UNITED STATES DEPARTMENT OF INTERIOR
GEOLOGICAL SURVEY

Geology and mineral deposits of the region surrounding the American Flats Wilderness Study Area, western San Juan Mountains, Colorado.

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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 Congress. This report presents the results of a mineral survey of the region surrounding the American Flats Wilderness Study Area (CO-030-217), Ouray and Hinsdale Counties, Colorado.

SUMMARY

The western San Juan Mountains, including the American Flats area, are part of a large erosional remnant of an extensive volcanic field that covered much of south-central Colorado during Oligocene and Miocene time. The earliest volcanic activity in the western San Juan volcanic field is represented by andesitic to dacitic lava flows and associated material erupted from clusters of large volcanoes. Beginning about 30 m.y. ago the nature of the volcanic activity changed dramatically. Tremendous volumes of ash and volcanic glass (50-500 cubic miles) were explosively erupted from large volcanic centers known as calderas and deposited as regional ash-flow sheets. One of the largest of these centers is the Uncompahgre-San Juan caldera complex and the associated Silverton caldera, a set of coalesced and nested calderas that extends from Lake City to Silverton. The main stage of caldera-forming eruptions ceased at about 27 m.y. in the western San Juan volcanic field. Miocene volcanic and intrusive activity (23 to 10 m.y. ago) consisted of volumetrically minor amounts of chemically distinct basalt and rhyolite, although some intermediate-composition intrusions were also emplaced during this time. Only one caldera, the 23.1-m.y.-old Lake City caldera, formed during this period, and it erupted a high-silica rhyolite that is petrologically distinct from the older ash-flow sheets.

The American Flats Wilderness Study Area lies along the north-central margin of the Uncompahgre-San Juan caldera complex, just to the northeast of the Silverton caldera. Rocks exposed within the study area consist largely of lavas and ash-flow tuffs that ponded within the Uncompahgre-San Juan caldera complex. However, along the northern boundary of the study area, rocks related to the earlier episode of volcano formation are exposed just outside of the margin of the Uncompahgre-San Juan caldera complex. A northeast- to southwest-trending zone of Miocene rhyolitic and intermediate intrusive rocks, which were emplaced during the period of basalt-rhyolite volcanism, also projects through the study area. However, only the intermediate-composition intrusive rocks are exposed within the study area.

Mineralization in the western San Juan Mountains took place during both Late Cretaceous to early Tertiary (60 to 70 m.y ago) and middle to late Tertiary (5 to 35 m.y. ago) periods of igneous activity. In the region surrounding the study area, all known mineral deposits are of mid- to late-Tertiary age and include: precious- metal (gold and silver) and base-metal (lead, zinc, and copper) vein, porphyry-type copper and molybdenum, silver and base-metal breccia-pipe, and rhyolite-related uranium deposits. These occur in a variety of geologic environments that span the entire age range of Oligocene and Miocene igneous activity in the area.

The only ore deposits with recorded production in the immediate vicinity of the study area are fault-controlled vein deposits located to the southwest, south, and southeast of the study area boundaries. These deposits produced small amounts (less than 10,000 tons) of relatively high-grade silver ore. Only a few prospected mineral occurrences, which are present to the southwest of the study area, lie along faults that project into the study area. However, no veins were found along faults within the study area, and little evidence of hydrothermal alteration or geochemical anomalies that might indicate the presence of mineralized rock at depth was found on the surface along these structures. A mineralized breccia pipe is present about 1 mile southwest of the study area, where it is associated with a Miocene rhyolite complex (12-16 m.y. old). However, similar deposits are not thought to occur within the study area because no intense alteration or geochemical anomalies characteristic of this deposit type are evident. There are also no surface

indications of intrusions or alteration patterns that might be related to porphyry-type copper and molybdenum or rhyolite-related uranium deposits within the study area. No rocks suitable for the formation of oil, gas, or coal occur within the study area, and no environments favorable for geothermal energy were identified.

INTRODUCTION

The American Flats Wilderness Study Area consists of 1505 acres of land administered by the Bureau of Land Management (BLM) within the San Juan Mountains between the towns of Ouray and Lake City, Colorado (fig. 1). The study area is adjacent to the Big Blue Wilderness Area (U.S. Forest Service (USFS)) on its north and west boundaries and lies to the northwest of the Redcloud Peak and Handies Peak Wilderness Study Areas (BLM) (fig. 1). The American Flats Wilderness Study Area is most easily reached on foot from jeep roads on Engineer Pass and along the North Fork of Henson Creek several miles to the south and east, respectively. The American Flats study area lies almost entirely above treeline with elevations ranging from approximately 11,500 to 13,000 feet above sea level.

This report presents the detailed results of U.S. Geological Survey (USGS) investigations of the American Flats Wilderness Study Area. Results of a companion study by the U.S. Bureau of Mines (USBM) have been published separately (Hannigan, 1985), although some of the information is summarized here. Geochemical data used in the evaluation of the study area are compiled in Hon (1986). These reports provide all of the available supporting information that was considered necessary to make the mineral resource evaluation of the American Flats Wilderness Study Area (Hon and others, in press).

Terminology of the various rock units follows that of Lipman and others (1973) and Lipman (1976a). Volcanic rock names used in this report were assigned according the IUGS classification recommended by Le Maitre (1984). Some rock names used differ from those used by Lipman (1976a) in that the terms quartz latite (65-70% SiO_2) and rhyodacite (60-65% SiO_2) (as defined by Lipman (1975)) are replaced by high-potassium dacite (63-69% SiO_2) and andesite (57-63% SiO_2). For ease of discussion, the high-potassium modifier has been left out and these rocks are referred to simply as dacite and andesite. Potassium argon (K-Ar) ages determined from rocks of the San Juan volcanic field prior to 1976 were recalculated ages by Hon and Mehnert (1983).

The geology of the American Flats area was previously mapped by Lipman (1976a) and the regional geology discussed by Lipman and others (1973), Steven and Lipman (1976), and Lipman (1976b). The resources and mineral potential of the adjoining Big Blue Wilderness Area (Uncompahgre Primitive and Continguous Areas) were evaluated by Fischer and others (1968) and Steven and others (1977). The geology and production of the ore deposits within the Galena and Mineral Point mining districts south of the American Flats Wilderness Study Area have been the subjects of reports by Ransome (1901), Irving and Bancroft (1911), Brown (1926), Kelley (1946), Burbank and others (1947), Hazen (1949), Burbank and Luedke (1969), Slack (1980), Goodknight and Ludlam (1981), and Maher (1983).

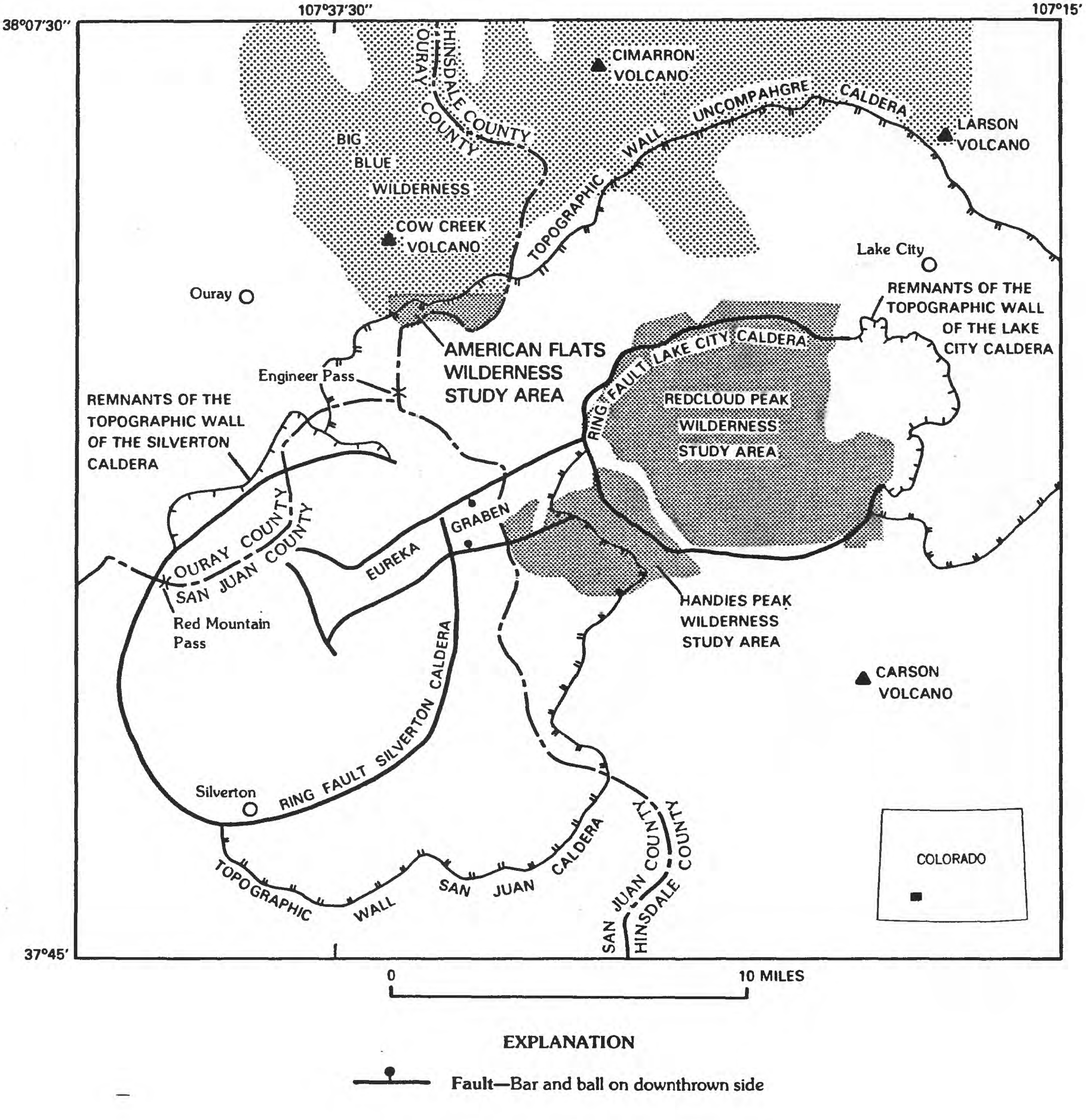


Figure 1. Index map showing geologic setting and location of the American Flats Wilderness Study Area in the western San Juan Mountains, Colorado (modified from Lipman, 1976a).

