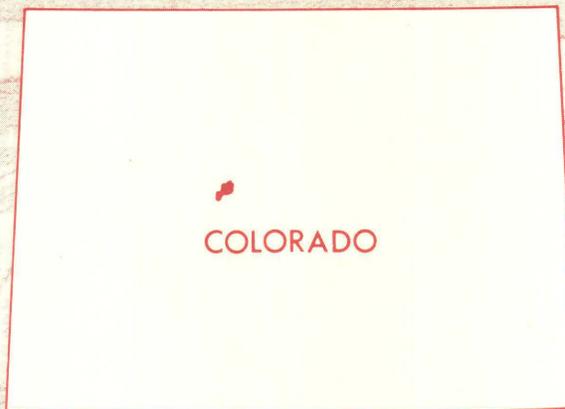


Mineral Resource Potential of Mount Massive Wilderness, Lake County, Colorado



U.S. GEOLOGICAL SURVEY BULLETIN 1636



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Mineral Resource Potential of Mount Massive Wilderness, Lake County, Colorado

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U.S. GEOLOGICAL SURVEY BULLETIN 1636
STUDIES RELATED TO WILDERNESS

DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, JR., Secretary



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

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STUDIES RELATED TO WILDERNESS

Under the provisions of the Wilderness Act (Public Law 88-577, September 3, 1964) and related acts, the U.S. Geological Survey and the U.S. Bureau of Mines have been conducting mineral surveys of wilderness and primitive areas. Areas officially designated as "wilderness," "wild," or "canoe" when the act was passed were incorporated into the National Wilderness Preservation System. The act provided that areas under consideration for wilderness designation should be studied for suitability for incorporation into the Wilderness System. The mineral surveys constitute one aspect of the suitability studies. The act directs that the results of each survey are to be made available to the public and be submitted to the President and the Congress. This report discusses the results of a mineral survey of the Mount Massive Wilderness, San Isabel National Forest, Lake County, Colorado. The area was established as a wilderness by Public law 96-560, known as the Colorado Wilderness Act of 1980.

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Mineral Resource Potential of Mount Massive Wilderness, Lake County, Colorado

By R.E. Van Loenen, G.K. Lee, and D.L. Campbell
U.S. Geological Survey, and

John R. Thompson
U.S. Bureau of Mines

SUMMARY

Abstract

The mineral resource potential of the Mount Massive Wilderness in Lake County, Colo., was evaluated in 1983–85. The wilderness consists of about 26,140 acres (40 square miles) of high, mountainous, rugged terrain along the eastern side of the Continental Divide in the northern part of the San Isabel National Forest. No mineral resources were identified within the wilderness, although resources were identified in adjacent mining districts on the south and northeast. A moderate mineral resource potential for stockwork deposits of molybdenum was assigned to a small area in the northeast part of the wilderness. The southwest part of the wilderness has a high mineral resource potential for gold, silver, lead, and zinc in small deposits in veins, and a small part of this area along Halfmoon Creek has a moderate potential for molybdenum associated with the Halfmoon Creek stock.

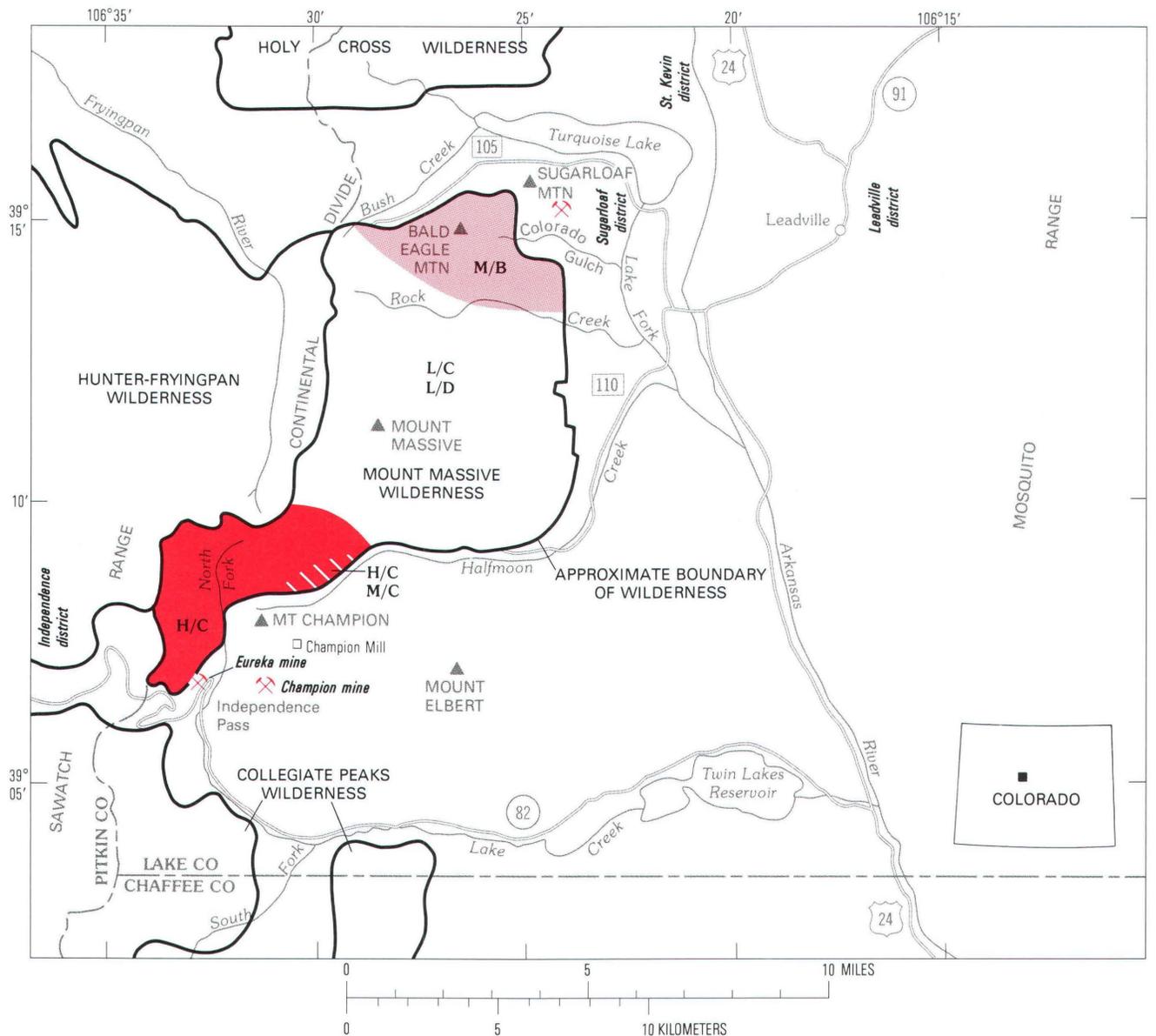
Character and Setting

The Mount Massive Wilderness is in the Sawatch Range of central Colorado, about 100 air miles west of Denver and 7 mi (miles) west of Leadville, Colo. (fig. 1). It is bounded on the west for 14 mi by the Continental Divide and on the east by the Arkansas River valley. The wilderness was named after Mount Massive (elevation 14,421 feet), the second highest peak in Colorado. Mount Massive is near the center of the wilderness. Many peaks in the wilderness rise above 13,000 ft (feet); some are 4,000–5,000 ft above the floor of the adjacent Arkansas River valley. The terrain shows evidence of past glacial activity: most peaks are surrounded

by cirques, the valleys are U-shaped, and the lower slopes are extensively mantled by glacial debris.

Access into the wilderness is provided by many well-maintained and clearly marked hiking trails. The trailheads can be reached by U.S. Forest Service roads. Road 105 accesses the northern part of the wilderness, and Road 110 follows the southern boundary (fig. 1). State Highway 82, which crosses Independence Pass, provides access to the southwestern part. Spectacular scenery, many lakes, and abundant wildlife make the wilderness a popular summer recreational area. Some of the trails are marked for use during the winter months by cross-country skiers.

Precambrian crystalline rocks are exposed throughout the Mount Massive Wilderness. These basement rocks were elevated during a period of mountain building known as the Laramide orogeny, which began in this region about 72 Ma (millions of years ago) with the arching of the Sawatch Range anticline, a very large structure that extends many tens of miles to the north and south. Younger sedimentary rocks that overlay the crystalline rocks before the arching began have been eroded from this area; remnants of them are exposed on the west flank of the anticline near Aspen, some 15 mi west of the wilderness, and in the Mosquito Range (fig. 1), which was originally the east flank of the Sawatch Range. The east flank was broken in the Miocene, about 25 Ma, when a long, narrow block was dropped between north-trending faults to form the Arkansas valley graben, the northernmost graben of the Rio Grande rift system. The graben became the upper Arkansas River valley, which now separates the Sawatch Range from the Mosquito Range. Block faulting has continued along the edges of the graben; small fault movements in the last 10,000 years have broken glacial deposits at the eastern front of the Sawatch Range. Modifications of this terrain by glacial and fluvial activity account for the physiography of the wilderness as seen today.



EXPLANATION

-  Mine or mining district having an identified resource of gold and silver
 -  Geologic terrane having high mineral resource potential for small vein deposits of gold, silver, lead, and zinc, at certainty level C
 -  Geologic terrane having moderate mineral resource potential for stockwork molybdenum deposits in igneous rocks, at certainty level C—Applies only to a small area near the Halfmoon Creek stock, within the area of high potential for vein deposits defined above
 -  Geologic terrane having moderate mineral resource potential for stockwork molybdenum deposits in igneous rocks, at certainty level B
 -  Geologic terrane having low mineral resource potential, at certainty level C, for vein deposits of gold, silver, lead, and zinc; placer gold deposits; pegmatite minerals (feldspar, mica, and gem minerals); and stratabound copper and zinc deposits—For vein deposits, applies only outside the area of high potential defined above. For all others, applies to entire study area
 -  Geologic terrane having low energy resource potential for oil and gas and for geothermal sources, at certainty level D—Applies to entire study area
- Levels of certainty:**
- B** Data indicate geologic environment and suggest the level of mineral resource potential
 - C** Data indicate geologic environment and give a good indication of the level of mineral resource potential
 - D** Data clearly define geologic environment and level of mineral resource potential

Figure 1. Identified resources, mineral resource potential, and location of Mount Massive Wilderness, central Colorado.

The wilderness is underlain almost entirely by metamorphic and igneous rocks of Early and Middle Proterozoic age. The geologic history recorded in the region started in Early Proterozoic time, before 1,800 Ma, when sedimentary and volcanic rocks were deposited. About 1,700 Ma, throughout central Colorado, these rocks were metamorphosed to the gneiss and schist complex recognized today. They were also greatly deformed by folding and faulting. These rocks were intruded by magmas that formed the St. Kevin Granite during Middle Proterozoic time (about 1,400 Ma) and were sheared in great northeast-trending zones. Episodes of mountain building and erosion have removed from the wilderness all rocks that record events during the period of time from the Middle Proterozoic (about 1,400 Ma) until the beginning of Laramide mountain building (about 70 Ma).

