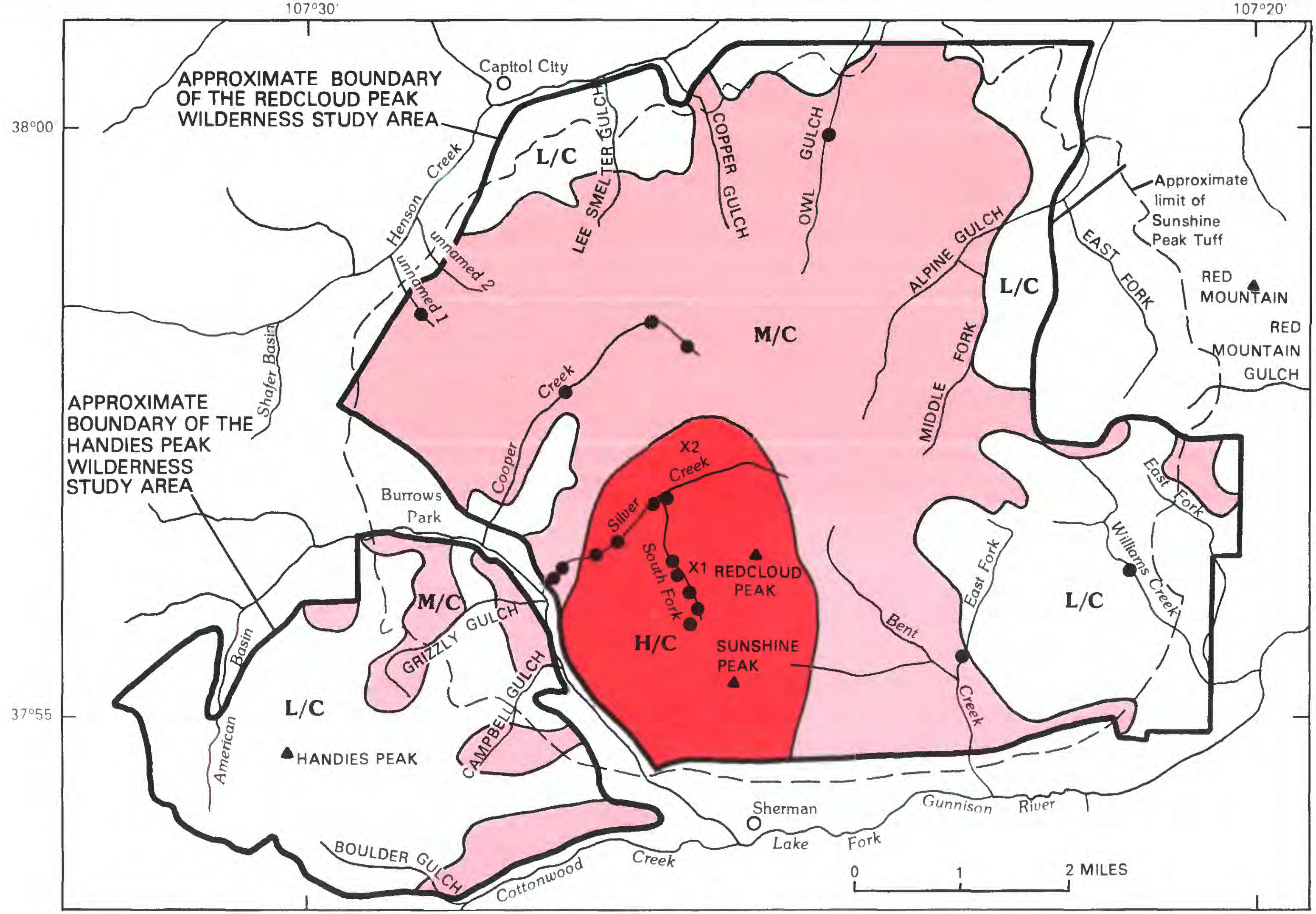
The resource potential for geothermal energy in the wilderness study areas is low, with certainty level B. Although no systematic survey of ground-water temperatures and composition in the wilderness study areas has been undertaken, no obvious evidence of present or recent geothermal activity was observed in the wilderness study areas. The San Juan Mountains region does contain at least 16 areas of thermal springs (Stearns and others, 1937). The one closest to the wilderness study areas is Ouray Hot Springs, 10 mi to the west-northwest. Also, warm mine water was found at the Gladiator mine (pl. 1), 4 mi east of the Redcloud Peak study area (A.R. Kirk, oral commun., 1982).