GEOLOGIC SETTING

Regional Geology

The American Flats Wilderness Study Area lies within the western portion of the San Juan volcanic field, the largest remnant of a widespread volcanic field that covered much of south-central Colorado during Oligocene and Miocene time (Steven, 1975). Eruption of calc-alkaline andesitic to dacitic composition lava flows and pyroclastic rocks commenced about 35 m.y. ago and continued until approximately 30 m.y. ago (Lipman and others, 1970; Steven and Lipman, 1976). Thick sequences of volcaniclastic sediments and lahars accumulated contemporaneously in basins between clusters of stratovolcanoes and became complexly interfingered with the near-source-facies lavas and breccias. Together these rocks make up the early intermediate-composition assemblage of Steven and Lipman (1976), Lipman and others (1973), and Lipman (1976a). Between 30 and 27 m.y. ago most of the volcanic activity associated with these earlier centers ceased as voluminous silicic ash-flow sheets erupted from concurrently forming calderas, which typically collapsed within clusters of the earlier volcanoes. These widespread ash-flow sheets, along with associated post-collapse lavas and intrusions, are thought to represent the tapping of high level cupolas during the final stages of emplacement of a major batholith beneath the San Juan volcanic field (Steven and Lipman, 1976; Plouff and Pakiser, 1972). Beginning about 25 m.y. ago, magmatism in the San Juan volcanic field shifted from dominantly calc-alkaline intermediate composition to a bimodal assemblage of silicic alkali basalt and high-silica rhyolite, which continued sporadically until about 5 m.y. ago. This switch probably reflects a contemporaneous change in the tectonic regime of the western United States (Lipman and others, 1973; Lipman and others, 1978).

Geology in the Vicinity of the Study Area

The American Flats Wilderness Study Area lies along the north-central margin of the 29- to 27-m.y.-old Uncompahgre-San Juan caldera complex (figs. 1 and 2). This large composite volcanic structure initially erupted and collapsed within a cluster of older (33-30 m.y.) andesitic stratovolcanoes (Lipman and others, 1973) and has an unusually strong northeast to southwest elongation. This orientation possibly reflects structural control of the complex by a zone of major crustal weakness, such as faults of the Colorado Mineral Belt, which project through the Lake City-Silverton area (Luedke and Burbank, 1968; Tweto and Sims, 1963).

West of the study area and just south of Ouray, early intermediate-composition volcanic rocks unconformably overlie Proterozoic metasedimentary rocks of the Uncompahgre Formation (Burbank, 1940; Luedke and Burbank, 1962), whereas to the south of the study area they are in contact with 1.4-b.y.-old granite (fig. 2) (Lipman, 1976a). Inclusions of both these Precambrian rock types within intracaldera ash-flow tuff of the Uncompahgre-San Juan caldera (Lipman and others, 1973) and porphyritic granite inclusions from a small extrusive complex north of Engineer Pass (fig. 2) (Maher, 1983) suggest that the region immediately surrounding the study area is underlain by these kinds of Precambrian rocks. The only other foreign rock fragments that occur in the exposed volcanic units are of other mid-Tertiary volcanic units, which indicates that sedimentary rocks are not present under this area. Paleozoic and Mesozoic sedimentary rocks are thought to have been either eroded or not deposited in the vicinity of the study area due to uplift during both Pennsylvanian-Permian and Late Cretaceous to early Tertiary time (Burbank, 1940; Kelley, 1957).

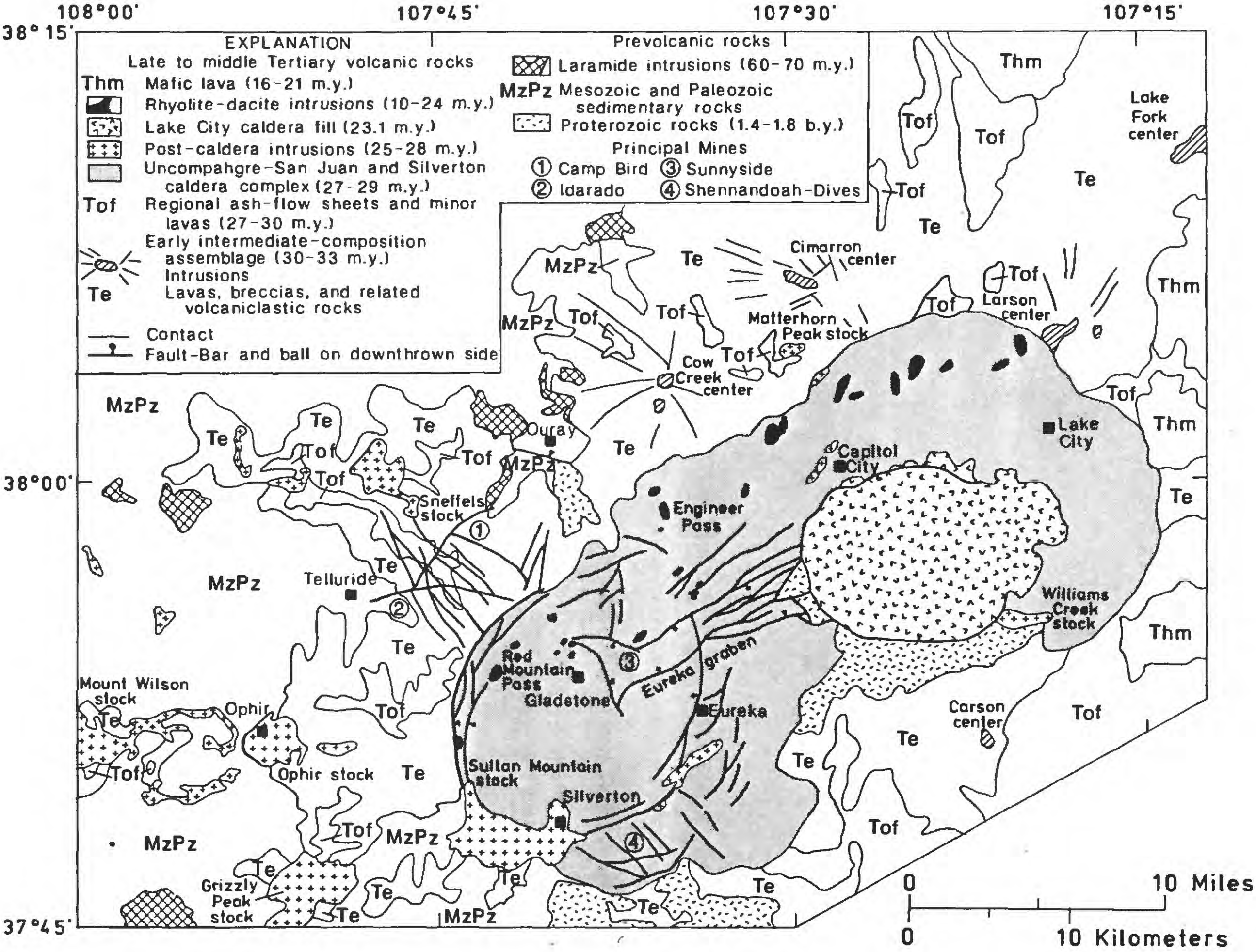


Figure 2 Generalized geologic map of the western San Juan Mountains, Colorado (modified from Burbank and Luedke, 1969; Steven, Lipman, Hail, and others, 1974; Steven and others, 1977; Casadevall and Ohmoto, 1977)

The Cow Creek center, which is about 2-3 miles north of the study area (figs. 2 and 3), is the eroded core of an early intermediate-composition volcanic center. Although earlier studies (Luedke and Burbank, 1964; Luedke, 1974) indicated that dikes related to this center cut ash-flow tuff (the Ute Ridge Tuff of Lipman and others (1973)), re-examination of key localities show that these dikes either intrude early intermediate volcaniclastic rocks or are small topographic highs protruding into the base of the Ute Ridge Tuff. The eroded remanents of another similar volcano, the Cimarron center (figs. 1 and 2), are present about 9 miles northeast of the study area (Lipman and others, 1973; Lipman, 1976a). Rocks related to both of these centers vary from andesite to dacite and are typically hornblende bearing (Cross and others, 1907; Luedke, 1972; Lipman, 1976a), a characteristic of many early intermediate-composition rocks.

The Uncompahgre-San Juan caldera complex collapsed about 29 m.y. ago and a thick accumulation (greater than 3000 ft) of the concurrently erupting ash-flow sheet (Eureka Member of the Sapinero Mesa Tuff) ponded within these calderas. Large masses of older rocks on the walls of the caldera caved into the subsiding calderas during eruption and became incorporated as megabreccia within the lower portion of the intracaldera ash-flow sheet (Lipman, 1976b). This insliding of debris caused the caldera margins to expand outwardly well beyond their structural boundaries. In addition, the septum of rock that initially divided the two structures largely caved away at this time, creating the large composite Uncompahgre-San Juan caldera complex. The study area is outside of the structural margin, but within the topographic boundary of the Uncompahgre-San Juan caldera complex (fig. 1).

Significant volcanic activity continued for several million years as evidenced by the accumulation of postcollapse dacitic to andesitic lavas and the eruption of the Crystal Lake Tuff from the Silverton caldera (figs. 1 and 2). This caldera collapsed as the older Uncompahgre-San Juan caldera was resurging (Lipman and others, 1973). During this period of activity several other regional ash-flow sheets, such as the Fish Canyon and Carpenter Ridge Tuffs, were erupted from other calderas in the central San Juan volcanic field and ponded within the Uncompahgre caldera. The final phase of igneous activity within the Uncompahgre-San Juan caldera complex was the emplacement of 25- 28-m.y.-old quartz monzonite to monzonite stocks (Lipman and others, 1973; Slack, 1980). Intrusions of this type occur near Capitol City, at the Iron Beds within the caldera complex, and at Matterhorn Peak, just outside of the caldera margin (figs. 2 and 3) (Lipman, 1976a).