Igneous rocks were emplaced within the wilderness in several stages from the Late Cretaceous into the mid-Tertiary (from 70 to 27(?) Ma). Magmas supplied heat and metals to hydrothermal systems that formed many of the ore deposits of the region. The first of these periods of igneous activity began during the early stages of the Laramide orogeny. Small sills and dikes of this age invade the Precambrian gneiss, schist, and granite in the wilderness. The final episode of igneous and related hydrothermal activity in the region began in mid-Tertiary time, about 40 Ma. Some of these intrusives were emplaced at the same time the Arkansas valley graben formed. The graben's border faults controlled the location and distribution of igneous bodies, and permeable fracture zones helped localize the hydrothermal fluids that formed ore bodies.

Small granitic stocks that intruded during the mid-Tertiary include the Turquoise Lake and Timberline stocks, just north of the wilderness, and the Halfmoon Creek stock, which lies at its southern boundary. Other rocks of this age nearby contain important ore deposits, such as the world-class Climax molybdenum deposit, 15 mi northeast of the wilderness.

Identified Resources

The Mount Massive Wilderness is centered within the Colorado mineral belt, an irregularly shaped, northeast-trending belt which contains many of the major base- and precious-metal mining districts in Colorado. Districts that contain ore deposits near the wilderness boundary include the St. Kevin-Sugarloaf, Mount Champion-Lackawanna Gulch, and Independence mining districts (Thompson, 1985). These exploited vein deposits that contain gold, silver, lead, and zinc. The deposits probably resulted from mid-Tertiary hydrothermal activity associated with the nearby stocks. The wilderness was extensively prospected during the late 1800's, in part because of its proximity to the Leadville mining district.

There are no identified mineral resources within the wilderness. Just outside the southern boundary, near Independence Pass, an identified resource of 2,000 tons of material containing 1.1 oz gold per ton and 1.0 oz silver per ton exists at the Eureka Mine. The deposit may extend west from the Eureka Mine into the wilderness, but the quantity

and grade of the deposit inside the wilderness are unknown. At the Champion Mine, about 1 mi south of the wilderness, a small identified gold and silver resource exists in several dumps and stockpiles, and a larger, but unknown, resource may also exist underground. About 1 mi northeast of the wilderness, a large identified silver and gold resource exists in the dumps of old mines, and possibly underground, in the Sugarloaf district.

Potential for Undiscovered Resources

Two parts of the wilderness are interpreted as favorable for the presence of undiscovered mineral resources (fig. 1). An area in the southern part of the wilderness surrounding the Halfmoon Creek stock is assigned a moderate resource potential for molybdenum in a porphyry or stockwork deposit. This stock, part of which is in the wilderness, is a porphyritic rhyolite that has a trace-element composition similar to that of other intrusives that contain molybdenum deposits. It is pervasively altered and contains disseminated pyrite; molybdenum was detected in some samples. Early-day miners explored a brecciated border phase of the stock in workings 1,000 ft long, which extend into the wilderness. The Halfmoon Creek stock lies within a magnetic low which is centered over the Grizzly Peak caldera, a volcanic depression about 5 mi southwest of the stock. The Grizzly Peak caldera complex and the Halfmoon Creek stock may be near-surface expressions of a large, deep-seated intrusive body.

The southwest part of the wilderness, which includes the area of molybdenum potential, is also assigned a high mineral resource potential for small vein deposits of silver, gold, lead, and zinc based on the following criteria: (1) marketable quantities of these metals have been produced near the wilderness boundary (Thompson, 1985) from the Champion and Eureka Mines and small mines in Halfmoon Creek basin; (2) reserves estimated for the Eureka Mine are significant (Thompson, 1985), and the veins that host metals there may extend into the wilderness; (3) anomalous amounts of metals occur in several of the prospects on veins in the area (Hopkins and others, 1989); and (4) the area is within a magnetic anomaly which might be due to hydrothermal alteration caused by the Grizzly Peak and Halfmoon Creek igneous activity.

The area in the northeast part of the wilderness is assigned a moderate potential for molybdenum in a porphyry or stockwork deposit and a low potential for vein deposits of gold, silver, lead, and zinc. This area of the wilderness was given special attention because of its proximity to the Turquoise Lake stock and the Sugarloaf mining district. The Turquoise Lake stock, northeast of the wilderness, has a potential for molybdenum deposits. Topical studies of the stock by Craig (1980) indicate that its composition, age, alteration patterns, and trace-element distribution are characteristic of porphyry molybdenum deposits, although no production or development has occurred. No intrusive rocks similar to the Turquoise Lake stock are exposed in the northeast part of the wilderness. Dikes are present, but they are probably older than the molybdenum-bearing intrusives of mid-Tertiary age. North-

trending fractures, which localized the Turquoise Lake stock, extend into the wilderness and may have localized similar intrusives at depth, but regional geophysical studies do not show the expression of any such bodies in this area of the wilderness. Nearby buried intrusives, however, may be the source of the molybdenum detected in two samples from prospect pits in this area and of the traces of fluorite noted in rock near Sugarloaf Mountain. Little evidence was found here for vein deposits. Although this area lies near the Sugarloaf mining district, no strong evidence suggests that the vein system there extends into the wilderness. Hydrothermal activity associated with the Turquoise Lake stock probably supplied the metals to veins in the Sugarloaf mining district, and this activity is apparently confined to the mining district and to the St. Kevin district to the north. There are a few prospects in the wilderness adjacent to the Sugarloaf mining district; however, none contain metals that indicate any resource potential. This area therefore has a low potential for vein deposits containing base and precious metals.

Nearly 50 percent of the wilderness is covered by thick deposits of glacial debris. This cover, on the eastern slope of Mount Massive and extending to the floor of the Arkansas River valley, lies primarily on St. Kevin Granite. The mineral resource potential in the bedrock beneath the glacial deposits is unknown.

Small pegmatite bodies intrude the older Proterozoic rocks in the wilderness. They are simple pegmatites containing massive quartz, large muscovite books, microcline feldspar, and occasional black tourmaline crystals. They are probably Proterozoic and, because of their small size, they have low potential. Beryllium-bearing pegmatites occur in the Sawatch Range farther southwest, near Buena Vista, Colo., but they are Tertiary in age.

The wilderness has low potential for stratabound metal deposits of Precambrian age. The bulk of the Precambrian rocks present are not considered favorable as host for this type of deposit.

The wilderness has low potential for gold in placer deposits. Colorado Gulch, northeast of the wilderness, and Halfmoon Creek, along the southern boundary, were sites of early (pre-1900) placer prospecting; however, the success of this activity is unknown. Panned concentrates of sediment collected from the wilderness contain only trace amounts of gold (Hopkins and others, 1989).

There are no oil and gas or geothermal leases within the wilderness. The geologic setting of the wilderness is unfavorable for these types of resources.

INTRODUCTION

The Mount Massive Wilderness (fig. 1) occupies 26,140 acres (40.8 square miles) in the northwestern part of the San Isabel National Forest in Lake County, Colo. The wilderness is on the east side of the Continental Divide, in the northern part of the rugged Sawatch Range. It was named after Mount Massive (elevation 14,421 ft), the second highest peak in Colorado, which stands near the center of the wilderness; Mount Elbert

(elevation 14,437 ft), the highest peak in Colorado, is about 7 mi south of Mount Massive.

The wilderness is approximately 100 mi west of Denver, Colo., and about 7 mi west of Leadville, Colo. Several roads, both paved and unpaved, provide access to the boundaries of the wilderness area during the summer months. Access to the southwestern part is from State Highway 82, which crosses the Continental Divide at Independence Pass. This highway is closed much of the winter due to snow. The northern part of the area is accessible from Leadville via U.S. Forest Service Road 105, which follows an old abandoned railroad bed along Turquoise Lake and Busk Creek. U.S. Forest Service Road 110 provides access to the eastern and southern parts. This road follows Halfmoon Creek along the southern boundary of the area to a large basin at the head of Halfmoon Creek, the site of the Champion Mill and its aerial tram. Many campgrounds and the trailheads for both Mount Massive and Mount Elbert are along this road.

Trails shown on recent U.S. Geological Survey topographic maps are well maintained and used frequently. The major trails are Main Range, Highline, Mount Massive, North Halfmoon Creek, and North Fork of Lake Creek. Logging roads, now overgrown with trees and unusable, were constructed throughout the lower timbered slopes east of Mount Massive. This area of the wilderness was logged during the late 1800's for lodgepole pine to be used as mine timbers and charcoal for the Leadville smelters. Remnants of some of the charcoal ovens can still be found near the eastern boundary.

The Leadville National Fish Hatchery, established in the early 1900's, controls about 2,500 acres within the wilderness along Rock Creek and its tributaries. The hatchery is adjacent to the eastern boundary of the wilderness.

Most of the Mount Massive Wilderness boundary is defined by prominent physiographic features. The western boundary follows the Continental Divide for 14 mi and intersects Mount Oklahoma, Deer Mountain, and Twining Peak, all more than 13,000 ft high. Independence Pass lies at the southwestern corner, and Halfmoon Creek parallels much of the southern border. The eastern side follows a land-net boundary on the west side of the Arkansas River valley, and Busk Creek and Bald Eagle Mountain help define the northern boundary. All drainage in the wilderness is into tributaries of the Arkansas River. These tributaries include Busk Creek (empties into Turquoise Lake, then into Lake Fork), Halfmoon Creek, and the North Fork of Lake Creek. There is nearly 5,000 ft of relief from the Arkansas River (9,500 ft) to the summit of Mount Massive.

The Mount Massive area was carefully examined by early prospectors during the late 1800's, in part because of its proximity to the Leadville, Sugarloaf, St.

Kevin, and Independence mining districts (fig. 1). The Leadville district, about 7 mi east of the wilderness, was one of the richest silver districts in the Western States. Gold was first discovered in California Gulch near Leadville in 1859.

Four wilderness areas have been established in the northern Sawatch Range (fig. 1). The Holy Cross Wilderness is north of the Mount Massive Wilderness, the Collegiate Peaks Wilderness lies to the south, the Hunter-Fryingpan Wilderness shares a common boundary to the west along the Continental Divide. The mineral resource potentials of the Holy Cross and Hunter-Fryingpan Wilderness areas were evaluated by Wallace and others (1989) and Ludington and Ellis (1981), respectively, and geophysical maps of the Hunter-Fryingpan area were prepared by Campbell (1981). The Collegiate Peaks Wilderness is currently being investigated by the U.S. Geological Survey and the U.S. Bureau of Mines.