The complete absence of suitable sedimentary host rocks makes the wilderness study areas unfavorable for coal, oil, and natural gas. Sedimentary rocks are neither exposed at the surface nor do they appear as fragments in breccia pipes in the area. Therefore the assessment is for no energy resource potential, with certainty level D.

RECOMMENDATIONS FOR FURTHER STUDY

By Richard F. Sanford and Stanley L. Korzeb

Additional surface exploration would help in assessing the potential for all types of resources and in discovering deposits themselves. Detailed geochemical sampling and geologic mapping of the veins and alteration zones is needed to locate the most favorable sites for vein- and breccia-type deposits. Such sites would have the widest veins or breccia zones, the highest geochemical anomalies, and the most intense alteration. Mapping of areas with high permeability and porosity together with geochemical sampling of volcanic and volcaniclastic rocks would aid the assessment of potential for disseminated



EXPLANATION OF MINERAL RESOURCE POTENTIAL FOR URANIUM IN VEINS

- **H/C** — Geologic terrane having high mineral resource potential, with certainty level C
- **M/C** — Geologic terrane having moderate mineral resource potential, with certainty level C
- **L/C** — Geologic terrane having low mineral resource potential, with certainty level C
- ● — Stream-sediment sample locality that contains >17 ppm uranium
- X1 — Location of a vein containing anomalous uranium, gold, and silver (samples RP251-RP254, Sanford and others, 1987)
- X2 — Location of a vein containing anomalous uranium and silver (sample RP255, Sanford and others, 1987)

Figure 12. Mineral resource potential for vein uranium deposits, and summary of relevant radiometric and geochemical data, Redcloud Peak and Handies Peak Wilderness Study Areas. (Data from Pitkin and Duval, 1982; Weiland and others, 1980.)

metals and uranium. Drilling would be needed to confirm the presence of deposits. Evidence relating to porphyry-type deposits suggests that the present erosion level is well above any possible deposits so that deep drilling probably would be necessary. Dating of vein material and host rocks would allow recognition of different episodes of mineralization and would help in distinguishing more productive from less productive vein systems and in relating mineralization to specific igneous intrusions. Petrologic and fluid-inclusion studies combined with statistical analysis of existing geochemical data would help to define thermal and geochemical halos around centers of most intense mineralization.

REFERENCES CITED

Ashley, R.P., 1982, Occurrence model for enargite-gold deposits, *in* Erickson, R.L., comp., Characteristics of mineral deposit occurrences: U.S. Geological Survey Open-File Report 82–795, p. 144–147.

Barton, P.B., Jr., Bethke, P.M., Wetlaufer, P.H., Foley, Nora, Hayba, Dorn, and Goss, James, 1982, Silver/base metal epithermal deposits, *in* Erickson, R.L., comp., Characteristics of mineral deposit occurrences: U.S. Geological Survey Open-File Report 82–795, p. 127–130.

Bejnar, Waldemere, 1958, Lithologic control of ore deposits in the southwestern San Juan Mountains: New Mexico Geological Society, Guidebook of Southwestern San Juan Mountains, Eighth Field Conference, p. 162–173.

Berger, B.R., 1982, The geological attributes of Au-Ag-base metal epithermal deposits, *in* Erickson, R.L., comp., Characteristics of mineral deposit occurrences: U.S. Geological Survey Open-File Report 82–795, p. 119–126.

Berger, B.R., and Tingley, J.V., 1980, Geochemistry of the Round Mountain gold deposit, Nye County, Nevada: Society of Mining Engineers, American Institute of Mining and Metallurgical Engineers, Northern Nevada Section, Precious Metals Symposium, Abstracts, p. 18c.