Late bimodal igneous activity in the western San Juan Mountains is represented by rocks of the 23.1-m.y.-old Lake City caldera, and by a linear trend of rhyolitic to dacitic and andesitic intrusive rocks extending from north of Lake City to Red Mountain Pass (fig. 2). Although silicic alkali basalts are not present in the immediate vicinity of the study area, they occur farther to the east (fig. 2) (Lipman and others, 1973; Lipman, 1976a).

The strong northeast to southwest trend of intrusive rocks, which passes through the study area, also appears to be controlled by the major structural weakness that influenced the form of the Uncompahgre-San Juan caldera complex. Northeast of Engineer Pass only 18- 19-m.y.-old, high-silica rhyolite porphyries occur along this trend (Lipman, 1976a; Lipman and others, 1976). In contrast, a diverse assemblage of nearly aphyric, high-silica rhyolite felsites, and sanidine-bearing dacites and andesites, which range in age from 10 to 24 m.y. (Lipman and others, 1976), are present to the southwest

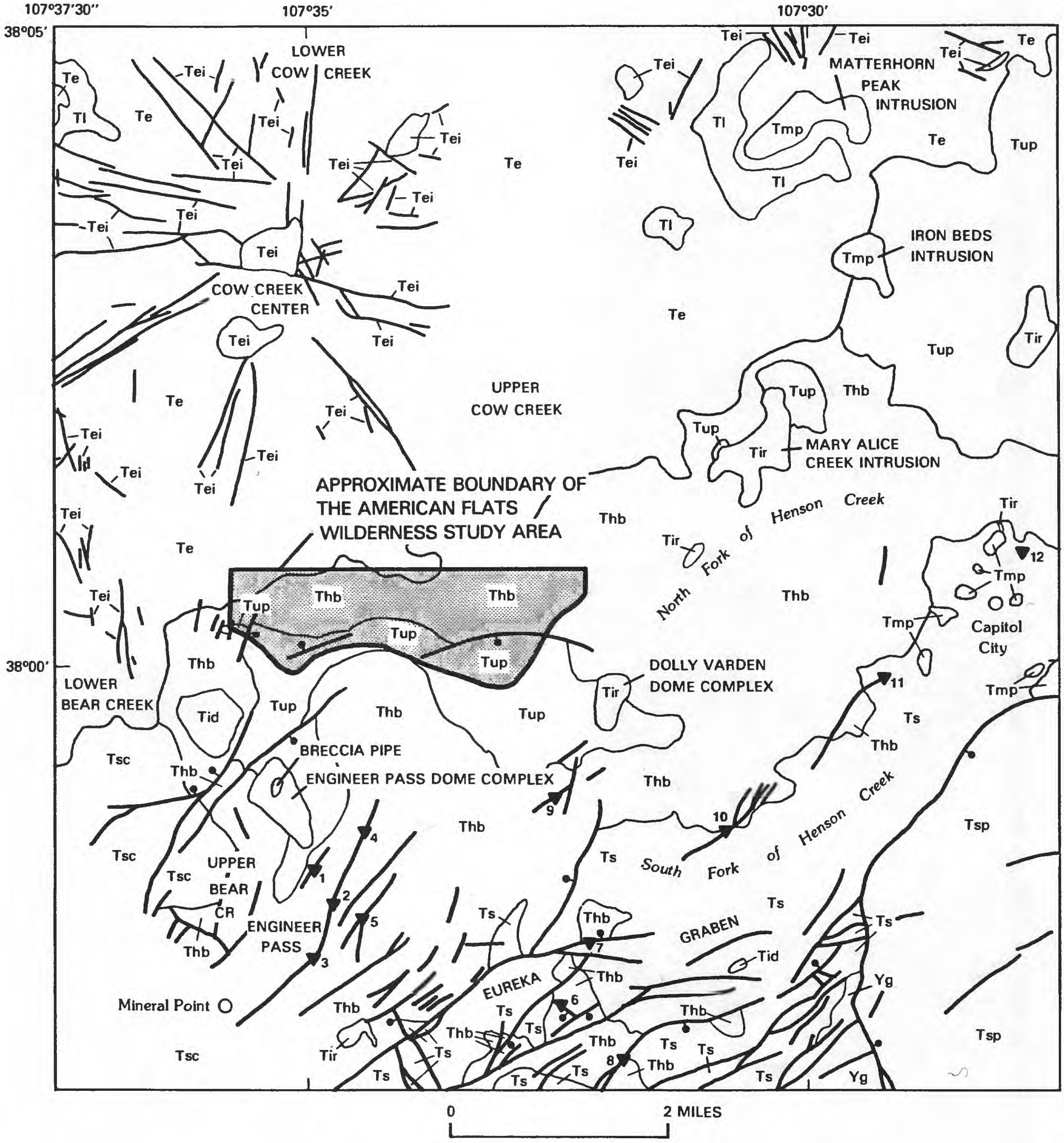


Figure 3. (above and next page). Generalized geologic map showing the location of principal mines in the vicinity of the American Flats Wilderness Study Area, Ouray and Hinsdale Counties, Colorado (simplified from Lipman, 1976a, with minor additions from Irving and Bancroft, 1911; Brown, 1926; Kelly, 1946; and Luedke, 1972).

EXPLANATION

Tertiary rocks

Tir	Rhyolite intrusions (15-19 m.y.)
Tid	Intermediate-composition intrusions (22-24 m.y.)
	Lake City caldera (23.1 m.y.)
Tsp	Ash-flow tuff, megabreccia, and intrusions
	Uncompahgre, San Juan, and Silverton calderas
Tmp	Late quartz monzonite to monzonite intrusions (25-28 m.y.)
Tsc	Postcollapse lavas of the Silverton caldera
Tup	Upper lavas, sediments, and ash-flow tuffs (27-28 m.y.)
Thb	Postcollapse lavas and sediments
Ts	Intracaldera Sapinero Mesa Tuff, includes megabreccia (29 m.y.)
Tl	Older ash-flow tuff (29-30 m.y.)
	Early intermediate-composition assemblage (30-33 m.y.)
Tei	Intrusions
Te	Lavas, breccias, and related volcaniclastic rocks
Yg	Middle Proterozoic granite (1.4 b.y.)
———	Contact
—•—	Fault—Bar and ball on downthrown side
▼9	Mine

1. Frank Hough
2. Polar Star
3. Mammoth
4. Palmetto
5. Wyoming
6. Golconda
7. Ruby-Pearl claims
8. Isolde and CFM
9. Dolly Varden group
10. Empire-Highland Chief
11. Moro
12. Czar and Czarina

of Engineer Pass (fig. 2). Although most of the rocks along this trend are clearly intrusive, a 15-to 16-m.y.-old rhyolite complex just north of Engineer Pass (fig. 3) and a 18-to 19-m.y.-old high-silica rhyolite porphyry that caps Dolly Varden Mountain (fig. 3 and pl. 1) are volcanic domes, which have intruded their associated ash-flow tuffs. The identification of these extrusive rocks clearly demonstrates that the paleo-ground surface in this area between 15 and 20 m.y. ago was near the stratigraphic horizon presently at about 13,000 feet in elevation.

Volcanic Stratigraphy of the Study Area

The oldest rocks exposed within the study area are volcaniclastic facies conglomerates (pl.1, unit Tec) of the Oligocene early intermediate-composition assemblage. These consist of poorly to moderately sorted boulders, cobbles, and pebbles of volcanic rock in a sandy tuffaceous matrix. A thin lens of lava (pl.1, unit Tef) is interlayered with these volcaniclastic rocks on the west side of Wildhorse Peak (pl. 1) and barely crops out within the study area. These early intermediate-composition units are truncated by the wall of the Uncompahgre-San Juan caldera complex along the northern edge of the study area (pl. 1) (Lipman, 1976a). In this region, the topographic wall of the caldera is expressed as a pronounced angular unconformity separating the older volcaniclastic conglomerates to the north from post-collapse lavas related to the Uncompahgre-San Juan caldera complex and Silverton caldera to the south.

Thick accumulations of biotite dacite of the Burns Member of the Silverton Volcanics (pl.1, unit Tbb) occur along the margin of the caldera. The porphyritic andesite (pl.1, unit Tap) and tuffaceous sandstone (pl.1, unit Ths) of the pyroxene andesite member and Henson Member of the Silverton Volcanics, respectively, both apparently lap against or interfinger complexly with this thick domal mass of dacite. The porphyritic andesite lavas and tuffaceous sandstone are the dominant rock types exposed in the American Flats Wilderness Study Area.

These units are overlain by the poorly welded distal end of the 28-m.y.-old Fish Canyon Tuff (pl.1, unit Tf) from the La Garita caldera in the central San Juan Mountains and the moderately welded Crystal Lake Tuff (pl.1, unit Tcl), which was erupted from the Silverton caldera (Lipman and others, 1973; Steven and Lipman, 1976). Both of these ash-flow sheets ponded passively within the San Juan-Uncompahgre caldera, probably in topographic lows adjacent to the resurgent dome. In the American Flats area, the ash-flow tuffs are locally separated from each other by volcaniclastic sedimentary rocks (pl. 1; unit Tvs). Outcrops of these units cover about 20-30 percent of the study area along its southern boundary. A small patch of rhyolite lava of the volcanics of Uncompahgre Peak (pl.1, unit Tur) overlies this sequence just south of the study area boundary, as does the much younger (18-19 m.y.) Dolly Varden rhyolite dome complex (pl.1, unit Tir).