Previous Studies

The northern Sawatch Range has been the subject of many geologic studies. Regional studies include those of Tweto and Sims (1960, 1963), who identified the relationship between Precambrian structures and the Colorado mineral belt. Stark and Barnes (1935) published the first comprehensive geologic map of the Sawatch Range. The geologic map of the Leadville 1° × 2° quadrangle (Tweto and others, 1978) provides the regional setting for the area. Tweto and Pearson (1964) studied and named the St. Kevin Granite, which is a batholith that underlies much of the wilderness. Topical studies of mining districts near the wilderness include the work by Zogg (1976) on the geology of the Sugarloaf and St. Kevin mining districts, Craig (1980) on the Turquoise Lake stock, Sandberg (1935) on the petrology of the ore veins in the Sugarloaf district, Singewald (1955) on the ore-bearing veins and major mines of the Sugarloaf and St. Kevin districts, Pierson and Singewald (1954) on radioactive sites in the Sugarloaf area, and Howell (1919) on the Mount Champion-Lackawanna Gulch mining area. Regional geophysical studies have been published by Tweto and Case (1972).

Present Investigation

This evaluation of the mineral resource potential of the Mount Massive Wilderness is based on field and laboratory studies by the U.S. Bureau of Mines (USBM) and the U.S. Geological Survey (USGS). The study included geologic mapping, geochemical sampling and analyses, geophysical interpretations, investigations of

mines and prospects, and evaluation of previous studies pertinent to the economic geology of the area. Field work for these studies was completed during the summer of 1983.

The USBM examined mining records, claims, prospects, underground workings, and other evidence of past activity to appraise identified resources within the wilderness. This work was reported by Thompson (1985). USGS investigations reported in other publications include the geologic studies by Van Loenen (1985) and the geochemical studies by Hopkins and others (1989).

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Special thanks are extended to Rodney D. Woodcock, mining engineer, U.S. Bureau of Mines, and to Paul Briggs and Mark Arnold, U.S. Geological Survey, who assisted in the field work. Personnel at the Leadville National Fish Hatchery and landowners John Sodic and Marty Williams, Jr., provided helpful information on trails and road conditions, and gave permission to cross their property.

APPRAISAL OF IDENTIFIED RESOURCES

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

Three mining districts adjacent to the study area are the Sugarloaf district to the northeast, the Mount Champion-Lackawanna district to the south, and the Independence district to the southwest. The St. Kevin mining district, north of Turquoise Lake, has veins, ore minerals, and hydrothermal alteration similar to those of the Sugarloaf district, and the two have been described together in the literature. The Independence district, 2.5 mi west of Independence Pass, was studied by Ludington and Ellis (1981) and is pertinent here because the style of mineralization there is similar to that at the Eureka and Champion Mines. Boundaries of the mining districts are ill defined.

Mining History

Metallic ores have been produced near the wilderness, from the Sugarloaf, Mount Champion-Lackawanna, and Independence mining districts and from the Independence Pass area, but mineral activity inside the wilderness has been limited to prospecting. Two small blocks of patented claims are within the wilderness (pl. 1), but neither contains identified resources.

Silver production from the Sugarloaf district started in the 1880's and declined after the drop in silver prices in 1893. Several of the larger mines, however, continued operations into the 1920's. The aggregate mineral value produced from the Sugarloaf district and the nearby St. Kevin district was about \$10–15 million (Singewald, 1955, p. 263). Since 1942, mining activities have virtually ceased. Recently, exploratory drilling has been done on most of the mine dumps in the Sugarloaf district. Continental Resources Corporation is planning to process the dumps to recover silver and is considering opening and dewatering some of the caved workings (Mining Record, 1983).

Gold, silver, copper, and lead were produced from the Mount Champion-Lackawanna mining district near the southeast boundary of the wilderness. The recorded production from the Champion Mine during 1912–1940 was 27,032 oz gold, 12,731 oz silver, 30,690 lb copper, and 97,839 lb lead; there are no records of production after 1940 (Ludington and Ellis, 1981). Recent activity is evident in that the road from the Champion Mill to the Champion Mine, which is snow covered most of the year, had been graded not long before this field investigation. The Eureka Mine, at Independence Pass, produced 665 oz gold and 291 oz silver between 1934 and 1951 (Ludington and Ellis, 1981), the only years for which production was recorded. The road from Independence Pass to the Eureka Mine was in disrepair, and there were no signs of any recent mining activity.

The Independence mining district, 2½ mi west of Independence Pass, produced gold from 1879 to 1899, and intermittently after 1900 (Ludington and Ellis, 1981).

Mineralized Areas

The mineralized areas in and near the wilderness are named and located on plate 1, and a summary of geology, production, resources, and commodities of these areas is given in table 1. From northeast to southwest the mineralized areas are Sugarloaf (no. 1), Main Range Trail (no. 2), Halfmoon Creek (no. 3), Mount Champion (no. 4), Lackawanna Gulch (no. 5), and Independence Pass (no. 6) (pl. 1). Data for eight unnamed prospect pits within the wilderness but outside the mineralized areas are also shown on plate 1 and described in table 1. Additional chemical data for these localities are given by Hopkins and others (1989).

Conclusions

Mineral prospects are present in the Mount Massive Wilderness, and large mines are present nearby. No identified resources are within the wilderness, although areas of mineralized rock were found.

Adjacent to the southern boundary of the wilderness, near Independence Pass, an indicated resource of 2,000 tons of rock containing 1.1 oz gold per ton and 1.0 oz silver per ton exists at the Eureka Mine. An inferred extension of this resource, of unknown quantity and grade, exists just inside the wilderness. Because of its high gold values and reasonably convenient access, the Eureka Mine has a good chance of resuming gold production.

The low-grade gold and silver occurrence at Halfmoon Creek, along the southern boundary, may extend into the wilderness. This mineralization may result from the intrusion of the Halfmoon stock. The structure controlling mineralization there trends northward into the wilderness.

About 1 mi northeast of the wilderness boundary, a large identified silver and gold resource exists in the dumps of old mines and possibly underground in the Sugarloaf area. Work is underway toward processing the large dumps in the Sugarloaf area for their silver content.

A small identified gold and silver resource, with byproduct lead and copper, exists in several dumps and possibly underground in the Mount Champion area, south of the wilderness boundary. Additional work is required to determine if any underground resources at Sugarloaf and Mount Champion extend into the wilderness. The Champion Mine will probably be reopened and evaluated because of high gold values, but the high elevation, avalanche danger, and uncertainty about underground reserves hinder development.

Placer deposits have been worked for gold along Halfmoon Creek below the Champion Mill and along creeks in the Sugarloaf area, but no specific information or production records were located. Unpatented placer claims, currently on file with the Bureau of Land Management, are located on North Halfmoon Creek, in the wilderness, but no evidence of mining activity was noted. A panned concentrate sample from Halfmoon Creek, about 1 mi downstream (east) from the mouth of North Halfmoon Creek, contained 0.01 oz gold per ton.

As of April 1984, no oil and gas leases or geothermal leases were located inside the wilderness.

ASSESSMENT OF POTENTIAL FOR UNDISCOVERED RESOURCES

By R.E. Van Loenen, G.K. Lee, and
D.L. Campbell
U.S. Geological Survey

Geologic Setting

The Mount Massive Wilderness lies within the Sawatch Range of central Colorado in the southern

Rocky Mountain province. The Sawatch Range is at the core of the broad Sawatch Range anticline, an uplift of early Laramide origin. This region was greatly deformed by later high-angle faulting, which began in Miocene time. This faulting formed a deep graben, now occupied by the Arkansas River valley east of the axis of the Laramide anticline. Both the Laramide and Neogene tectonism were accompanied by igneous activity.

The wilderness is chiefly underlain by metamorphic and igneous rocks of Early and Middle Proterozoic age. The geologic history recorded in the rocks of the wilderness started nearly 2 billion years ago, during Early Proterozoic time, with the accumulation of sedimentary and volcanic debris. These rocks were metamorphosed in the Early Proterozoic, then intruded by granitic rocks during the Middle Proterozoic at about 1,400 Ma.

Regional information indicates that basement rocks were deeply eroded by the end of Precambrian time, then buried under a thick sequence of Phanerozoic sediments. Periods of uplift and erosion accompanied the deposition of clastic and carbonate sediments from Cambrian through Mississippian time. During late Paleozoic time, basins and ranges of the Ancestral Rockies formed; the region that includes the wilderness then was situated in a basin between the highlands. Deposition of sediment probably continued intermittently during the Mesozoic but ceased near the end of Cretaceous time with the onset of the Laramide orogeny at 72 Ma. Major uplift of the region began at that time, and the Phanerozoic cover was eroded from the wilderness, exposing the basement rock complex. Sedimentary rocks of the types that once overlay the crystalline rocks of the wilderness are now exposed on the west, north, and east flanks of the uplift. Magmatic activity occurred both during the Laramide orogeny (70–40 Ma) and afterwards (35–25 Ma). Small stocks, dikes, and sills of porphyry intruded the Precambrian rocks of the wilderness. Volcanic rocks undoubtedly covered much of the wilderness during Neogene igneous activity but have since been entirely eroded away. Veins and porphyry-type mineral deposits in the area are associated with these intrusive rocks.

Block faulting, which began during Miocene time and continues to the present; alpine glaciation during the Pleistocene; and Holocene erosion and deposition by rivers and streams are largely responsible for the physiography of the wilderness as seen today.

Early Proterozoic Gneiss

The oldest and most abundant rock type in the wilderness is an assemblage of gneiss, schist, and migmatite of Early Proterozoic age. Prior to metamorphism, these were mainly sedimentary and volcanoclastic rocks deposited more than 1,750 Ma. The rocks are strongly foliated and schistose, and they belong to the amphibolite

facies of regional metamorphism. Biotite gneiss and schist, commonly containing sillimanite, are the major rock types. Proterozoic dikes and sills of mafic or granite-pegmatite composition intrude the layered gneiss.

Middle Proterozoic Granites

During Middle Proterozoic time the older gneiss was intruded by a large, complex granite batholith. The granite was described and named the St. Kevin Granite by Tweto and Pearson (1964), and it was correlated with the 1,400- to 1,470-Ma Berthoud Plutonic Suite by Tweto (1987). This batholith is heterogeneous; it largely consists of two-mica granites of several textural and compositional facies. These granitic facies, formed at least in part by assimilation of the older gneisses, are “two mica” granite, “coarse porphyritic” granite, “fine-grained” granite, “trachyoid hybrid” granite, and “granodioritic” (Tweto and Pearson, 1964). The St. Kevin Granite forms a batholith that underlies the northeast half of the wilderness and also forms small concordant bodies within the gneiss, scattered throughout the southwestern part. Contacts with the host gneiss and schist are gradational to sharp; some contacts between granite and gneiss at the borders of plutons are gradational over many tens of feet.