Billings, Patty, and Kalliokoski, J.O., 1982, Alteration and geologic setting of the Golden Wonder mine, western San Juan Mountains, Colorado: Geological Society of America Abstracts with Programs, v. 14, p. 443–444.

Bonham, H.F., Jr., 1984, Three types of epithermal precious-metal deposits: Geological Society of America Abstracts with Programs, v. 16, p. 449.

———1986, Models for volcanic-hosted epithermal precious-metal deposits; a review, *in* Volcanism, hydrothermal systems, and related mineralization: International Volcanological Congress, Proceedings of Symposium V, Hamilton, New Zealand, p. 13–17.

Bove, D.J., 1984, Geology and hydrothermal alteration of the Red Mountain alunite deposit, Lake City, Colorado: Geological Society of America Abstracts with Programs, v. 16, p. 216.

Burbank, W.S., 1941, Structural control of ore deposition in the Red Mountain, Sneffels, and Telluride districts of the San Juan Mountains, Colorado: Colorado Scientific Society, Proceedings, v. 14, p. 141–261.

———1947a, Lake City area, Hinsdale County, *in* Vanderwilt, J.W., ed., Mineral resources of Colorado: Denver, Colo., Colorado Mineral Resources Board, p. 439–443.

———1947b, Red Mountain District, Ouray County, *in* Vanderwilt, J.W., ed., Mineral resources of Colorado: Denver, Colo., Colorado Mineral Resources Board, p. 428–431.

Burbank, W.S., and Luedke, R.G., 1968, Geology and ore deposits of the western San Juan Mountains, Colorado, *in* Ridge, J.D., ed., Ore deposits of the United States, 1933–1967 (Graton–Sales Volume), v. 7: New York, American Institute of Mining, Metallurgical, and Petroleum Engineers, p. 714–733.

———1969, Geology and ore deposits of the Eureka and adjoining districts, San Juan Mountains, Colorado: U.S. Geological Survey Professional Paper 535, 73 p.

Casadevall, Tom, and Ohmoto, Hiroshi, 1977, Sunnyside mine, Eureka mining district, San Juan County, Colorado—Geochemistry of gold and base metal ore deposition in a volcanic environment: Economic Geology, v. 72, p. 1285–1320.

Caskey, D.J., 1979, Geology and hydrothermal alteration of the Iron Beds area, Hinsdale County, Colorado: Austin, Tex., University of Texas, M.S. thesis, 111 p.

Crock, J.G., Lichte, F.E., and Briggs, P.H., 1983, Determination of elements in National Bureau of Standards' Geologic Reference Materials SRM 278 obsidian and SRM 688 basalt by inductively coupled argon plasma–atomic emission spectrometry: Geostandards Newsletter, v. 7, p. 335–340.

Del Rio, S.M., 1960, Mineral resources of Colorado; first sequel: Denver, Colo., Colorado Mineral Resources Board, 763 p.

Fischer, R.P., Luedke, R.G., Sheridan, M.J., and Raabe, R.G., 1968, Mineral resources of the Uncompahgre Primitive Area, Colorado: U.S. Geological Survey Bulletin 1261–C, 91 p.

Fisher, F.S., and Leedy, W.P., 1973, Geochemical characteristics of mineralized breccia pipes in the Red Mountain district, San Juan Mountains, Colorado: U.S. Geological Survey Bulletin 1381, 43 p.

GeoMetrics, Inc., 1979, Aerial gamma ray and magnetic survey, Uncompahgre uplift project, Salina, Utah, Moab, Utah and Colorado, Montrose and Leadville, Colorado quadrangles: U.S. Department of Energy Open-File Report GJBX–95(79), 2 volumes.

Goddard, E.N., Trask, P.D., De Ford, R.K., Rove, O.N., Singewald, J.T., Jr., and Overbeck, R.M., 1980, Rock-color chart: Boulder, Colo., Geological Society of America, 11 p.

Goodell, P.C., 1985, Classification and model of uranium deposits in volcanic environments, *in* Uranium deposits in volcanic rocks: Vienna, Austria, International Atomic Energy Agency, p. 1–16.