Intrusive Rocks of the Study Area

Only two small plug like intrusions of dacite (pl.1, unit Tid) are known to occur within the study area, although a much larger stock of similar composition is present immediately southwest of the study area boundary (fig. 3, pl. 1) (Lipman, 1976a). The two plugs apparently intruded fault zones near the southwest border of the study area; however, neither intrusion displays any significant effects of alteration or shearing indicative of postemplacement fault movement. Lipman (1976a) grouped all of these intrusions with the 23 to 24 m.y. quartz-bearing plug on Engineer Mountain and similar rocks of the same age that are spatially associated with many of the breccia pipes near Red Mountain Pass (Lipman and others, 1976; Burbank, 1941). However, the mineralogy of the intrusions within the study area differs from that of the Engineer Mountain-Red Mountain Pass intrusions, most conspicuously by the absence of quartz and the relative scarcity of large (> 1 cm) sanidine phenocrysts. Although major-element chemistry indicates that all of these intrusions are similar and range in composition from andesite to dacite (57.5 to 63.5% SiO_2), trace-element data suggest geochemical differences between the two mineralogically distinct types of intrusions (K. Hon, unpub. data).

Structure of the Study Area

Three faults having mappable displacements occur within the wilderness study area (pl. 1), and two of these appear to be extensions of faults that are better developed to the southwest (fig. 3). These two faults have small displacements (less than 100 feet) and define a minor uplifted block (fig. 3). Along the western edge of the study area and extending into the adjacent Big Blue Wilderness there is a series of small north- to north-northeast-trending faults (pl. 1). Only the easternmost of these structures has any mappable displacement, and the rest seem to be little more than fractures along which weak hydrothermal alteration has been localized.

The American Flats study area lies outside of the projected structural boundaries of the Uncompahgre-San Juan and Silverton calderas as shown by Steven and Lipman (1976). It also lies well to the northwest of the prominent northeast-trending zone of tensional faults known as the Eureka graben (fig. 2), which developed along the crest of the resurgent dome of the San Juan-Uncompahgre caldera (Lipman and others, 1973; Lipman, 1976a). This zone is most complex structurally about 5 miles to the southwest of the study area, in the vicinity of the Sunnyside mine (fig. 2), where it intersects faults thought to have formed during collapse of the Silverton caldera within the concurrently resurging San Juan-Uncompahgre caldera (Steven and Lipman, 1976). To the southeast of the American Flats area, between Engineer Pass and the Eureka graben, a zone of northeast trending discontinuous faults is present (fig. 3). These structures have no mappable displacements (Lipman, 1976a) and are marked by small bodies of aphyric rhyolite and quartz veins; however, the faults generally cannot be traced for distances much greater than 1 mile (Lipman, 1976a; Maher, 1983; Kelley, 1946).

Age of Mineralization in the Vicinity of the Study Area

Two major periods of mineralization have been recognized in the western San Juan Mountains: one occurred during Late Cretaceous and early Tertiary time (60-70 m.y. ago), and one took place in the middle to late Tertiary (5-33 m.y. ago) (Burbank, 1940; Burbank and Luedke, 1968; Lipman and others, 1976). Only mid- to late-Tertiary mineral deposits are known to occur in the vicinity of the study area. These are associated with precaldera intermediate-composition centers (30-35 m.y.), late-stage magmatic activity within the Uncompahgre caldera (25-28 m.y.), and hydrothermal activity along faults of the Eureka graben (figs. 2 and 3) that were reactivated during the Miocene (10-20 m.y.) (Lipman and others, 1976). Productive and potential deposit types in the region immediately surrounding the study area include (1) precious- and base-metal vein deposits that formed as open-space fillings of faults; (2) precious- and base-metal vein deposits that formed as replacements of wallrocks adjacent to faults; (3) disseminated porphyry-type copper and molybdenum deposits that are related to precaldera and late-stage caldera intrusions; (4) precious- and base-metal breccia-pipe deposits that are spatially related to Miocene intrusions; and (5) disseminated uranium deposits that formed during the late stages of crystallization of Miocene rhyolite intrusions.

Mid- to late-Tertiary mineral deposits occur in geologically and temporally distinct settings in the vicinity of the study area. Northeast of the wilderness study area, weak porphyry-type, disseminated mineralization and alteration were associated with the emplacement of a composite central stock late in the development of the 33- 30-m.y.-old Cow Creek volcano (figs. 1 and 2) (Steven and others, 1977). Veins and mineralized shears thought to be of about this age also occur along the margins of dikes and in radial fractures related to this volcanic complex (Burbank, 1940). Similar disseminated and vein mineralization is also related to the 30-m.y.-old Cimarron volcano (Fischer and others, 1968; Lipman and others, 1976; Steven and others, 1977), which is about 9 miles northeast of the study area (figs. 2 and 3). Anomalous amounts of copper and molybdenum are also associated with monzonitic intrusions that were emplaced late in the Uncompahgre caldera cycle. These intrusions extend northward from the Capitol City area to Matterhorn Peak (figs. 2 and 3) (Lipman, 1976a) and some of the vein mineralization in the Capitol City area could conceivably be related to these intrusions (Lipman and others, 1976; Steven and others, 1977; Slack, 1980). Northeast-trending veins south of the wilderness area occupy fracture systems within or subparallel to the Eureka graben that formed during resurgence of the Uncompahgre-San Juan caldera complex (Lipman and others, 1973). However, geologic relations and available age data indicate that most of this mineralization occurred during the late Miocene, some 10-15 m.y. after caldera formation (Lipman and others, 1976). In the Engineer Pass area (figs. 2 and 3), a fine-grained mixture of illite/smectite ("sericite") obtained from a mineralized breccia pipe associated with an aphyric rhyolite intrusion yielded an age of 12.4 $\pm$ 0.5 m.y. for emplacement and mineralization of the pipe (Maher, 1983, Hon and Mehnert, 1983). An apatite separate from the immediately surrounding rhyolite complex gave a less precise fission-track age of 11.8$\pm$ 2.4 m.y. (Lipman and others, 1976), which is in agreement with the "sericite" date. The 12.4 m.y. age should probably be considered a minimum for breccia-pipe mineralization and the intrusion of the rhyolite, as these minerals could have been reset by later thermal events. Anomalous concentrations of uranium occur around the margins of 18- 19-m.y.-old high-silica rhyolite porphyry intrusions; these high uranium concentrations are thought to have formed by explusion of uranium, beryllium, molybdenum, lithium, and fluorine during the late stages of crystallization and devitrification of these plutons (Steven and others, 1977; Gibbs, 1981).

GEOLOGY OF THE MINERAL DEPOSITS IN THE VICINITY OF THE STUDY AREA

History and Production

Mineral production from mines within 1 to 4 miles of the American Flats Wilderness Study Area is estimated to have been about $1,500,000 in silver, copper, gold, lead, and zinc ore. Most of the recorded production came from the Engineer Pass region (fig. 3) of the Mineral Point and Galena districts, which is about 2 miles south and southeast of the study area boundary. Approximately $1,000,000 in ore (value at the time of production) was mined between 1880 and 1920 from the Frank Hough ($600,000), Polar Star ($250,000), Palmetto ($150,000), Wyoming ($50,000?), and Engineer ($50,000) mines located in this area (fig. 3) (Kelley, 1946). However, Ransome (1901) indicates that very few of the many mines in the Mineral Point district ever yielded a net profit. Ransome (p. 22, 1901) states "Around Mineral Point probably $2,000,000 or $3,000,000 were squandered in mining operations which resulted in no permanent improvements or actual development". He goes on to say that "Although so numerous and persistent, the lodes of Mineral Point have been productive of more disappointment than profit" (p. 185, Ransome, 1901). These and other statements suggest that even though numerous large quartz veins are present in the Mineral Point district, the tenor of the ore found was generally insufficient to repay the cost of exploration.

The Frank Hough mine (fig. 3) was probably the only mine to produce a substantial profit in the eastern part of the Mineral Point district and far western part of the Galena district. Approximately 350,000 ounces of silver, 1,600 ounces of gold, and 2,500 tons of copper were mined from this deposit (Kelley, 1946). In contrast, the Polar Star mine (fig. 3), which was the second largest producer in the area, was apparently only marginally profitable (Ransome, 1901). Other principal mines of the western part of the Galena district extend along the South Fork of Henson Creek from Capitol City to Dolly Varden Mountain and are east and southeast of the study area (fig. 3). Collectively these deposits probably produced between $100,000 and $500,000, mostly from the Golconda, Empire-Highland Chief, and Moro mines (fig. 3) (Irving and Bancroft, 1911; Burbank and others, 1947; unpublished mining company reports). Again, the degree of development of these properties suggests such extensive investment that probably little net profit was returned on these ventures. The estimated, combined production value of $1,500,000 for all of the mines in the vicinity of the study area represents only a small fraction of the nearly one billion dollar total value (at the time of production) of the ore mined from the western San Juan region.

Engineer Pass Area

The Engineer Pass area (fig. 3) contains the most productive deposits of any of the areas adjacent to the wilderness study area. Three types of mineralization occurred in the vicinity of Engineer Pass and, in the order of their economic importance, these are: (1) rich silver-copper vein and replacement mineralization unique to the Frank Hough mine; (2) quartz-silver-lead-zinc-copper veins that contain small irregular pods of rich silver ore, as typified by the Polar Star, Palmetto, and Wyoming mines (veins in upper Bear Creek are also probably of this type, but have not undergone extensive development); (3) silver-lead-zinc mineralization associated with the breccia pipe located just north of Engineer Pass.

The Frank Hough mine, located just south of Engineer Pass (fig. 3), was the largest producing mine (Kelley, 1946) near the American Flats Wilderness Study Area (table 1). Mineralization apparently followed a northeasterly fault which cuts the tuffaceous sandstone (Henson Member of the Silverton Volcanics) (Lipman, 1976a; Kelley, 1946; Maher, 1983). The deposit was worked over a vertical interval of 200 feet and had minable widths of 12-25 feet that increased with depth. The width of the ore zone apparently greatly exceeded that of the fault, and descriptions of the ore suggests an origin by replacement of the surrounding wall rock (Ransome, 1901; Kelley, 1946). Ore consists of a fine-grained granular aggregate of quartz intergrown with chalcopyrite, pyrite, tetrahedrite, minor galena, and traces of hessite (Ag_2Te) (table 1) (Kelley, 1946) Chalcocite reportedly occurs as a secondary mineral. A sample of ore collected from the mine dump (no. 722, Fischer and others, 1968) contained anomalous to ore-grade values of silver, gold, copper, lead, arsenic, antimony, zinc, bismuth, molybdenum, and tin (table 2). The

TABLE 1 Grade and mineralogy of ore from producing mines in the vicinity of the American Flats Wilderness Study Area (compiled from Kelley, 1946; Irving and Bancroft, 1911; and Burbank and Luedke, 1969).