Late Cretaceous and Tertiary Igneous Rocks

The most important ore deposits in central Colorado mining districts are related to two periods of igneous activity—the first in the Laramide (Late Cretaceous and early Tertiary), the second in the mid-Tertiary. The deposits at Leadville are mostly if not entirely Laramide, whereas those at Climax, Sugarloaf, and St. Kevin, and several small deposits southwest of the wilderness near Independence Pass are probably entirely mid-Tertiary.

The bulk of the Cretaceous and Tertiary intrusives in the wilderness are sills and dikes (shown as TKqp on pl. 1 and in Van Loenen, 1985), which invade both the Early and Middle Proterozoic rock terranes. These rocks intruded during the Laramide orogeny. They are usually light-gray to greenish-gray rhyolite to quartz-latitude and are characterized by an aphanitic groundmass, which contains several percent phenocrysts of quartz, feldspar, and biotite. Bipyramidal quartz phenocrysts as much as 5 mm long are quite distinctive. These intrusive bodies range from a few inches to several feet in thickness and are commonly concordant, especially where foliation is well developed in the host rock. Whole-rock K-Ar ages determined for two sills in the southern part of the wilderness are 64 and 65 Ma (table 2, samples MM-35 and MM-01). Although most of the sills and dikes of quartz porphyry in the wilderness have not been radiometrically dated, they resemble, both chemically and

Table 1. Mines, prospects, and areas containing several mines in and near the Mount Massive Wilderness

Map No. (pl. 1)	Name	Geology	Workings and production	Resource/sample data
1	Sugarloaf area-----	More than 50 major veins identified, mostly trending north. Quartz veins occupy fault fissures that approximately parallel block faulting along Arkansas River valley. Host rocks are sericitized, pyritized, and fractured Precambrian granite. Most veins more than 1,000 ft long, but none could be traced into wilderness.	More than 100 caved adits and shafts in area. Entire mining district produced about \$10 million worth of ore; five mines produced \$100,000-\$1,000,000 each (Singewald 1955).	Dumps of examined workings constitute an indicated resource of 120,000 tons of material with average grade of 0.05 oz/ton Au and 15 oz/ton Ag. Ore remaining underground could not be estimated. Work to process the Ag and Au resource in the dumps has begun.
2	Prospects at Main Range Trail.	Northwest-trending quartz pegmatite containing 6-in.-wide muscovite books, cuts Precambrian granite. A granite-schist contact has also been explored.	Eight prospect pits; one shaft.	All samples had minor amounts of Ag; highest value is 0.8 oz/ton Ag. One sample from pegmatite had 0.01 oz/ton Au; some samples contained Li and Co.
3	Halfmoon Creek area	Two northerly trending fault zones in Precambrian gneiss and Halfmoon Creek stock. Faults contain gouge, hematite, calcite, and disseminated pyrite.	Two open adits, one caved adit comprise 1,200 ft of workings. No production records available.	Li, Be, Cd, and Sb occur in minor amounts.
4	Mt. Champion area--	At Champion Mine, a broad quartz vein ranging from 3 ft to more than 20 ft wide trends N. 55° E. and dips almost vertical. Vein occupies a fault fissure in quartz monzonite, gneiss, and schist.	Champion Mine has three levels with more than 1,000 ft of workings on each. All portals are caved. A 6,100-ft aerial tram having 42 buckets, each of 9 ft ³ capacity, carried ore from the mine to Champion Mill (Howell, 1919). A rod mill, a ball mill, and four concentrating tables were in Champion Mill in 1983. Recorded production from Champion Mine during 1912-1940 was 27,032 oz Au, 12,731 oz Ag, 30,690 lb Cu, and 97,839 lb Pb. No records of production after 1940 (Ludington and Ellis, 1981).	Grab sample of ore stockpiled at Champion Mill had 2.48 oz/ton Au and 0.9 oz/ton Ag. Au and Ag present in almost every sample from this area. Ore remaining underground could not be estimated.

Table 1. Mines, prospects, and areas containing several mines in and near the Mount Massive Wilderness—Continued

Map No. (pl. 1)	Name	Geology	Workings and production	Resource/sample data
5	Lackawanna Gulch---	Northwest-trending quartz veins and faults. Veins average 2 ft thick, consist of bull quartz with minor hematite.	One short adit, one prospect pit, three caved adits. One caved working estimated at 1,000 ft long was probably dug trying to intersect veins of Champion Mine.	Grab sample of stockpiled quartz assayed 0.22 oz/ton Au. Chip sample of quartz vein contained 0.01 oz/ton Au, but most vein samples were barren.
6	Independence Pass (Eureka Mine).	A 0.3-2.0 ft thick quartz vein with hematite, pyrite, and chalcopyrite strikes northwesterly along a vertical fault fissure. Eureka Mine is patented, with portal outside the wilderness boundary, but the vein may be on or inside boundary.	A 1,600-ft adit with unmeasured stopes; parts of the mine caved or flooded. Produced 665 oz Au and 291 oz Ag in 1934-1951 (Ludington and Ellis, 1981). Exploration declines and prospects above the Eureka may have been seeking main ore vein.	Au occurs erratically, ranging from 0.01 to 3.87 oz/ton. Vein inferred to contain 2,000 tons of material averaging 1.1 oz/ton Au and 1.0 oz/ton Ag. Additional vein and Au resources are likely, perhaps extending into wilderness.
7	Unnamed prospect---	Altered and fractured biotite gneiss. Fracture zone about 30 ft wide.	Prospect pit within a patented claim.	Pyrite-rich grab sample had 3 ppm Ag and 200 ppm Zn.
8	---do-----	Altered biotite gneiss and migmatite. Mineralization localized along foliation planes.	One prospect pit and a 6-ft-deep shaft.	Analyzed grab sample had 100 ppm Ag, 5,000 ppm Cu, 2,000 ppm Pb, and 2,000 ppm Zn.
9	---do-----	Fracture zone in St. Kevin Granite	Two workings; upper pit in saddle, caved adit in cirque below.	Grab sample from prospect pit had 5 ppm Ag, 200 ppm Pb, and 200 ppm Zn. Material on dump in front of adit is barren.
10	---do-----	Aplite dike in St. Kevin Granite.	Small prospect pit.	Grab sample had 7 ppm Ag and 300 ppm Pb.
11	---do-----	Small fractures in St. Kevin Granite.	Three prospect pits and one 20-ft shaft.	One of four samples analyzed had 7 ppm Mo.
12	---do-----	Fractures in St. Kevin Granite.	Two prospect pits.	One of two samples analyzed had 7 ppm Mo and 300 ppm Pb.
13	---do-----	Stratabound metals(?) in Proterozoic gneiss.	Two very shallow prospect pits (indicated by separate symbols on pl. 1).	Two pyrite-rich grab samples had 500 and 1,000 ppm Cu and 25 and 70 ppm Zn.
14	---do-----	Fractures in St. Kevin Granite.	One prospect pit.	Grab sample had 300 ppm Pb, 300 ppm Zn, and 150 ppm Cu.

Table 2. Potassium-argon analyses and ages for Upper Cretaceous and Tertiary igneous rocks from Mount Massive Wilderness

[Analyses by R. F. Marvin, U.S. Geological Survey]

Field No.	Average K ₂ O (pct)	⁴⁰ Ar (10 ⁻¹⁰ mol/g)	⁴⁰ Ar (pct of total Ar)	Age (Ma ±2σ)
MM-35	4.09	3.833	96	63.9±2.3
MM-01	4.23	4.058	95	65.4±2.4
MM-12	4.39	2.837	93	44.3±1.6
MM-90	6.47	5.143	97	54.4±2.0

petrographically, the Upper Cretaceous Pando Porphyry as described by Tweto (1974).

The rocks in the small Timberline, Turquoise Lake, and Halfmoon Creek stocks (pl. 1) are similar in composition to the rocks that make up the dikes and sills in the wilderness; but they are deuterically and hydrothermally altered, contain disseminated pyrite, and are often brecciated. The 35-Ma radiometric age of the Timberline stock (Tweto, 1974) and the 35-Ma age of the Turquoise Lake stock (Craig, 1980) place them with the younger (mid-Tertiary) igneous activity (20–40 Ma). The age of intrusion of the Halfmoon Creek stock could not be reliably determined owing to intense alteration. Although the whole-rock K-Ar ages of 44 and 54 Ma determined for this stock (table 2, samples MM-12 and MM-90) are not adequate to date either intrusion or alteration, the rock resembles the middle Tertiary intrusive rocks.

Structural Geology

Major structural features in the wilderness resulted from periods of tectonism during Late Proterozoic, late Paleozoic, Laramide, Neogene, and Quaternary time. Some faults of Late Proterozoic origin may have been reactivated during these later times (Tweto, 1968).

Folding in the gneiss terrane during Early Proterozoic time produced small- and large-scale isoclinal folds with axial planes that trend locally north-northeast. Proterozoic gneiss in the southern part of the wilderness is folded into a large northeast-plunging anticline. Superimposed on the anticline is an intense and intricate system of drag and ptygmatic folds.

Faults in the wilderness generally trend north-northwest and northeast, the predominant trend being north-northwest, which is also the predominant trend in the Proterozoic rocks elsewhere in Colorado. Both of these trends are thought to have been established during Late Proterozoic time.

Northeast-trending faults in the wilderness could be in part related to the northeast-trending zones of shearing that developed during Proterozoic time. Two

such shear zones close to the wilderness are the Home-stake shear zone, about 10 mi to the north, and the Independence Pass shear zone, which cuts the southwest part of the wilderness (Tweto and Sims, 1960). These and other shear zones were interpreted by Tweto and Sims (1960) to influence the location of Laramide magmatic activity within the Colorado mineral belt. The Colorado mineral belt (shown on fig. 2) is a northeast-trending belt that contains most of the major mining districts in Colorado (Tweto and Sims, 1963). The wilderness is centered within this belt.

During late Paleozoic time the area now occupied by the wilderness lay in a basin west of the Front Range highland of the Ancestral Rockies (Mallory, 1972). The trend of the Front Range highland and the adjoining basin roughly parallels the north-northwest fault trends established in Proterozoic time. Faulting may have been reactivated during the late Paleozoic along these trends.

The major structural event in the Mount Massive region during the Laramide orogeny was the uplift of the Sawatch anticline. The axis of this anticline trends north-northwest through the southwest part of the wilderness. Faulting accompanied the uplift and apparently followed the ancestral north-northwest trends and, to a lesser extent, the northeast trends. Many of the faults, either reactivated or newly formed during the Laramide, were intruded by small porphyritic intrusives. Zogg (1976) noted that some northeast-trending faults in the Turquoise Lake area are occupied by Early Laramide porphyries.