Goudarzi, G.H., comp., 1984, Guide to preparation of mineral survey reports on public lands: U.S. Geological Survey Open-File Report 84–787, 42 p.

Grauch, V.J.S., 1985, Aeromagnetic and gravity models of the pluton below the Lake City caldera, Colorado, *in* Kraft, Kathleen, ed., USGS research on mineral resources, 1985; program and abstracts: U.S. Geological Survey Circular 949, p. 15–16.

———in press, Interpretive aeromagnetic map using the horizontal gradient—Lake City caldera area, San Juan Mountains, Colorado: U.S. Geological Survey Geophysical Investigations Map GP–974, scale 1:48,000.

Grauch, V.J.S., and Campbell, D.L., 1985, Gravity survey data and a Bouguer gravity anomaly map of the Lake City caldera area, Hinsdale County, Colorado: U.S. Geological Survey Open-File Report 85–208, 11 p., scale 1:48,000.

Grimes, D.J., and Marranzino, A.P., 1968, Direct-current arc and alternating-current spark emission spectrographic field methods for the semiquantitative analysis of geologic materials: U.S. Geological Survey Circular 591, 6 p.

Hall, R.H., 1978, World nonbauxite aluminum resources—Alunite: U.S. Geological Survey Professional Paper 1076–A, 35 p.

Hayba, D.O., Bethke, P.M., Heald, Pamela, and Foley, N.K., 1985, Geologic, mineralogic, and geochemical characteristics of volcanic-hosted epithermal precious-metal deposits, *in* Berger, B.R., and Bethke, P.M., eds., Geology and geochemistry of epithermal systems: Society of Economic Geologists, Reviews in Economic Geology, v. 2, p. 129–167.

Heald, Pamela, Foley, N.K., and Hayba, D.O., 1987, Comparative anatomy of volcanic-hosted epithermal deposits—Acid-sulfate and adularia-sericite types: Economic Geology, v. 82, p. 1–26.

High Life Helicopters/QEB, 1981, Contour maps of uranium, uranium-thorium ratio, and total field magnetics, Lake City area, San Juan Mountains, Colorado, *with* an introduction by Heran, W.D.: U.S. Geological Survey Open-File Report 81–568, 40 p., 33 over-size plates.

———1983, Airborne gamma-ray spectrometer and magnetometer survey, Durango A, B, C and D, Colorado, detail areas: U.S. Department of Energy Open-File Report GJBX-031(83).

Hildebrand, J.R., 1957, The Idarado mine: New Mexico Geological Society Guidebook, 87th Field Conference, p. 130–140.

Hon, Ken, 1987, Geologic, alteration, and vein maps of the Redcloud Peak (Lake City caldera) and Handies Peak Wilderness Study Areas, Hinsdale County, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF–1949, scale 1:24,000.

Hon, Ken, Lipman, P.W., and Mehnert, H.H., 1983, The Lake City caldera, western San Juan Mountains, Colorado: Geological Society of America Abstracts with Programs, v. 15, p. 389.

Hon, Ken, and Mehnert H.H., 1983, Compilation of revised ages of volcanic units in the San Juan mountains, Colorado—Recalculated K-Ar age determinations using IUGS standards: U.S. Geological Survey Open-File Report 83–668, 14 p.

Irving, J.D., and Bancroft, Howland, 1911, Geology and ore deposits near Lake City, Colorado: U.S. Geological Survey Bulletin 478, 128 p.

Kalliokoski, J.O., and Billings, Patty, 1982, Sediment-filled veins of the Golden Wonder Mine, Lake City, Colorado: Geological Society of America Abstracts with Programs, v. 14, p. 524.

Kelley, V.C., 1946, Geology, ore deposits, and mines of the Mineral Point, Poughkeepsie, and Upper Uncompahgre districts, Ouray, San Juan, Hinsdale Counties, Colorado: Colorado Scientific Society, Proceedings, v. 14, p. 287–466.

Korzeb, S.L., 1986, Mineral investigation of the Redcloud Peak (CO–030–208) and the Handies Peak (CO–030–241) Wilderness Study Areas, Hinsdale County, Colorado: U.S. Bureau of Mines Mineral Land Assessment Open-File Report MLA–68–86, 105 p.