NAME OF MINE	DEPOSIT TYPE	REPRESENTATIVE GRADES Ag(oz/ton)	Au(oz/ton)	Pb%	Cu%	Zn%	Bi%	Mineralogy[1]
Engineer Pass area								
Frank Hough mine	vein and replacement	36	.16	3.7	26	<1	—	qz, py, cp, tt?, gn, hs, (ch)
Polar Star, Palmetto, Wyoming, and Engineer mines	silver-rich quartz veins	50-350	.10-5	0-5?	<1	0-5?	0-1.5	qz, py, gn, sp, cp, rs, bs, (ac), (Ag)
Mammoth mine	base-metal quartz vein	10-15	<.10	10-20	<1	5-15	—	qz, py, gn, sp, cp, tt, rs, bs
Mineral Point area								
Frisco and Vermillion tunnels	base-metal quartz veins	1-2	.01-.02	2-4	<1	1-4	—	qz, py, gn, sp, cp rc, rn, tt, rs
South Fork of Henson Creek								
Moro mine	base-metal quartz vein	10-17	.5-3	7-30	2-4	6-15	—	qz, py, gn, sp, cp, tt, ba, cc
Capital City area								
Czar mine	base-metal quartz vein	9-14	<.10?	14-22	3-4	26-39	—	qz, py, gn, sp, cp

[1] qz=quartz, py=pyrite, gn=galena, sp=sphalerite, cp=chalcopyrite, tt=tetrahedrite, cc=calcite, ba=barite, rs=ruby silver minerals, bs=bismuth sulfides, rc=rhodochrosite, rn=rhodonite, ac=acanthite, Ag=native silver, ch=chalcocite, hs=hessite. Minerals in parentheses are thought to be of secondary origin.

— no data

TABLE 2 Abundances of selected elements in vein and mineralized rock samples collected from the region surrounding the American Flats Wilderness Study Area (compiled from Fischer and others, 1968; Steven and othera, 1977; Hannigan, 1985; Maher, 1983; Hon, 1986; and from R. F. Sanford and R. I. Grauch, unpublished data).

NAME OF AREA	ELEMENTAL CONCENTRATIONS (ppm) Ag	Au	Pb	Cu	Zn	As	Sb	Bi	Cd	Mo	Sn	U
Engineer Pass area												
Frank Hough mine	1000	1.3	2000	>100,000	1500	100,000	10,000	1000	<50	500	200	—
Mammoth mine	200-500	.9-3	3000 - 20,000	3000-5000	20,000- >100,000	2000-7000	700-1500	<10-20	150-1000	<3-20	<10	—
upper Bear Creek	3-300	.2-.6	200 - 10,000	150-1000	1500 - 15,000	300 - 400	<10-1500	<10- 1500	70-150	7-700	<10-30	—
breccia pipe	17-170	<.7-1.7	500-5000	<100	100-500	50-500	20-130	50-700	—	20-120	<10	—
Mineral Point area												
San Juan Chief vein system	1-1500	<.02-7	50 - >100,000	20-5000	<200 - >100,000	2000 - >10,000	<200-3000	<10-500	<50-1000	5-200	<10	—
South Fork of Henson Creek												
Ruby - Pearl claims	30 - 10,000	.9-17	46-30,000	<5-7600	230- 130,000	20-530	26-2100	<20	<4-3600	30-340	—	<1-27,400
Dolly Varden group	6-1340	.02-1.5	<20-10,000	20- 40,000	100-6000	300-800	<600	<400	<5	<1 - 5	<90	—
Moro mine	30-70	.5-1.5	58-1200	7-9600	80-7300	<20-1600	<20-330	<20	10-25	<4-15	<8	—
Capitol City area												
Czar and Czarina mines	7-7000	.03-11	100 - >100,000	30- >20,000	500 - >100,000	70-1100	<100-500	<10 - 29,000	<20-1000	<3-150	<10	—
Cow Creek area												
lower Cow Creek	<.5-300	<.02-.8	30 - >100,000	5-10,000	<200 - 30,000	<200 - 2000	<10-5000	<10-50	<20-200	<3-500	<10	—
upper Cow Creek	<.5	<.02	70	70	<200	<200	<100	<10	<20	<5	<10	—
Lower Bear Creek area												
east-trending vein	2.3-115	.06-.87	<2	6-20	<3-800	300-1000	<600	<500	<5	<1-4	<9	—
north-trending vein	110	<.01	102,000	300	250,000	700	<600	<500	50	<1	<9	—
American Flats												
in and near atudy area	<1	<.02	<50-300	<6-150	<200	<200-600?	<600	<400	<1	<3-50	<10	—

very high ratio (10 :1) of arsenic to antimony reported from this sample suggests that the sulfosalt mineral in this deposit, identified as tetrahedrite by Kelley (1946), may actually be tennantite. A sample of altered wallrock collected from near this deposit (no. 721, Fischer and others, 1968) had an elevated copper content (500 ppm), but did not display anomalous amounts of the other elements detected in the ore sample. The ranges of values for elements in these samples are given in table 2. The very high copper and low lead-zinc values from this deposit (tables 1 and 2) are not typical of ores from the western San Juan Mountains. The high tin content (200 ppm) of the sample number 722 analyzed by Fischer and others (1968) is also unusual.

The Fish Canyon Tuff, which crops out just to the north of the vein, is argillized and contains disseminated pyrite (Maher, 1983). This ash-flow sheet undoubtedly capped the deposit at the time of its formation, and may have caused the mineralizing fluids to invade and replace the relatively permeable tuffaceous sandstone. The mechanical properties of similar outflow sheets, observed capping veins elsewhere in the western San Juan Mountains, generally did not permit the propagation of open fractures necessary for fluids to freely migrate upward through these units (Burbank, 1941). Because replacement deposits such as the Frank Hough deposit are not commonly found below these capping horizons, the presence of a host rock with suitable permeability, such as the tuffaceous sandstone, is considered to be an important factor.

Several features of the Frank Hough deposit are distinctively different from other deposits in the area, including: (1) the very high copper content of the ore with correspondingly low lead and zinc values, (2) the replacement nature of much of the ore, (3) the occurrence of the deposit within the Henson Member of the Silverton Volcanics, (4) the presence of the silver telluride mineral hessite, and (5) the very anomalous tin value (200 ppm) reported from the ore.

Other producing mines in the Engineer Pass area (Polar Star, Palmetto, Wyoming, Engineer, Mammoth) (fig. 3) exploited veins that are much more typical of the ore deposits in the region. Mineral deposits are localized along 2- to 4-foot wide quartz-filled veins that cut both the porphyritic andesite (pyroxene andesite member) and the biotite dacite (Burns Member) of the Silverton Volcanics (Lipman, 1976a). Kelley (1946) states that the best ore was reportedly associated with auto-breccias between lava flows. The upper portions of the vein systems were characterized by rich, but irregular, pockets of silver ore containing ruby silver minerals and acanthite (argentite of Kelley (1946)) in a matrix of vuggy quartz. Galena, sphalerite, and chalcopyrite were relatively sparse in this upper zone, but increase in abundance with depth (200 to 300 feet) where the veins consist largely of massive quartz with pyrite and base-metal sulfides (Kelley, 1946). The Mammoth and other mines that worked even lower levels of these veins 800-900 feet) encountered similar, but lower grade, quartz-pyrite and base-metal ore. In the Mammoth traces of argentiferous tetrahedrite, ruby silver, and a bismuth sulfide were identified (Kelley, 1946). Very high concentrations of bismuth (1-1.5%) occurred in ores taken from the upper workings of the Wyoming mine (table 1); the high levels of bismuth apparently reflect the presence of an argentiferous bismuth sulfide mineral (Kelley, 1946). Several different minerals of this type have been identified from mines in the Mineral Point and adjacent Poughkeepsie districts (Kelley, 1946; Burbank and Luedke, 1969). In contrast to the Frank Hough deposit, all of these vein deposits contain more lead and zinc than copper (tables 1 and 2); these abundances are more typical of ore from mid-Tertiary veins of the western San Juan Mountains (Burbank and Luedke, 1969). Based on mineralogy, both Kelley (1946) and Burbank and Luedke (1969) concluded that much of the silver enrichment was due to primary hypogene zonation within these deposits, however, some of the silver ore within the upper portions of these deposits is clearly supergene in origin. Burbank and Luedke (1969) further postulated that the mineralogy and chemistry of the ores, along with the presence of acid-sulfate alteration, indicated a near-surface origin for these deposits. This theory is supported by the preservation of eruptive products within two nearby volcanic complexes that occur at structural levels similar to those of the ore deposits. These complexes have been dated at 15 to 16 m.y. and 18 to 19 m.y.,respectively, which corresponds to the time period that vein mineralization is thought to have taken place in the Eureka graben and related structures (Lipman and others, 1976).