From about 25 Ma (near the beginning of the Neogene Subperiod) until the present, the Laramide structural features have been affected by intermittent stages of block faulting associated with the Rio Grande rift system. The Upper Arkansas graben, a product of this rifting, cuts through the east flank of the Sawatch anticline. The graben, part of which lies in the wilderness, is the northernmost graben of the Rio Grande rift system; it terminates a few miles northwest of Leadville, Colo. Many faults in the wilderness trending north-northwest may be part of the Rio Grande rift system. Some of these faults were newly formed in Neogene time; others may be reactivated older faults.

The latest Neogene and Quaternary movement along the system of north-northwest-trending faults in the wilderness is mainly that of down-dropping to the east, reflecting continued subsidence of the Upper Arkansas graben.

Faults in the region are significant in that they controlled the location of intrusive bodies, some of which are mineralized, and also provided passage for hydrothermal fluids and depositional sites for metals. Proterozoic granites and gneiss in the region surrounding the wilderness contain fractures, some of which are filled with mineralized veins. The bulk of the favorable

fractures are in granite, which is homogeneous and brittle and hence fractures more easily than the gneiss. The gneiss tends to absorb stress along planes of well-developed foliation rather than fracture cleanly along a single zone. Faults are commonly occupied by silicified breccias, quartz veins, and porphyritic intrusives, all of which show various degrees of alteration. Near the wilderness, rich ore-bearing silicic veins filled fractures in granite in the Sugarloaf, St. Kevin, and Mount Champion mining districts. The Eureka Mine is on fractures in the gneiss.

Geophysics

Map A (pl. 2) is a complete Bouguer gravity anomaly map of the Mount Massive Wilderness. The gravity stations and values plotted on it are from the U.S. Geological Survey files; no new gravity data were collected for this study. Map B (pl. 2) is an aeromagnetic map of the study area that in part shows data collected for this study (Godson and others, 1985) and in part was taken from an earlier aeromagnetic survey (U.S. Geological Survey, 1979).

Previous studies of gravity and magnetic features in the region were by Tweto and Case (1972), who concentrated on an area centered to the east of the Mount Massive Wilderness, and by Campbell (1981), who was primarily concerned with an area just west of it. Both studies overlap the Mount Massive Wilderness and are useful for their descriptions of the regional geophysical setting, but, with one exception described below, neither discussed anomalies inside the wilderness.

The Mount Massive Wilderness lies on a strong regional gravity gradient that marks the northwest side of the lowest Bouguer gravity anomaly in the central United States. This low (fig. 2) is interpreted to be caused by Laramide or Tertiary granitic intrusive bodies (Behrendt and others, 1968) which are probably related genetically to the Colorado mineral belt (Tweto and Sims, 1963). All of the Mount Massive Wilderness lies inside the -300 milligal gravity contour, indicating that such granitic intrusive bodies probably are present at depth. Map A shows the trend and magnitude of the steep gravity gradient in the area. Gravity stations in the Mount Massive Wilderness, however, are too sparse to reliably define more local gravity features that may reflect particular geologic sources there.

The interpretation of geophysical features given here is based on the geologic map and description of rock units given by Van Loenen (1985), which are generalized here on plate 1. The regional geologic setting and the mineral deposits of this area have been described in earlier sections of this report.

Figure 3 shows histograms of magnetic susceptibilities of 80 rock samples collected in the study area for

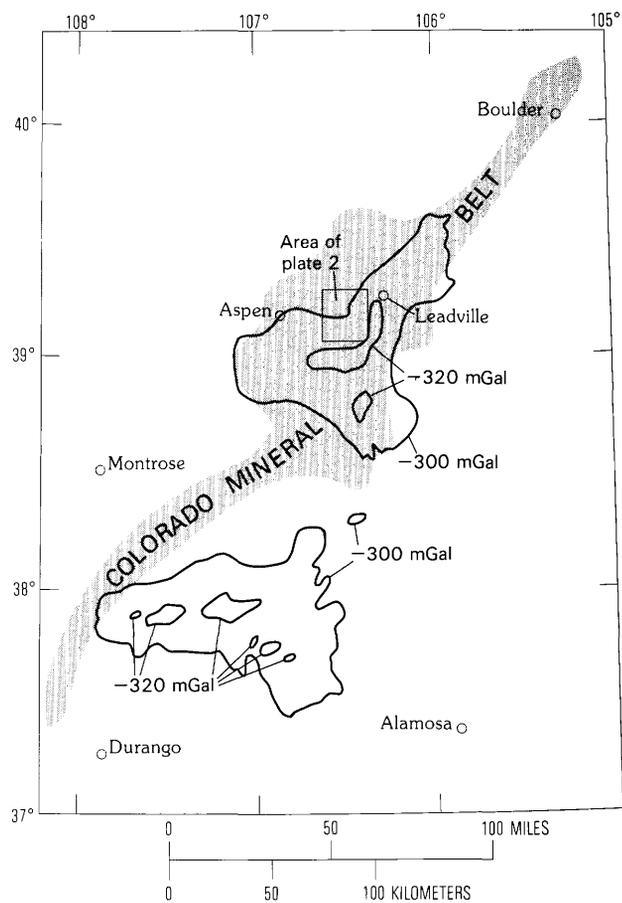


Figure 2. Map showing correlation between complete Bouguer gravity anomaly low, indicated by -300 and -320 mGal (milligal) contours (from Behrendt and Bajwa, 1974), and the Colorado mineral belt (shaded, from Tweto and Sims, 1963).

petrographic and geochemical analyses. Susceptibilities were measured using a Geoinstrument JH-8 meter. The JH-8 meter has a measurement threshold of approximately 2×10^{-5} (using SI units; 1 SI unit = $1/4\pi$ cgs unit); all rocks with lower susceptibilities are shown as 1×10^{-5} (SI). Rocks with such low susceptibilities were common in the southern part of the study area. The highest susceptibility measured was $14,000 \times 10^{-5}$ (SI) for a sample of magnetite-bearing pegmatite of presumed Middle Proterozoic age collected just east of the Continental Divide, across the divide from Lost Man Lake (pls. 1 and 2).

The samples were separated into three classes: Early Proterozoic metamorphic rocks, Middle Proterozoic granites, and Cretaceous-Tertiary dike rocks. Figure 3 shows that magnetic susceptibilities of rocks in these three classes vary widely. Some of the variability is due to collection procedures: many unusual rocks were collected for the petrographic/geochemical sample suite that was measured, resulting in an overrepresentation of many rock types that are volumetrically minor in the

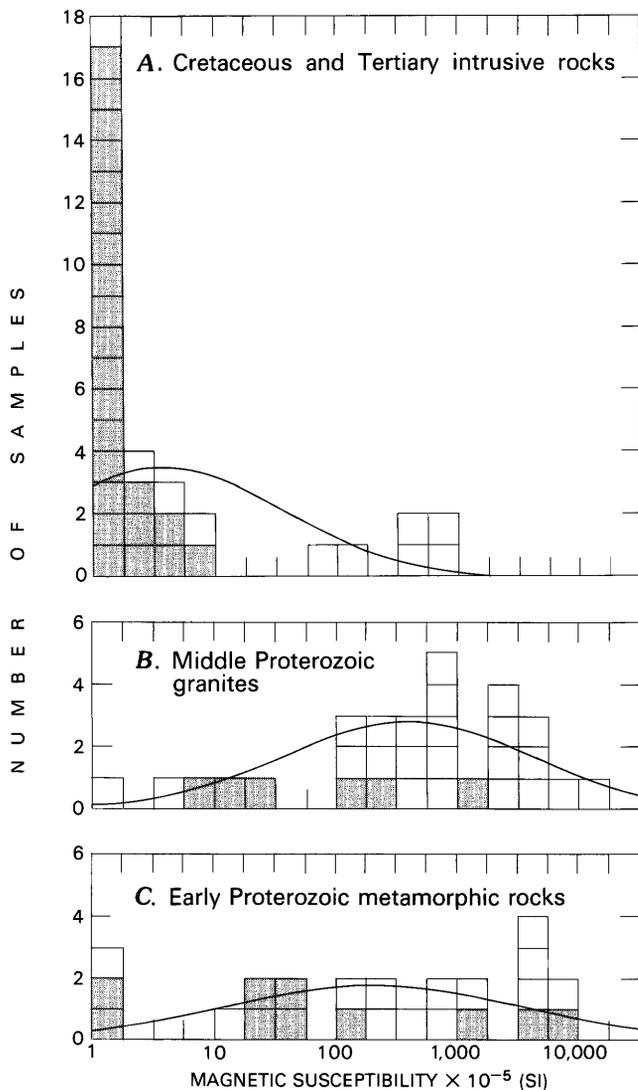


Figure 3. Magnetic susceptibilities measured from samples collected in and near the Mount Massive Wilderness. Shading indicates samples from inside the Halfmoon lows (arbitrarily defined as the region having a magnetic field of 50,700 gammas or less on part 1 of map B (plate 2) and -100 gammas or less on part 2 of map B). A normal curve which best fits the histogram is also shown (continuous curve).

study area. Note, though, that the magnetic susceptibilities of even "typical" rocks in a map unit are usually distributed lognormally, and so will vary widely. The geometric mean (= antilog of the mean of the logs) susceptibility of measured samples of Cretaceous-Tertiary dike rocks was 4×10^{-5} (SI), that of the Early Proterozoic metamorphic rocks was 200×10^{-5} , and that of the Middle Proterozoic granites was 400×10^{-5} . "Typical" rock samples from each class generally had susceptibilities near these reported geometric means.

Aeromagnetic features on map B (pl. 2) reflect the major bedrock lithologies of the Mount Massive

Wilderness (pl. 1). Aeromagnetic lows in the southern half of the study area overlie the low- to moderate-susceptibility Early Proterozoic schists and gneisses. Somewhat higher magnetic fields are seen in the northern half of the area, where Middle Proterozoic granites make up the dominant lithology. Very low magnetic fields are seen in the southern third of map B (pl. 2), where Cretaceous-Tertiary rocks are common.

Early Proterozoic metamorphic rocks in the study area include several different local rock types, and the susceptibilities of the samples vary correspondingly. Of the samples measured, the highest susceptibility values were found for a sample of chloritized meta-amphibolite from the ridge between Mount Champion and Deer Mountain ($8,700 \times 10^{-5}$ (SI)); a metadiorite collected from the Continental Divide northeast of Lost Man Lake ($6,300 \times 10^{-5}$); a biotite-sillimanite-garnet gneiss from a ridge between Halfmoon and North Halfmoon Creeks ($5,200 \times 10^{-5}$); and a migmatite gneiss from Mount Oklahoma, on the Continental Divide west of North Halfmoon Lakes ($5,000 \times 10^{-5}$). (See pl. 2 for locations of all these geographic features.) The gneiss samples are relatively typical-looking rock for the area, though somewhat darker in color than most. The other high-susceptibility lithologies listed above are volumetrically minor in the study area. Except for the Mount Oklahoma location, none of the sites where these samples were collected are near aeromagnetic highs.