Larsen, E.S., 1911, The economic geology of Carson Camp, Hinsdale County, Colorado: U.S. Geological Survey Bulletin 470–B, p. 22–30.

Larson, P.B., 1983, An $^{18}O/^{16}O$ investigation of the Lake City caldera, San Juan Mountains, Colorado: Pasadena, Calif., California Institute of Technology, Ph.D. thesis, 467 p.

Larson, P.B., and Taylor, H.P., Jr., 1986, An oxygen-isotope study of water-rock interaction in the granite of Cataract Gulch, western San Juan Mountains, Colorado: Geological Society of America Bulletin, v. 97, p. 505–515.

Lee, Keenan, 1986, Map showing areas of limonitic hydrothermal alteration in the Lake City caldera area, western San Juan Mountains, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF–1868, scale 1:48,000.

Le Maitre, R.W., 1984, A proposal by the IUGS subcommission on the systematics of igneous rocks for a chemical classification of volcanic rocks based on the total alkali silica (TAS) diagram: Australian Journal of Earth Sciences, v. 31, p. 243–255.

Lipman, P.W., 1976a, Geologic map of the Lake City caldera area, western San Juan Mountains, southwestern Colorado: U.S. Geological Survey Miscellaneous Investigations Series Map I–962, scale 1:48,000.

———1976b, Caldera-collapse breccias in the western San Juan Mountains, Colorado: Geological Society of America Bulletin, v. 87, p. 1397–1420.

Lipman, P.W., Doe, B.R., Hedge, C.E., and Steven, T.A., 1978, Petrologic evolution of the San Juan volcanic field, southwestern Colorado—Pb and Sr isotope evidence: Geological Society of America Bulletin, v. 89, p. 59–82.

Lipman, P.W., Fisher, F.S., Mehnert, H.H., Naeser, C.W., Luedke, R.G., and Steven, T.A., 1976, Multiple ages of mid-Tertiary mineralization and alteration in the western San Juan Mountains, Colorado: Economic Geology, v. 71, p. 571–588.

Lipman, P.W., Steven, T.A., Luedke, R.G., and Burbank, W.S., 1973, Revised volcanic history of the San Juan, Uncompahgre, Silverton, and Lake City calderas in the western San Juan Mountains, Colorado: U.S. Geological Survey Journal of Research, v. 1, p. 627–642.

Lipman, P.W., Steven, T.A., and Mehnert, H.H., 1970, Volcanic history of the San Juan Mountains, Colorado, as indicated by potassium-argon dating: Geological Society of America Bulletin, v. 81, p. 2329–2352.

Lowell, J.D., and Guilbert, J.M., 1970, Lateral and vertical alteration mineralization zoning in porphyry ore deposits: Economic Geology, v. 65, p. 373–408.

Luedke, R.G., and Burbank, W.S., 1968, Volcanism and cauldron development in the western San Juan Mountains, Colorado, *in* Cenozoic volcanism in the southern Rocky Mountains: Golden, Colo., Colorado School of Mines Quarterly, v. 63, p. 175–208.

———1987, Geologic map of the Handies Peak quadrangle, San Juan, Hinsdale, and Ouray Counties, Colorado: U.S. Geological Survey Geologic Quadrangle Map GQ–1595, scale 1:24,000.

Maher, Brian, 1983, Geology, geochemistry, and genesis of the Engineer Pass intrusive complex, San Juan Mountains, Colorado: Fort Collins, Colo., Colorado State University, M.S. thesis, 226 p.

Mayor, J.N., and Fisher, F.S., 1972, Middle Tertiary replacement ore bodies and associated veins in the northwest San Juan Mountains, Colorado: Economic Geology, v. 67, p. 214–230.

Mehnert, H.H., Lipman, P.W., and Steven, T.A., 1973, Age of the Lake City caldera and related Sunshine Peak Tuff, western San Juan Mountains, Colorado: Isochron/West, no. 6, p. 31–33.

Mehnert, H.H., Slack, J.F., and Cebula, G.T., 1979, K-Ar age of alunite alteration at Red Mountain, Lake City area, western San Juan Mountains, Colorado: U.S. Geological Survey Open-File Report 79–1642, 8 p.