Numerous prospect pits and a few small exploratory adits are also present along fissure-filling quartz veins in the upper reaches of Bear Creek, immediately north of Engineer Pass (fig. 3). Mineralized faults cut post-collapse lavas of the pyroxene andesite member (Silverton Volcanics) and local volcaniclastic sediments of the Uncompahgre-San Juan caldera complex, and, to a lesser extent, dacite lavas (dacite of Diamond Creek) thought to be related to the Silverton caldera (Lipman, 1976a). Two prominent faults are exposed in the upper Bear Creek area (Lipman, 1976a) and have some mineralized and altered rock associated with them. These faults are probably the southwestern continuations of the structures that define the minor "horst-like" block within the wilderness study area. Maher (1983) identified a zone of quartz-sericite-pyrite and argillic alteration that might be related to mineralization along the hanging wall of the southernmost of the major faults in the area. Small quartz stringers containing barite and pyrite are present in this zone and are associated with anomalous amounts of silver, molybdenum, lead, and zinc (Maher, 1983). A number of small discontinuous faults that occur within the upper Bear Creek basin (Maher, 1983) are sporadically filled with mineralized quartz veins. Analytical results from some samples of mineralized vein material (Fischer and others, 1968) show significant concentrations of silver, arsenic, bismuth, cadmium, copper, molybdenum, lead, antimony, and zinc; and traces of gold and tin (table 2). These veins appear to be geochemically and mineralogically similar to the silver lead-zinc veins that occur just south of Engineer Pass, and elsewhere in the Mineral Point district. In contrast to the vein samples, most samples of altered rock taken from the upper Bear Creek drainage (Fischer and others, 1968) do not contain anomalous amounts of metallic elements.

The two principal fault zones have also been sampled further to the northeast (Fischer and others, 1968; Hannigan, 1985), within one-half mile of the wilderness study area boundary. Several samples collected by Hannigan (1985) have detectable levels of arsenic (data for this element is questionable, see geochemistry section) and one of the samples analyzed by Fischer and others (1968) contains 700 ppm copper. However, none of the other elements known to be associated with mineralization in the Engineer Pass area were detected in anomalous amounts. The available geochemical data provide little evidence that any significant mineralization occurred along these structures in this area; it is possible, however, that some mineralized rock is present at depth, as this area is 500 to 800 feet higher in elevation than the area of exposed veins in upper Bear Creek.

A mineralized breccia pipe has also been identified immediately to the north of Engineer Pass (Lipman, 1976a) and was studied in detail by Maher (1983). The breccia pipe and an intimately related, nearly aphyric (crystal-poor), high-silica rhyolite intrusion cut a slightly older dacite to rhyolite dome complex and associated ash-flow tuff (Maher, 1983; K. Hon, unpub. data). This igneous complex lies directly along the trend of Miocene intrusions, but the emplacement of the breccia pipe does not appear to have been controlled by any recognizable near-surface faults or veins (Maher, 1983). The interior of the pipe is intensely silicified and related alteration grades outward in a roughly concentric pattern from quartz-sericite-pyrite to weak argillic to widespread regional propylitic alteration (Maher, 1983). Relationships seen in surface outcrops and core from two drill holes indicate that the breccia pipe grades from a coarse angular rubble breccia along its margins to a much finer (<2 in.) subangular to subrounded breccia within the interior of the pipe (Maher, 1983). Large angular blocks along the edge of the structure show little or no evidence of rotation, whereas smaller fragments within the interior of the pipe are commonly matrix supported and some are composed of lithologies that indicate at least 400 to 500 feet of upward transport. The presence of several generations of clastic and pebble dikes, along with clasts of breccia, provide evidence for episodic activity within the pipe. Maher (1983) reported clasts of the nearly aphyric rhyolite intrusion, which also cross-cuts the margin of the pipe, within the breccia. The preceding observations led Maher (1983) to conclude that the breccia pipe formed by forcible intrusion of the surrounding rock, possibly by a partially fluidized mixture of volcanic gas and broken or pulverized rock produced during the contemporaneous emplacement of the nearly aphyric rhyolite intrusion.

Mineralized zones are confined to the interior of the pipe, especially in association with "pebbly" (<2 in.) breccia and to a lesser extent with pebble dikes. Paragenetic relationships indicate formation of an initial quartz-pyrite phase of mineralization that was followed by a pyrite and galena stage, which apparently was partially replaced by minor amounts of acanthite (Maher, 1983). Late stage native silver and sulfates (jarosite, argentojarosite, plumbojarosite, barite, and anglesite) are thought to be products of supergene oxidation (Maher, 1983). Geochemical data indicate that the upper 70 feet of the pipe are characterized by high lead and zinc values (table 2). The highest silver grades occur over the interval from 70 to 350 feet below the surface (no drill hole data is available below 350 ft.) and are confined to the central portion of the pipe. Anomalous amounts of arsenic, antimony, bismuth, and gold are also present in the silver zone (table 2). The margins of the breccia pipe have elevated concentrations of lead, bismuth, arsenic, molybdenum, and antimony (table 2), but contain little or no detectable silver or gold (Maher, 1983). Copper values are notably low throughout the breccia pipe. High molybdenum values (20-200 ppm) are associated with the rhyolite intrusion where it cuts or is adjacent to the breccia pipe (Maher, 1983). No anomalies of tin or tungsten were detected in surface samples collected around the pipe (Maher, 1983).

Mineral Point Area

The vein systems of the Mineral Point area are among the largest and best developed in the western San Juan region. Because the veins of the previously described Engineer Pass area represent the northeastern extension of these systems, the Mineral Point deposits will be briefly covered. The veins, which are hosted by biotite dacite of the Burns Member of the Silverton Volcanics, attain widths commonly in excess of 20 feet. However, most of the veins are primarily composed of barren quartz with only narrow ore shoots ranging from a few inches to a few feet in width (Kelley, 1946). Discontinuities often occur within the mineralized portions of these veins due to pinching and swelling, offsets by barren structures, unproductive vein intersections, and changes in strike of the veins. Most of the ore was of the low grade silver-lead-zinc-copper variety (table 1) and two long haulage tunnels were driven to exploit these ores, but these efforts met with little success (Kelley, 1946). The Mineral Point veins are mineralogically similar to the lower parts of the silver-lead-zinc veins near Engineer Pass (table 1), but differ by the relatively widespread occurrence of the manganese gangue minerals rhodonite and rhodochrosite, which are abundant in some of the veins (Kelley, 1946). Samples taken by Fischer and others (1968) show that arsenic, antimony, bismuth, cadmium, and molybdenum are associated with the silver and base-metal ore (table 2). The elevated concentrations of bismuth in the ores of the Mineral Point district and the adjacent Poughkeepsie Gulch district are due to complex intergrowths of bismuth sulfides such as cosalite, matildite, aikinite, schirmerite, and bismuthinite (Burbank and Luedke, 1969).

South Fork of Henson Creek

Two distinct types of mineralized veins are present along the South Fork of Henson Creek within 3 miles of the study area's southern boundary. To the north of the South Fork, the vein deposits are of the silver-lead-zinc-copper type; whereas, to the south, gold-silver veins with generally lower base-metal contents predominate.

The silver and base-metal veins occur in discontinuous faults, which are subparallel to the Eureka graben system, on the south side of Dolly Varden Mountain (Dolly Varden group) and the southeast side of Sunshine Mountain (Empire-Highland Chief and Moro mines) (fig. 3). On Dolly Varden Mountain quartz-calcite veinlets occupy a north-northeast trending zone of sheeted fractures within the porphyritic andesite (pyroxene andesite member of the Silverton Volcanics) (Hannigan, 1985; Lipman, 1976a; Ransome, 1901). Mineralized veins on the southeast side of Sunshine Mountain fill an apparently en echelon system of faults that tend to form single structures within the intracaldera Eureka Member of the Sapinero Mesa Tuff (such as at the Moro mine), but splay into a complex network of faults within the overlying postcollapse dacite lavas (Burns Member) near the Empire-Highland Chief mine (fig. 3). The principal minerals in these veins are quartz, pyrite, galena, sphalerite, chalcopyrite, and minor calcite. In addition, pyrargyrite, of probable hypogene origin, partially replaces sphalerite in some samples from the Dolly Varden group (Brown, 1926). Tetrahedrite, barite, and minor rhodochrosite accompany the base-metal sulfides at the Moro and Empire-Highland Chief mines (Irving and Bancroft, 1911). Mineralized samples taken from the Moro mine (R. Sanford, unpub. data) and the Dolly Varden group (Hannigan, 1985) contain high values of silver, lead, zinc, and copper with traces of gold and arsenic. Vein material analyzed from the Moro mine also had elevated concentrations of antimony, molybdenum, and cadmium (table 2).

The gold-silver veins are localized in major faults of the Eureka graben system in the vicinity of Hurricane and Horseshoe basins. These veins were exploited by the Isolde, Golconda, and CFM mines, and were prospected by workings on the Ruby and Pearl claims (fig. 3). The most productive ore zones were in post-collapse biotite dacite flows (Burns Member of the Silverton Volcanics), although some of the veins extend downward into the intracaldera Eureka Member of the Sapinero Mesa Tuff. The productive portions of veins are primarily composed of chalcedonic quartz, minor adularia, and pyrite (possibly auriferous), typically accompanied by variable amounts of galena, sphalerite, and chalcopyrite (Brown, 1926). In addition, the gold-silver telluride mineral calaverite was tentatively identified in one sample from the Isolde mine, which shipped ore with gold values as high as 140 ounces per ton (Brown, 1926). Acanthite (argentite of Brown (1926)), pyrargyrite, native gold, and carbonate minerals are also present in the Golconda mine, but are thought to be of secondary origin (Brown, 1926). Grauch and others (1985) reported highly anomalous values of tellurium and uranium from analyzed samples collected from the Ruby and Pearl claims on Gravel Mountain (fig. 3) and noted the similarity of this assemblage with that of the uranium-bearing gold-silver telluride ores of the Golden Fleece mine near Lake City (Hon and others, 1985; Slack, 1980). Anomalous to ore-grade concentrations of silver, gold, lead, zinc, copper, antimony, arsenic, molybdenum, cadmium, and thorium were also detected in the same samples (table 2) (R. I. Grauch and R. F. Sanford, unpub. data). Where extensions of these veins cut the underlying Eureka Member, such as in Horseshoe Basin to the east of the Golconda (fig. 3), they contain much greater proportions of galena and sphalerite.