Figure 3 and the patterns on map B suggest that Middle Proterozoic granites generally are somewhat more magnetic than the Early Proterozoic metamorphic rocks; the granites evidently contain concentrations of magnetic minerals which lead to local magnetic highs. The highs are strongest over peaks, but this is probably a topographic effect. One such high occurs over Mount Massive and a second over the Continental Divide just south of Pear Lake. Rock samples from these areas had high susceptibilities ($2,700 \times 10^{-5}$ (SI) for the Mount Massive sample; $5,400 \times 10^{-5}$ and $6,400 \times 10^{-5}$ for two Pear Lake samples). All three high-susceptibility samples were coarse-grained porphyritic granites; magnetic highs throughout the study area generally coincide with outcrops of such granites, and this relationship suggests that the granites must be the most magnetic phase there. Both the Mount Massive and Pear Lake magnetic highs are elongated to the southeast, paralleling the general contact between Early and Middle Proterozoic rocks. These highs form part of the "Mount Massive-Fulford lineament" (Campbell and Wallace, 1986), a series of aligned magnetic features that extends from near Mount Massive more than 25 mi to the north-northwest.

In the southern part of the Mount Massive Wilderness a band of deep magnetic lows, herein termed the "Halfmoon lows," follows the west-trending part of Halfmoon Creek and extends west to cross the

Continental Divide west of Blue Lake. The Halfmoon lows occur over a zone containing dikes and sills that were interpreted (Campbell, 1981) to be associated with the Grizzly Peak caldera (Candee, 1971), a mid-Tertiary volcanic feature located outside of the wilderness to the southwest. However, recent K-Ar ages (R.F. Marvin, written commun., 1985) of several of the dikes and sills show they are Cretaceous and hence pre-date volcanic activity at the Grizzly caldera.

Samples of Cretaceous intrusive rocks and Proterozoic rocks from sites in the Halfmoon lows have lower magnetic susceptibilities than Proterozoic rocks from sites north of the Halfmoon lows (fig. 3; see also Campbell, 1981). Although the Cretaceous dikes and sills characterize the zone, they are a volumetrically minor constituent of it and have sharp contacts with the Proterozoic rocks they intrude. These tabular intrusive bodies commonly are parallel to the foliation of the country rocks, though some of them intersect the foliation.

Rocks underlying some parts of the Halfmoon lows appear to be altered. Tweto and Case (1972, p. C26) note that in places they "weather yellowish-brown, suggesting widely disseminated pyrite, especially in the north fork of Halfmoon drainage." However, in other parts of the Halfmoon lows, such as along the North Fork of Lake Creek and the upper reaches of Halfmoon Creek, both dikes and country rocks appear fresh. Hence, it is not clear whether the Early Proterozoic country rocks in the Halfmoon low zone have always lacked magnetic minerals, or whether they once had magnetic minerals that were subsequently altered and destroyed.

Tweto and Case (1972) suggest that the Halfmoon lows reflect a shallow pluton whose emplacement led to processes that destroyed magnetic minerals in the country rocks. Judging from the regional magnetic map, the pluton might be some 9 mi in diameter with only its northeastern part extending under the wilderness area. If so, the rocks of this pluton must have low magnetic susceptibility (most likely) or else have reversed polarity. The Halfmoon Creek stock, exposed along Halfmoon Creek at about 11,400 ft elevation, may be an outcrop of this pluton. The two rock samples collected from the Halfmoon Creek stock have relatively low susceptibilities (1×10^{-5} and 5×10^{-5} (SI)). Radiometric ages of 44 and 54 Ma for Halfmoon Creek stock fail to agree with the 64- and 65-Ma ages of sills in the Halfmoon lows (table 2), suggesting that intrusive rocks of two ages may be present in this area, both possibly contributing to hydrothermal alteration. Another large, weakly magnetic pluton near the wilderness is the Twin Lake stock, just south of map B. The Twin Lake stock, however, is marked by a strong gravity low, whereas the Halfmoon Creek stock has no associated gravity low. (For further discussion, see Tweto and Case, 1972, p. C26.)

Geochemistry

Sampling and Analytical Methods

Materials collected for geochemical analyses consisted of 50 stream-sediment samples, 29 panned concentrates, 102 rock samples, and 18 soil samples. Sediment was collected from most active first-order drainages in the study area and from all second-order and larger streams. Each stream-sediment sample is a composite of fine material from several sites within the stream at a given locality; the sediments were air dried and sieved before analysis. In addition, panned concentrates were collected from drainages that were big enough to deposit gravel. These heavy-mineral concentrates were obtained close to stream-sediment localities but were derived from coarser material representing a higher energy depositional environment in the stream. The rock and soil samples were collected for two purposes: (1) to characterize chemically the mineralized and (or) altered rocks from the study area, and (2) to provide background abundances of elements in unaltered country rock throughout the study area. The rock samples were usually taken as representative composites of chips from outcrops. Where alteration was apparent, the most mineralized or altered material was collected preferentially. Occasionally, specimens of float were taken if mineralized and if the source was inaccessible or did not crop out. Soil samples were obtained at some of the rock sample localities for comparison purposes.

All rock samples were crushed, ground, split, and analyzed. Soil and stream-sediment samples were dried and sieved through an 80-mesh (177-micrometer) screen, and the finer fraction was analyzed. Panned concentrates were dried and a small split of each sample was separated for spectrographic analysis. The entire remainder of each concentrate was weighed and chemically analyzed for its gold content.

All samples were analyzed for 31 elements by R.T. Hopkins, Jr., using the six-step semiquantitative emission spectrographic method of Grimes and Marranzino (1968). Panned concentrates were analyzed for gold by atomic absorption. Atomic-absorption determinations of antimony, bismuth, cadmium, lead, and zinc were made on the rock samples using the method described by Viets (1978), in which the readily soluble portion of these elements is dissolved and analyzed. The analytical results and sample localities for all analyzed samples are listed in a companion publication by Hopkins and others (1989).

Discussion

The geochemical survey was directed primarily towards assessment of undiscovered metallic resources,

specifically porphyry stockwork deposits (molybdenum and copper), vein deposits (gold, silver, and the base metals lead and zinc), and placer deposits (gold).

The geochemical survey of the wilderness did not disclose any previously unknown mineralized rocks. Most of the rock samples that contained anomalous amounts of metals were taken from prospect pits in the wilderness and mines located just outside the wilderness boundary. These samples enable characterization of metals in veins and altered rock, especially Cenozoic intrusives. Metals occurring in anomalous amounts include gold, silver, lead, zinc, copper, and molybdenum.

Amphibolites within the Proterozoic gneiss commonly contain elevated amounts of copper and zinc, although the amounts are considered typical of this rock type. These elements also occur in anomalous concentrations in gneiss in what appear to be small stratabound-type occurrences northwest of Mount Massive. Copper found in stream sediment from North Halfmoon Creek might have been derived from this type of occurrence. The dearth of copper and zinc in other stream sediment samples probably indicates that stratabound metal deposits are either absent, not exposed, or very small and low grade. Low levels of zinc also occur in fractured rock in fault zones in the southwest part of the wilderness. In most cases these altered zones were explored in prospects.

Gold, ranging from 0.1 to 5.7 ppm, was measured in five panned-concentrate samples. Two of these samples, taken from Halfmoon Creek, most likely reflect the gold content of the area around the Champion Mine and Mill; another is from a stream draining the Bald Eagle Mountain vicinity, where there are several small prospects near the Sugarloaf district; a fourth was collected from the east fork of the headwaters of North Fork Lake Creek and probably indicates gold content in a northwest-trending silicified shear zone in that drainage; and one taken from a minor drainage between Willow Creek and North Willow Creek (pl. 1) showed trace amounts of gold.

Somewhat elevated lead concentrations were found in samples of each type and are scattered throughout the study area. The highest values are at or near mines and prospects. Inasmuch as the other high values are widely scattered and not associated with extensive alteration or mineralization, they seem more suggestive of a relatively high background value for lead in the area than of significant undiscovered mineral deposits.

Low but detectable amounts of molybdenum were found in two stream-sediment samples collected in the northeast part of the wilderness. Lead and copper were also detected in panned concentrates from the same sites. These sediments were derived from terrane underlain by St. Kevin Granite; however, the source of the metals is

not known for certain. They may be derived from the St. Kevin Granite or from weakly mineralized veinlets within the granite. The Turquoise Lake stock, which contains molybdenum, is about 4 mi northeast of the area where the molybdenum-bearing samples were collected. Molybdenum was also found in two stream-sediment samples from the southwest part of the wilderness in terrane underlain by gneiss and granite. Molybdenum found there is not associated with other elements and its source is unknown. The only rock samples collected in the wilderness that contain detectable molybdenum are from the Halfmoon Creek stock. Stream sediments collected from drainage below the stock did not contain molybdenum. Overall, molybdenum occurs only sporadically and its geochemical distribution does not suggest an exploitable deposit. Other elements that would characterize a stockwork molybdenum deposit, such as tin, tungsten, and copper, are sparse or absent in the stream sediments.

Silver in the geochemical samples is confined to the southwest part of the wilderness, where it occurs in prospects on hydrothermal veins in the gneiss and granite and in the Tertiary age intrusives.

Of the nearly 200 samples collected and analyzed, only the few scattered samples discussed above contain metals in amounts that might suggest mineralization. Prospects and mines that yielded metalliferous samples are concentrated in and near the southwest part of the wilderness. Statistical examination of the analytical data did not indicate elemental associations or patterns that would be expected in the presence of significant ore bodies or mineral deposits within the wilderness. The analytical results and sample localities are given in full by Hopkins and others (1989).

Mineralization and Intrusive Centers

Intrusive centers located very near the wilderness that may include areas of mineralized rock are the Turquoise Lake stock, the Halfmoon Creek stock, and the Grizzly Peak caldera complex.