Moehlman, R.S., 1936, Ore deposition south of Ouray, Colorado, pt. I: Economic Geology, v. 31, p. 377–397.

Mutschler, F.E., Wright, E.G., Ludington, Steve, and Abbot, Jeffrey, 1981, Granite molybdenum systems: Economic Geology, v. 76, p. 874–897.

Myers, A.T., Havens, R.G., and Dunton, P.J., 1961, A spectrochemical method for the semiquantitative analysis of rocks, minerals, and ores: U.S. Geological Survey Bulletin 1084–I, p. 207–229.

Naeser, C.W., Cunningham C.G., Marvin R.F., and Obradovich, J.D., 1980, Pliocene intrusive rocks and mineralization near Rico, Colorado: Economic Geology, v. 75, p. 122–127.

Pierce, Herb, and Hoover, D.B., 1985, Electrical studies conducted on the Lake City caldera, Colorado: U.S. Geological Survey Open-File Report 85–147, 43 p.

Pitkin, J.A., and Duval, J.S., 1982, Interpretation of areal radiometric data for the Lake City caldera and vicinity, Hinsdale, San Juan, and Ouray Counties, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF–1449, scale 1:100,000.

Ransome, F.L., 1901, A report on the economic geology of the Silverton quadrangle, Colorado: U.S. Geological Survey Bulletin 182, 265 p.

Reynolds, R.L., Hudson, M.J., and Hon, Ken, 1986, Paleomagnetic evidence for the timing of collapse and resurgence of the Lake City caldera, San Juan Mountains, Colorado: Journal of Geophysical Research, v. 91, p. 9599–9613.

Rice, J.A., 1984, The Creede Formation silver deposit: Geological Society of America Abstracts with Programs, v. 16, p. 252.

Sander, M.V., and Mills, B.A., 1984, The Round Mountain gold-silver mine, Nye County, Nevada, *in* Christensen, Olin, ed., Field trip guidebook to the mineral deposits of central Nevada: Geological Society of America Annual Meeting, v. 3, p. 176–180.

Sanford, R.F., Korzeb, S.L., Seeley, J.L., and Zamudio, J.A., 1987, Geochemical data for mineralized rocks in the Lake City area, San Juan volcanic field, southwest Colorado: U.S. Geological Survey Open-File Report 87–54, 213 p.

Sanford, R.F., Kramer, A.M., and O'Brian, Hugh, 1986, Geology, mineralogy, and paragenesis of the Pride of America mine, Lake City, Hinsdale County, Colorado: U.S. Geological Survey Open-File Report 86–629, 21 p.

Sanford, R.F., and Ludwig, K.R., 1985, Lead-isotopic evidence on the origin of hydrothermal veins, Lake City, Colorado: Geological Society of America Abstracts with Programs, v. 17, p. 706.

Sanford, R.F., and Seeley, J.L., 1987, A new method of analysis for trace elements in gold-silver deposits—Comparison with Lake City data: U.S. Geological Survey Open-File Report 87–67, 39 p.

Silberman, M.L., 1982, Hot-spring type, large tonnage, low-grade gold deposits, *in* Erickson, R.L., comp., Characteristics of mineral deposit occurrences: U.S. Geological Survey Open-File Report 82–795, p. 131–143.

Slack, J.F., 1976, Hypogene zoning and multistage vein mineralization in the Lake City area, western San Juan Mountains, Colorado: Stanford, Calif., Stanford University, Ph.D. thesis, 327 p.

———1980, Multistage vein ores of the Lake City district, western San Juan Mountains, Colorado: Economic Geology, v. 75, p. 963–991.

Smith, J.W., 1981, Bachelor Mountain silver deposit, Mineral County, Colorado, *in* Lindemann, J.W., Babcock, J.W., and King, J.R., eds., Field trip notes, Creede mining district: Denver, Colo., Denver Region Exploration Geologists' Society, p. 11–18.

Stearns, N.D., Stearns, H.T., and Waring, G.A., 1937, Thermal springs in the United States: U.S. Geological Survey Water Supply Paper 679–B, 206 p.