Capitol City Area

Veins of the Capitol City area occupy short (<1000 feet) discontinuous faults that have unusual north-northwest orientations as opposed to the dominant northeasterly trend of structures in the region (Slack, 1980; Irving and Bancroft, 1911; Lipman and others, 1976). The veins display a close spatial relationship to small quartz monzonite intrusions, which, along with the intracaldera Eureka Member of the Sapinero Mesa Tuff, form the walls of the veins. Aeromagnetic data (High Life Helicopters/QEB, 1981) and limited paleomagnetic data (R. Reynolds, unpub. data) suggest that a much larger pluton with a northeast-southwest orientation underlies the smaller outcropping bodies in the vicinity of Capitol City. It is possible that the north-northwest faults, as well as the veins that fill them, may be related to the emplacement of this intrusion (Steven and others, 1977). Mineralized portions of the faults are restricted in size, and are composed of the minerals quartz, galena, sphalerite, chalcopyrite, pyrite, tetrahedrite, and barite. An occurrence of telluride minerals was reported by Irving and Bancroft (1911) at the Gallic and Vulcan mines, which have no reported production. Native copper and silver, along with azurite and malachite, occurred as oxidation products at the Excelsior mine, but these did not constitute a significant source of ore (Irving and Bancroft, 1911). In addition to precious- and base-metal content, samples of vein material from the Capitol City area contain anomalous amounts of arsenic, antimony, bismuth, cadmium, and molybdenum (table 2) (Fischer and others, 1968; R. F. Sanford, unpub. data).

Widespread alteration has affected much of the rock in the area surrounding Capitol City and probably occured during the emplacement of the quartz monzonite intrusions (Steven and others, 1977; Lipman and others, 1976). Samples of altered rock collected west of Capitol City have elevated concentrations of silver, copper, molybdenum, lead, zinc, antimony, and arsenic, which suggests that some disseminated mineralization may have accompanied the alteration in this area (Steven and others, 1977). Sparse, widely disseminated microscopic grains of chalcopyrite were recognized within altered parts of the Capitol City intrusions (Slack, 1976).

Similar intrusives the Matterhorn Peak and the Iron Beds (fig. 3) are also highly altered, but generally contain only slightly anomalous concentrations of the elements copper, molybdenum, lead, zinc, silver, and arsenic (Steven and others, 1977; Caskey, 1979; Pyle, 1980). Alteration zoning, thought to be associated with the development of weak porphyry molybdenum-copper mineralization, has been defined around both of these composite intrusive complexes (Caskey, 1979; Pyle, 1980). In addition, traces of chalcopyrite and molybdenite were identified in a few samples from the Matterhorn stock (Pyle, 1980). Although previous workers were unable to document the occurrence of macroscopic molybdenite (Steven and others, 1977; Slack, 1976; Pyle, 1980), small outcrops containing molybdenite-coated fractures were found along the East Fork of the Cimarron River between 12,100 and 12,400 feet in elevation during the course of this investigation.

North Fork of Henson Creek

No evidence of base- and precious-metal vein or disseminated mineralization has been found along the North Fork of Henson Creek above the intersection with Matterhorn Creek. However, a high-silica rhyolite intrusion at the mouth of Mary Alice Creek has anomalous concentrations of uranium localized along its margins (Goodknight and Ludlam,1981; Steven and others, 1977). The Mary Alice intrusion has been extensively explored by four surface prospects (Eagle and Mary Alice prospects) (Goodknight and Ludlam, 1981; Nelson-Moore and others, 1978) and by at least six drill holes. Data and core made available to the Geological Survey by a mining company, and information provided to the Bureau of Mines by the claim owner indicate that no substantial amount of mineralized rock was delineated by these efforts. Highly variable concentrations of uranium up to 2240 ppm were obtained from samples collected near the margin of the Mary Alice Creek intrusion and from within the adjacent Fish Canyon and Crystal Lake Tuffs (R. Sanford, unpub. data). The most common occurrence of uranium is as hexavalent uranium minerals coating fractures, but at one locality microscopic spheroids of uraniferous silica are associated with the fibrous zeolite mordenite in lithophysae of the Crystal Lake Tuff, near the contact of the Mary Alice intrusion (R. A. Zielinski, unpub. data). Occurrences of hexavalent uranium minerals on fractures from this locality have also been previously described by Steven and others (1977) and Goodknight and Ludlam (1981), who reported samples with similar uranium contents.

No anomalous concentrations of uranium were found in association with the high-silica rhyolite dome complex that is present near Dolly Varden Mountain about 1 mile south of the study area (pl. 1). Thin veinlets (<.5 in.) and fracture coatings of fluorescent secondary silica (opal C-T) were found on the southeast side of the rhyolite mass. However, an analysis of one sample showed that it is composed of nearly pure silica with an uranium concentration of only 28 ppm (R. A. Zielinski, unpub. data). This uranium value is considerably higher than average crustal abundances (Levinson, 1980), but less than those obtained from glassy samples of the rhyolite dome and associated ash-flow tuff (41 and 35 ppm U, respectively), which probably reflect the initial magmatic concentrations of these rocks.

Both the Mary Alice and Dolly Varden rhyolites contain elevated primary abundances of the elements uranium, thorium, beryllium, lithium, molybdenum, and fluorine in comparison to other volcanic and intrusive rocks of the region (K. Hon and R. A. Zielinski, unpub. data). In addition, a few scattered analyses reported by Goodknight and Ludlam (1981) from the Mary Alice intrusion show detectable amounts of tungsten, and some detectable tin values occur sporadically in samples collected from similar intrusions to the northeast (Steven and others, 1977). Late fluorite occurs filling vugs within the Mary Alice Creek intrusion, and Steven and others (1977) reported both fluorite and topaz as late vapor phase minerals within some of the other rhyolite bodies. The high initial contents of the lithophile elements are undoubtedly due to primary magmatic enrichment, whereas the formation of late concentrations of hexavalent uranium minerals apparently resulted from expulsion of uranium, probably in a vapor phase, from the interiors of these plutons during the final stages of crystallization and devitrification (Steven and others, 1977).

Uranophane is the principal uranium mineral identified from other uranium mineralized localities in the area (Steven and others, 1977; Gibbs, 1981). Slack (1976) also reported that johannite mixed with minor amounts of carnotite, autunite, and uranophane is present in samples from the Beth mine in upper El Paso Creek, about 5 to 6 miles to the northeast of the study area (Goodknight and Ludlam, 1981). Although uranium was probably initially deposited in a hexavalent state, it is unclear if the minerals present in these occurrences represent the original mineralogy or if they were produced by secondary processes. The Beth mine is the only rhyolite-related uranium occurrence with any recorded production (about 100 tons of ore) (Slack, 1976; Nelson-Moore and others, 1978); although the intrusive between the West and East Forks of Nellie Creeks has been extensively drilled (Gibbs, 1981; Steven and others, 1977), as has the previously mentioned Mary Alice intrusion.

Cow Creek Area

Vein and weak disseminated mineralization are associated with a dacitic intrusive complex near the intersection of Cow and Difficulty Creeks (Burbank, 1940; Fischer and others, 1968; Steven and others, 1977), about 3 miles north of the wilderness study area boundary. The veins occupy either shears along the margins of dikes related to this center or similarly oriented radial fissure systems (Fischer and others, 1968; Burbank, 1940). Several vein deposits that occur in this structural setting were worked near Ouray, where they contained either complex base-metal ores or siliceous gold-silver ore composed of quartz, pyrite, proustite, and native gold (Burbank, 1940). Similar veins containing base-metal sulfides have been prospected north of the upper Cow Creek center and samples from these contained anomalous concentrations of silver, gold, lead, zinc, arsenic, bismuth, cadmium, and molybdenum (table 2) (Fischer and others, 1968). However, samples collected from the same locality by Steven and others (1977) contained only minor amounts of the elements arsenic and antimony. Traces of silver, copper, and lead were found in samples taken from within the central intrusive complex, near the intersection of Cow and Difficulty Creeks, and these weak anomalies appear to be associated with alteration around a late, cross-cutting quartz monzonite plug (Steven and others, 1977). No mineralized structures related to this complex have been found to the south toward the American Flats Study Area boundary. However, the rugged and largely inaccessible terrain in the region north of the study area has undoubtedly served as a deterrent to prospecting (Fischer and others, 1968).

Lower Bear Creek Area

Two mineralized veins, which have been explored along adits, occur along the lower part of the Bear Creek drainage (fig.2) (Hannigan, 1985). One of these veins trends nearly due east toward the study area and consists primarily of pyrite in shear zones. The other vein trends nearly due north and contains abundant base-metal sulfides (Hannigan, 1985).

The east-trending vein occupies a mineralized fracture zone, 1-4 feet wide, along the margin of an altered andesitic to dacitic dike, which cuts early intermediate-composition assemblage volcaniclastic rocks. The only sulfide mineral identified at this locality was pyrite, but samples of mineralized rock contained appreciable amounts of silver and arsenic, some zinc, and traces of gold (table 2) (Hannigan, 1985). This mineralized fissure appears to be similar in many respects to the precious-metal veins associated with the Cow Creek center.

The north-trending vein is subparallel, but not adjacent to another dike mapped by Lipman (1976a). A mineralized sample collected from this locality by Hannigan (1985) contained a distinctly different mineralogical assemblage consisting of quartz, pyrite, galena, and sphalerite. Calcite was also identified in this sample, but the high manganese content (>30,000 ppm) suggests that a manganiferous carbonate mineral is also present in significant quantities. Anomalous amounts of silver, lead, zinc, arsenic, cadmium, and copper were detected in the specimen from this locality (table 2) (Hannigan, 1985). Burbank (1940) described a group of northwest-trending quartz and manganiferous-carbonate-bearing veins with nearly identical mineralogy that extend from the lower Bear Creek area to the Amphitheater near Ouray. The vein sampled by Hannigan (1985) is probably associated with this group of veins, but could also conceivably be related to mineralization of the Cow Creek or Mineral Point areas.