The Turquoise Lake stock (pl. 1) is exposed—albeit very poorly—along the north shore of Turquoise Lake (Tweto, 1974; Craig, 1980), about 2 mi north-northeast of the Mount Massive Wilderness. Although exposures of the Turquoise Lake stock are entirely outside the wilderness boundary, parts of the hydrothermal system related to this igneous mass may have affected the terrane within the wilderness. The Turquoise Lake area, which contains both the St. Kevin and Sugarloaf mining districts, has been studied by Zogg (1976) and by Craig (1980). Zogg reported on the geology and distribution of ores in the Sugarloaf district, and Craig studied the Turquoise Lake stock and established a genetic relationship between the stock and the

mineralization in the Sugarloaf district. The stock and dikes related to it are thought to have intruded near the intersection of an east-west fault and the Central fault, which trends southerly into the wilderness. This composite intrusive contains rocks of quartz latite and rhyolite composition and was radiometrically dated as early Oligocene, 35 Ma, by Craig (1980). Characteristics of alteration associated with the stock are described by Craig as follows: (1) alteration halos centered on the stock include propylitic, phyllic, and quartz-topaz subzones, and a kaolinite-sericite zone at depth within the stock; (2) the pyrite content of the wall rocks increases towards the stock; (3) molybdenite is present in the quartz-topaz subzone and in quartz veinlets surrounding this subzone; (4) in drill holes in the subzone of phyllic alteration, Mo, Cu, and W increase with depth; (5) Cu, Mo, Pb, Zn, Sn, W, and F are present in anomalous amounts in dispersion halos centered on the stock. These characteristics closely resemble the alteration patterns seen around porphyry-type stockwork molybdenum deposits. Craig (1980) has also shown that the metals Cu, Mo, Pb, Zn, Ag, Sn, W, and Bi found in veins in the Sugarloaf district are concentrated in halos around the Turquoise Lake stock. These patterns strongly suggest that the stock has a genetic relationship to the veins in the Sugarloaf and St. Kevin districts. The comprehensive study by Zogg (1976) of structure, alteration patterns, and geochemistry of the vein systems in the Colorado Gulch area (pl. 1), at the southern edge of the Sugarloaf district (the northeast boundary of the wilderness), indicates no anomalous metal enrichment south or west of the Sugarloaf district.

The Halfmoon Creek stock (pl. 1) is in upper Halfmoon Creek basin below the Champion Mill. It consists of two small intrusive masses, probably connected at depth, that were emplaced into Early Proterozoic gneiss. The intrusive rocks are deuterically and hydrothermally altered quartz porphyry of rhyolitic composition. Dikes of similar composition cut the gneiss around the stocks. The easternmost body is bordered by contact breccia several feet wide that has been explored by early miners. Extensive workings include an adit whose portal is located outside the wilderness; however, it is over 1,000 ft long and probably extends north into the wilderness (Thompson, 1985). Clasts of gneiss are incorporated within the brecciated part of the intrusive. Rock in the large dump near the adit contains abundant disseminated pyrite. Samples collected and analyzed from the breccia zone and other parts of the stock contain traces of gold, silver, and molybdenum (Thompson, 1985; Hopkins and others, 1989). The stock was explored by drilling within the past 10 years by a private mining company, but the company has not

released any information about it. The age of this stock is unknown; however, it may be related to the Oligocene Grizzly Peak caldera complex (5 mi to the southwest).

The Grizzly Peak caldera complex, centered about 5 mi southwest of Independence Pass, is a suite of mid-Tertiary intrusive and extrusive rock. Collapse structures associated with the Grizzly Peak caldera may extend into the southwest part of the wilderness. Mineralization associated with this igneous complex is probably related to that in the Independence district and may also have affected the southwest part of the wilderness.

Mineral and Energy Resource Assessment

The geologic environment of the Mount Massive Wilderness could be compatible with several types of ore deposits. The following types of deposits (listed in order of decreasing importance) will be discussed: (1) epithermal veins (Au, Ag, Pb, and Zn); (2) molybdenum stockwork deposits (Mo, Cu); (3) placers (Au); (4) Precambrian pegmatites (feldspar, mica, gem minerals); and (5) Precambrian stratabound deposits (Cu, Zn).

Epithermal Veins (Gold, Silver, Lead, and Zinc)

Characteristics favorable to the occurrence of epithermal vein deposits are these:

1. Host rock—Any brittle rock that fractures readily is favorable. The St. Kevin Granite is a more favorable host than the gneiss complex. The gneiss tends to absorb stress along its well-developed foliation rather than to develop open fractures and fracture permeability.
2. Structure—The most favorable fractures are those that developed under tensional stress; they were more likely to remain open, thus providing conduits for hydrothermal fluids. North-south-trending fractures of this type developed during mid-Tertiary rifting of the Upper Arkansas valley graben.
3. Metal source—The igneous activity of Tertiary age generated hydrothermal ore fluids, which had access to a system of fissures and fractures.

The southwest part of the wilderness is assigned a high mineral resource potential with a certainty level of C (see Appendix for explanation of certainty levels) for the occurrence of small high-grade vein deposits of silver, gold, lead, and zinc based on the following criteria: (1) ore has been produced near the wilderness boundary from the Champion and Eureka Mines and from small mines in Halfmoon Creek basin (Thompson, 1985); (2)

the gold reserves estimated for the Eureka Mine are significant (Thompson, 1985), and the veins that contain the gold may extend into the wilderness; (3) anomalous amounts of metals occur in several of the prospects on veins (Hopkins and others, 1989); and (4) the area is within a magnetic anomaly, which might be due to alteration caused by a hydrothermal system related to the igneous activity at the Grizzly Peak caldera and the Halfmoon Creek stock.

The northeastern part of the wilderness was assigned a low resource potential for vein deposits, with a C level of certainty, based on the following criteria: (1) the metal-bearing veins seen in the Sugarloaf mining district do not extend into the wilderness, even though the Central fault and other north-trending faults that carried the mid-Tertiary hydrothermal fluids from the Turquoise Lake stock do extend into the wilderness; and (2) none of the prospects on veins in this part of the wilderness contain sufficient amounts of metals or combinations of elements to suggest concealed resources, even though some do have slightly elevated metal concentrations (Hopkins and others, 1989). Although the area is underlain by the St. Kevin Granite, a rock susceptible to fractures, it apparently lies outside of the mineralized part of the Sugarloaf district.

The north-trending fracture system that is mineralized in the Sugarloaf district forms the west side of the upper Arkansas valley graben and continues south for several miles. A large segment is concealed beneath glacial till, and the potential for vein deposits there is unknown. Farther south this system of faults cuts gneiss and granite exposed in the southeast part of the wilderness. Several prospects explored veins in the fracture system there (see Nos. 2 and 14 on pl. 1 and table 1), but samples from these prospects did not contain metals in amounts that would indicate a resource, nor did the geochemical survey of the area indicate the presence of an unknown resource. Weakly mineralized veins do occur in fractures there; however, past exploration and geochemical data obtained for this study do not indicate that the area is favorable for vein deposits. Rock is well exposed in this area, and a sufficient number of geochemical samples were analyzed to assign a low mineral resource potential for vein deposits with a C level of certainty.

Stockwork Molybdenum Deposits in Plutonic Rocks

The following characteristics are favorable for the occurrence of molybdenum stockwork deposits:

1. Host rocks—Multiple phase porphyritic intrusions of granite-rhyolite composition: >74 percent SiO₂, Rb/Sr > 4; relatively high Y and Nb; border phases often brecciated.

2. Age—Mid-Tertiary (50 m.y. or younger).
3. Structure—Intersection of major faults provides site for localizing source intrusive; radial fractures around intrusion may be formed during emplacement.
4. Geophysical signature—Magnetic and gravity anomalies (lows) characterize altered intrusives surrounded by less altered crystalline rocks.
5. Geochemical signature—Mo, Sn, W, Ag, Zn, Pb, Mn, F, and Cu dispersed, according to their mobility, in halos around the intrusive.
6. Alteration—Zonal alteration patterns visible in the intrusive and the surrounding rocks.

The area surrounding the Halfmoon Creek stock (within the area of high potential for vein deposits in the southern part of the wilderness) was assigned a moderate resource potential for molybdenum in a porphyry stockwork type deposit based on the presence of (1) two small porphyritic rhyolite stocks, one of which extends into the wilderness; (2) radiating dikes of similar composition; (3) pervasive alteration of the intrusive rocks; (4) the presence of disseminated pyrite and anomalous amounts of Mo and other metals in the intrusive rocks; (5) a favorable brecciated border phase in the eastern part of stock; (6) a favorable composition in the intrusive rocks (>74 percent SiO₂, Rb/Sr > 4, and relatively high contents of Y and Nb); and (7) a magnetic low in this area, centered over the Grizzly Peak caldera. The low may represent a buried pluton, even though the Proterozoic host rocks show little alteration. Available evidence, suggesting the occurrence of molybdenum in a porphyry stockwork deposit in this area, allows the assignment to be made with a C level of certainty.

The area in the northeast part of the wilderness has a moderate (M) potential for the occurrence of molybdenum in a porphyry stockwork type deposit. This area was given special attention because of its proximity to the Turquoise Lake stock. The area was assigned moderate potential, based on the following criteria: (1) a favorable area is nearby; (2) fractures that localized the Turquoise Lake stock extend into the wilderness, and these fractures may have localized similar intrusives beneath the wilderness (even though current geophysical studies do not indicate any anomalies there); and (3) molybdenum was detected in two prospects in this area and traces of fluorite were noted in rock near Sugarloaf Mountain, and these may have been derived from a nearby buried intrusive. Although strong evidence indicating the possibility of a molybdenum deposit was not found, the geologic setting and geochemical studies allow the assignment to be made with a B level of certainty.

Many dikes and sills of quartz porphyry occur throughout the wilderness (Van Loenen, 1985); however, none contain any anomalous amounts of important metals. These might be derived from plutons at depth beneath the wilderness, but the nature of the sources is unknown. Although a few of the sills are rhyolite in composition (> 74 percent SiO₂), most are quartz latite; their Rb/Sr ratios are mostly < 1, and their Y and Nb contents are low. They are chemically and petrologically similar to the early Laramide porphyries, and two of them give whole-rock K-Ar ages of 65 and 64 Ma (table 2, samples MM-01 and MM-35). They are unlikely to be related to porphyry molybdenum stockwork deposits.

Placer Deposits (Gold)

The wilderness has low potential for gold in placer deposits. Colorado Gulch, northeast of the wilderness, and Halfmoon Creek, south of the southern boundary, were sites of early placer mining and exploration (prior to 1900). The success of this activity is unknown. Five panned concentrates of stream sediment collected from the wilderness contain only trace amounts (< 10 ppm) of gold (Hopkins and others, 1989), amounts too small to suggest the occurrence of placer deposits. Gold was not detected in any of the 55 stream-sediment samples nor in 24 other panned concentrates collected in the wilderness.

Precambrian Pegmatites (Feldspar, Mica, Gem Minerals)

The mineral resource potential for pegmatite minerals in the Mount Massive Wilderness is low (L) with a certainty level of C. Small pegmatite bodies intrude the older Proterozoic rocks in the wilderness. They are compositionally simple, containing massive quartz, large muscovite books, microcline feldspar, and occasional black tourmaline. They are probably of Proterozoic age and, because of their small size, are unlikely to contain feldspar or mica in amounts that could be profitably extracted. They differ from the beryllium-bearing pegmatites that occur in the Sawatch Range further south, which are Tertiary in age.