Steven, T.A., Cunningham, C.G., and Machette, M.N., 1981, Integrated uranium systems in the Marysvale volcanic field, west-central Utah, *in* Goodell, P.C., and Waters, A.C., eds., Uranium in volcanic and volcaniclastic rocks: American Association of Petroleum Geologists, Studies in Geology No. 13, p. 111–122.

Steven, T.A., and Eaton, G.P., 1975, Environment of ore deposition in the Creede mining district, San Juan Mountians, Colorado, 1. Geologic, hydrologic, and geophysical setting: Economic Geology, v. 70, p. 1023–1037.

Steven, T.A., and Lipman, P.W., 1976, Calderas of the San Juan volcanic field, southwestern Colorado: U.S. Geological Survey Professional Paper 958, 35 p.

Steven, T.A., Lipman, P.W., Fisher, F.S., Bieniewski, C.L., Meeves, H.C., Popenoe, Peter, and Luedke, R.G., 1977, Mineral resources of study areas contiguous to the Uncompahgre primitive area, San Juan Mountains, southwestern Colorado, *with a section on* Interpretation of aeromagnetic data: U.S. Geological Survey Bulletin 1391–E, 126 p.

Steven, T.A., and Ratté, J.C., 1965, Geology and structural control of ore deposition in the Creede district, San Juan Mountains, Colorado: U.S. Geological Survey Professional Paper 486, 90 p.

Streckeisen, A., 1976, To each plutonic rock its proper name: Earth Science Reviews, v. 12, p. 1–33.

Theis, N.J., Madson, M.E., Rosenlund, G.C., Reinhart, W.R., and Gardner, H.A., 1981, National uranium resource evaluation, Durango quadrangle, Colorado: U.S. Department of Energy Open-File Report GJQ–011(81), 68 p.

Tooker, E.W., 1985, Geologic characteristics of sediment- and volcanic-hosted disseminated gold deposits—Search for an occurrence model: U.S. Geological Survey Bulletin 1646, 150 p.

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, 5 p.

U.S. Geological Survey, 1972, Aeromagnetic map of the Ridgway–Pagosa Springs area, southwestern Colorado: U.S. Geological Survey Geophysical Investigations Map GP–840, scale 1:250,000.

Weiland, E.F., Johnson, S.A., and Grauch, R.I., 1980, Stream-sediment geochemical survey of the Bureau of Land Management's American Flats–Silverton Planning Unit in southwest (Lake City area) Colorado: U.S. Geological Survey Open-File Report 80–541, 111 p.

Western Geophysical Company of America, Aero Service Division, 1979, Airborne gamma-ray spectrometer and magnetometer survey, Durango quadrangle [Colorado]: U.S. Department of Energy Open-File Report GJBX–143(79), 2 volumes.

White, W.W., Bookstrom, A.A., Kamilli, R.J., Ganster, M.W., Smith, R.P., Ranta, D.E., and Steninger, R.C., 1981, Character and origin of Climax-type molybdenum deposits: Economic Geology, 75th Anniversary Volume, p. 270–316.

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 ↑

<table>
<tr><td rowspan="4">U/A
UNKNOWN POTENTIAL</td><td>H/B
HIGH POTENTIAL</td><td>H/C
HIGH POTENTIAL</td><td>H/D
HIGH POTENTIAL</td></tr>
<tr><td>M/B
MODERATE POTENTIAL</td><td>M/C
MODERATE POTENTIAL</td><td>M/D
MODERATE POTENTIAL</td></tr>
<tr><td rowspan="2">L/B
LOW POTENTIAL</td><td rowspan="2">L/C
LOW POTENTIAL</td><td>L/D
LOW POTENTIAL</td></tr>
<tr><td>N/D
NO POTENTIAL</td></tr>
<tr><td>A</td><td>B</td><td>C</td><td>D</td></tr>
</table>

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:

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.

Goudarzi, G. H., compiler, 1984, Guide to preparation of mineral survey reports on public lands: U.S. Geological Survey Open-File Report 84–0787, p. 7, 8.

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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