Precambrian Stratabound Deposits (Copper and Zinc)

Stratabound metal deposits containing mainly copper and zinc occur in Proterozoic rock in other parts of the San Isabel National Forest. A large deposit of this type is about 50 mi south of the wilderness near Salida, Colo. These deposits commonly consist of small to large lenses containing copper and zinc or tungsten and copper, and some include silver and gold; the most favorable host rock is interlayered feldspathic, calc-

silicate and hornblende gneiss of Proterozoic age (Taylor and others, 1984, p. 13-16). The mineral resource potential for Proterozoic age stratabound deposits in the Mount Massive Wilderness is considered low because geochemical anomalies and favorable host rocks are rare. Favorable host rocks do occur in the wilderness, but the bulk of the Early Proterozoic rocks are biotite gneiss and schist and migmatite. Copper (chalcopyrite) and traces of zinc are found at two sites on the ridge just northwest of Mount Massive (see prospect 13, pl. 1 and table 1) in biotite and migmatite gneiss. These occurrences resemble stratabound deposits, but due to the type of host rock, their small size, and their low grade, they do not indicate a resource. They do, however, indicate that base metals were available in the depositional environment during Proterozoic time. Therefore, other occurrences in the wilderness are theoretically possible, though none have been observed. The geology and the geochemical signature of the wilderness are well defined, allowing assignment of a low resource potential for stratabound metal occurrences with a C level of certainty.

Energy Resources

There are no oil and gas or geothermal leases within the wilderness. The geologic setting of the wilderness is unfavorable for these types of resources. The potential therefore is low with a certainty level of D.

REFERENCES CITED

- Behrendt, J.C., and Bajwa, L.Y., 1974, Bouguer gravity map of Colorado: U.S. Geological Survey Geophysical Investigations Map GP-895, scale 1:500,000.
- Behrendt, J.C., Brinkworth, G.L., and Popenoe, Peter, 1968, Geophysical investigations in the Colorado mineral belt [abs.]: *Geophysics*, v. 33, no. 6, p. 1030.
- Campbell, D.L., 1981, Aeromagnetic and complete Bouguer gravity anomaly maps of the Hunter-Fryingpan Wilderness Area, Pitkin County, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-1236-C, 2 sheets, scale 1:50,000.
- Campbell, D.L., and Wallace, A.R., 1986, Aeromagnetic map of the Holy Cross Wilderness Area, Eagle, Lake, and Pitkin Counties, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-1841-B, scale 1:100,000, 1 sheet.
- Candee, C.R., 1971, The geology of the Lincoln Gulch stock, Pitkin County, Colorado: Golden, Colo., Colorado School of Mines, M.S. thesis, 86 p., 5 pl.
- Craig, S.D., 1980, The geology, alteration, and mineralization of the Turquoise Lake area, Lake County, Colorado: Fort Collins, Colo., Colorado State University, M.S. thesis, 147 p.
- Godson, R.H., Plesha, J.L., Sneddon, R.A., and Krizman, R.W., 1985, Aeromagnetic map of Mount Massive and vicinity, Colorado: U.S. Geological Survey Open-File Report 85-735, 2 sheets, scale 1:100,000.

- Grimes, D.J., and Marranzino, A.P., 1968, Direct-current and alternating-current spark emission spectrographic field methods for the semiquantitative analysis of geologic materials: U.S. Geological Survey Circular 591, 6 p.
- Hopkins, R.T., Jr., Lee, G.K., Leinz, R.W., and Sharkey, J.D., 1989, Analytical results and sample locality map of rock, soil, heavy-mineral-concentrate, and stream-sediment samples from the Mount Massive Wilderness Study Area, Lake County, Colorado: U.S. Geological Survey Open-File Report 89-530.
- Howell, J.V., 1919, Twin Lakes district of Colorado: Colorado Geological Survey Bulletin 17, p. 86-93.
- Ludington, Steve, and Ellis, C.E., 1981, Mineral-resource potential of the Hunter-Fryingpan Wilderness and the Porphyry Mountain Wilderness Study Area, Pitkin County, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-1236-D, scale 1:50,000.
- Mallory, W.W., 1972, Pennsylvanian arkose and the ancestral Rocky Mountains, *in* Mallory, W.W., ed., Geologic atlas of the Rocky Mountain region: Denver, Colo., Rocky Mountain Association of Geologists, p. 131-132.
- Mining Record, 1983, Texas firm acquires interests in Colorado/Arizona properties: v. 95, no. 33 (August 17, 1983), p. 7.
- Pierson, C.T., and Singewald, Q.D., 1954, Occurrences of uranium-bearing minerals in the St. Kevin district, Lake County, Colorado: U.S. Geological Survey Circular 321, 17 p.
- Sandberg, A.E., 1935, Notes on ore minerals from the Sugar Loaf district, Lake County, Colorado: Colorado Scientific Society Proceedings, v. 13, p. 485-504.
- Singewald, Q.D., 1955, Sugar Loaf and St. Kevin mining districts, Lake County, Colorado: U.S. Geological Survey Bulletin 1027-E, p. 251-297.
- Stark, J.T., and Barnes, F.F., 1935, Geology of the Sawatch Range, Colorado: Colorado Scientific Society Proceedings, v. 13, p. 467-479.
- 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, *with a section on* Salable minerals, by J.S. Dersch: U.S. Geological Survey Bulletin 1638, 42 p., 2 pls.
- Thompson, J.R., 1985, Mineral investigation of the Mount Massive Wilderness, Lake County, Colorado: U.S. Bureau of Mines Open-File Report MLA20-85, 65 p.
- Tweto, Ogden, 1968, Geologic setting and interrelationships of the mineral deposits in the mountain province of Colorado and south-central Wyoming, *in* Ridge, J.D., ed., Ore deposits of the United States (Graton-Sales volume): New York, American Institute of Mining, Metallurgical, and Petroleum Engineers, p. 551-588.
- _____, 1974, Geologic map and sections of the Holy Cross quadrangle, Eagle, Lake, Pitkin, and Summit Counties, Colorado: U.S. Geological Survey Miscellaneous Investigations Series Map I-830, scale 1:24,000.
- _____, 1987, Rock units of the Precambrian basement in Colorado: U.S. Geological Survey Professional Paper 1321-A, 54 p.
- Tweto, Ogden, and Case, J.E., 1972, Gravity and magnetic features as related to geology in the Leadville 30-minute quadrangle, Colorado: U.S. Geological Survey Professional Paper 726-C, 31 p.
- Tweto, Ogden, Moench, R.H., and Reed, J.C., Jr., 1978, Geologic map of the Leadville 1°x2° quadrangle, northern Colorado: U.S. Geological Survey Miscellaneous Investigations Series Map I-999, scale 1:250,000.
- Tweto, Ogden, and Pearson, R.C., 1964, St. Kevin Granite, Sawatch Range, Colorado, *in* Short papers in geology and hydrology: U.S. Geological Survey Professional Paper 475-D, p. D28-D32.
- Tweto, Ogden, and Sims, P.K., 1960, Relation of the Colorado mineral belt to Precambrian structure: U.S. Geological Survey Professional Paper 400-B, p. B8-B10.
- _____, 1963, Precambrian ancestry of the Colorado mineral belt: Geological Society of America Bulletin, v. 74, p. 991-1014.
- U.S. Geological Survey, 1979, Aeromagnetic map of the Hunter-Frying Pan area, Colorado: U.S. Geological Survey Open-File Report 79-1226, scale 1:62,500.
- Van Loenen, R.E., 1985, Geologic map of the Mount Massive Wilderness, Lake County, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-1792-A, scale 1:50,000.
- Viets, J.G., 1978, Determination of silver, bismuth, cadmium, copper, lead, and zinc in geologic materials by atomic absorption spectrometry with tricaprylylmethylammonium chloride: Analytical Chemistry, v. 50, p. 1097-1101.
- Wallace, A.R., Lee, G.K., Campbell, D.L., Lundby, William, and Brown, S.D., 1989, Mineral resources of the Holy Cross Wilderness Area, Eagle, Pitkin, and Lake Counties, Colorado: U.S. Geological Survey Bulletin 1879, 26 p.
- Zogg, W.D., 1976, Geology of the Colorado Gulch-Turquoise Lake area, northern Sawatch Range, Lake County, Colorado: Golden, Colorado School of Mines, M.S. thesis, 187 p.

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	U/A	H/B HIGH POTENTIAL	H/C HIGH POTENTIAL	H/D HIGH POTENTIAL
	UNKNOWN POTENTIAL	M/B MODERATE POTENTIAL	M/C MODERATE POTENTIAL	M/D MODERATE POTENTIAL
		L/B LOW POTENTIAL	L/C LOW POTENTIAL	L/D LOW POTENTIAL
	N/D NO POTENTIAL			
	A	B	C	D
	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	
	Measured	Indicated		Hypothetical	(or) Speculative
	ECONOMIC	Reserves		Inferred Reserves	+
MARGINALLY ECONOMIC	Marginal Reserves		Inferred Marginal Reserves		
SUB-ECONOMIC	Demonstrated Subeconomic Resources		Inferred Subeconomic Resources		

Major elements of mineral resource classification, excluding reserve base and inferred reserve base. Modified from McKelvey, 1972, Mineral resource estimates and public policy: American Scientist, v.60, p.32-40, and U.S. Bureau of Mines and U.S. Geological Survey, 1980, Principles of a resource/reserve classification for minerals: U.S. Geological Survey Circular 831, p.5.

GEOLOGIC TIME CHART
Terms and boundary ages used in this report

EON	ERA	PERIOD	EPOCH	BOUNDARY AGE IN MILLION YEARS		
Phanerozoic	Cenozoic	Quaternary		Holocene	0.010	
				Pleistocene		
		Tertiary	Neogene Subperiod	Pliocene		1.7
				Miocene		5
				Oligocene		24
			Paleogene Subperiod	Eocene		38
				Paleocene		55
						66
		Mesozoic	Cretaceous		Late Early	96
				138		
	Jurassic		Late Middle Early	205		
				240		
	Triassic		Late Middle Early	~ 240		
				290		
	Paleozoic	Permian		Late Early	290	
		Carboniferous Periods	Pennsylvanian	Late Middle Early	~ 330	
			Mississippian	Late Early	360	
		Devonian		Late Middle Early	410	
					435	
		Silurian		Late Middle Early	435	
					500	
Ordovician		Late Middle Early	500			
			570 ¹			
Proterozoic	Late Proterozoic			~ 570 ¹		
	Middle Proterozoic			900		
	Early Proterozoic			1600		
Archean	Late Archean			2500		
	Middle Archean			3000		
	Early Archean			3400		
pre-Archean ²		3800?		4550		

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

² Informal time term without specific rank.