GEOCHEMISTRY

Methods

Samples of unaltered and altered rock, vein material, and stream sediments were collected from sites within and immediately adjacent to the American Flats Wilderness Study Area during the course of this study and earlier investigations. Details of sample preparation, analytical techniques, and results are listed in the original reports (Fischer and others, 1968; Weiland and others, 1980; Hannigan, 1985) and the pertinent geochemical data, as well as the sample localities have been compiled for this investigation in a companion report (Hon, 1986). Most of the samples were analyzed by the direct-current arc and alternating-current spark emission spectrographic method described by Grimes and Marranzino (1968) in the laboratories of the USGS, Denver, Colorado and the USBM Metallurgy Research Center, Reno, Nevada (Hannigan, 1985). The 6 stream-sediment samples listed in table 4 of Hon (1986) were analyzed by a combination of induction-coupled argon plasma spectrographic (ICP), atomic-absorption, and colorimetric techniques in the laboratories of Barringer Research, Inc. (Weiland and others, 1980). In addition, all of the samples collected by the USBM in and adjacent to the study area (Hannigan, 1985; Hon, 1986) were analyzed for gold and silver by fire assay-ICP, but were below the detection limits for these elements (Ag <0.3 ppm, Au <0.007 ppm). The samples collected by Fischer and others (1968) were also analyzed for gold by atomic-absorption spectroscopy, but none contained gold unequivocally above the reported detection limit (0.02 ppm Au).

The semiquantitative emission spectrographic values are reported to the nearest number in the series 10, 15, 20, 30, 50, 70, 100 and so forth, where these numbers are approximate geometric midpoints of the concentration ranges. The best precision to be expected is for replicate analyses to lie within two adjoining intervals 96 percent of the time (Motooka and Grimes, 1976). However, many of the reported values (Hon, 1986) may not represent this level of precision. Because the samples were collected at different times and analyzed by a variety of laboratories, the results are not strictly comparable. The term "anomalous" is used to describe only those values that exceed levels commonly found in igneous rocks (Turekian and Wedepohl, 1961; Taylor, 1964; Levinson, 1980) and unaltered rocks in the region (Hon, 1986, table 5) by a margin greater than two standard deviations from the mean. No analytical error was specified for the ICP and other data presented by Weiland and others (1980). However, the values they reported for tin and boron are spurious and were not evaluated or included in table 4 of Hon (1986). Similarly, the values reported by Hannigan (1985) for tin and tellurium were also found to be unreliable. In addition, comparison of selected arsenic values given by Hannigan (1985) that were obtained for samples analyzed by emission spectrography and the more reliable atomic absorption method, indicates that the arsenic data listed in table 2 of Hon (1986) are of questionable reliability.

Stream-Sediment Samples

Neither the stream-sediment nor panned-concentrate samples collected from the headwaters of Wildhorse and Cow Creeks, within the wilderness study area (pl. 1) (Hon, 1986), contain any anomalous amounts of the elements that are associated with the ore deposits in the surrounding region. Nearly all of the samples listed in table 2 of Hon (1986) contained elevated levels of zinc; however, these concentrations correlated well with measured abundances of iron, manganese, titanium, and vanadium, as well as with high levels of cobalt, chromium, scandium, and nickel in panned-concentrate samples. This assemblage of elements, including zinc, is associated with iron-titanium oxide minerals (titanomagnetite and ilmeno-hematite) in igneous rocks and indicates that the zinc anomalies resulted from placer concentrations of rock-forming oxide minerals rather than from the presence of an ore-forming mineral, such as sphalerite. One of the stream-sediment samples (Hon, 1986, table 2, no. 22) had a much higher manganese content (>20,000 ppm) than the others, but this sample also yielded correspondingly high values of iron, titanium, vanadium, and zinc. Again, this association suggests a relationship to the rock-forming oxides, rather than to minerals of hydrothermal origin, such as manganiferous carbonates. Two of the stream-sediment samples (Hon, 1986, table 2, nos. 28 and 63) have reported concentrations of arsenic near the detection limit of the analytical technique. Because of the previously mentioned problems with the arsenic values listed in table 2 of Hon (1986), it is very difficult to assess the validity of these apparent anomalies. Detectable, but not anomalous, molybdenum values (7 ppm and 10 ppm) were reported for only two of the panned-concentrate samples (Hon, 1986, table 2, nos. 56 and 64). One relatively high concentration of barium (2,000 ppm) was present in the panned concentrates (Hon, 1986, table 2, no. 21), but is associated with the highest potassium value and probably represents the presence of K-feldspar rather than barite of hydrothermal origin. The observed drop in barium values between the paired sediment and panned-concentrate samples listed in table 2 of Hon (1986) undoubtedly reflects a simple decrease in the feldspar content of the heavy-mineral fraction. This relationship is antithetic to that expected if barite were the phase controlling the barium concentration.

Examination of data from stream-sediment samples taken from the region immediately adjacent to the wilderness study area (Hon, 1986) also failed to reveal any anomalous concentrations of elements indicative of mineralization. The single panned concentrate (Hon, 1986, table 2, no. 54) did have an elevated zinc content (900 ppm), but was associated with the assemblage of elements related to iron-titanium oxide minerals that was discussed previously. Neither the zinc or the molybdenum (7 ppm) values in this sample are considered to be indicative of mineralization.

In contrast, stream-sediment samples taken from drainages from the region surrounding the study area that contain mineralized rock or veins commonly have anomalous amounts of base-metal elements lead, copper, and zinc, as well as erratic traces of silver (table 3). Arsenic is anomalous in many of the samples, but reaches its highest values in Palmetto Gulch (table 3) (Weiland and others, 1980), which contains the dump of the Frank Hough mine. The ore from this mine was exceedingly high in both copper and arsenic (table 2), as are the stream sediments. There can be little doubt that mining activity has enhanced the anomalies present in many of these drainages. Molybdenum was also detected, but was not anomalous, in most of these stream-sediment samples (table 3). Other elements, such as gold, antimony, bismuth, tin, and cadmium were at or below detection limits where data was available. Values for uranium are uniformly low in stream-sediment samples from throughout the region.

Vein and Rock Chip Samples

Twenty-eight rock and "vein" samples were collected within the boundaries of the American Flats Wilderness Study Area (Hon, 1986). These samples are mostly slightly altered (generally iron-stained) or unaltered rock. No true open-space filling veins were found within the wilderness study area, and the few samples classified as vein material are actually weakly altered and silicified rock that occurs along fractures and faults. The silicified zones are generally narrow, but range from less than 1 inch to several feet in width and are in places surrounded by envelopes of bleached rock. Most of these zones can be traced for only a few tens of feet along the fracture and fault zones. Only a few of the samples analyzed from the study area contain even slightly anomalous amounts of the elements that are considered to be of economic interest. None of the samples analyzed contains any detectable silver or gold. One sample (Hon, 1986, table 3, no. 700) gave a mildly anomalous lead value of 300 ppm with detectable, but not anomalous, copper (70 ppm). None of the other samples contain lead in excess of 50 ppm. Sample number 906 (Hon, 1986, table 3) has 150 ppm of copper, and several others gave values of 70 ppm copper (Hon, 1986, table 3, nos. 700, 707, 897, 899, 903, and 905). Only the 150-ppm value of copper is considered to be mildly anomalous, but it is not associated with any other elements of economic interest. Molybdenum reached detectable levels in only two of the samples; these contained 50 ppm (Hon, 1986, table 1, no. 101) and 10 ppm (Hon, 1986, table 3, no. 702). No other values for elements indicative of hydrothermal mineralization are associated with the anomalous molybdenum value (50 ppm). Another sample (Hon, 1986, table 2, no. 26), which was taken from near the locality of the anomalous sample, did not contain detectable amounts of molybdenum. These facts suggest that the elevated concentration of molybdenum found in the one sample is an isolated occurrence and is not representative of more widespread mineralization.

TABLE 3 Abundances of selected elements in stream-sediment samples collected from mineralized areas surrounding the American Flats Wilderness Study Area (compiled from Fischer and others, 1968; Steven and others, 1977; Weiland and others, 1980; Hannigan, 1985; and Hon, 1986).

NAME OF AREA	ELEMENTAL CONCENTRATIONS (ppm) Ag	Au	Pb	Cu	Zn	As	Sb	Bi	Cd	Mo
Engineer Pass area										
Palmetto Gulch	<5-7	—	50-305	88-3404	139-2173	126-480	—	—	<7	2-6
Red Cloud Gulch	<5	--	30-70	33-43	398-523	30-37	--	--	<7	1-2
Bear Creek	<1	<.02	20-70	50-300	<200-500	<2000	<200	<10	<50	<3-5
South Fork of Henson Creek										
American Flats	<5	—	15-90	16-41	74-197	3-6	—	—	<7	1-4
Schafer Gulch	<5	--	75-435	37-207	313 - 1969	44-106	--	—	<7	3-13
Dolly Varden Mountain	<5-5	—	55-70	56-219	176-676	14-31	--	--	<7	1-4
Horseshoe Basin	<5	—	255-420	41-56	1003 - 1293	22-33	—	—	<7	5-9
Schafer Basin	<5	--	370-1025	59-147	390-841	20-56	--	--	<7	4-13
Sunshine Mountain	<5	—	20-315	45-103	103-382	5-11	—	—	<7	3-6
Henson Creek	<5-5	--	20-750	28-241	9-1023	8-50	--	--	<7	<1-13
Capitol City area										
Capital City	<.5-7	<.02-.02	50-2000	70-500	<200-7000	<2000	<200	<10	<50	<3-5
Mary Alice	<1	<.02	10-50	30-150	<200	<2000	<200	<10	<50	<5
lower Cow Creek	<1	<.02	10-30	7-30	<200	<2000	<200	<10	<50	<5
upper Cow Creek	<.5	<.02	20-50	10-30	<200	<200	<100	<10	<20	<5
American Flats study area										
in and near study area	<.3	<.007	<40	<6-6	100-1000	<300	<600	<200	<5	<1

Many of the samples collected and analyzed by the USBM from within the wilderness study area (Hon, 1986, table 2) display apparently anomalous amounts of arsenic (300-600 ppm). Relatively high concentrations of iron and manganese in some of these samples, suggests that arsenic could have been concentrated in iron-manganese oxide coatings on the rocks. However, leachates of iron-manganes oxides from two samples collected by the USGS during this study (nos. 101 and 102) showed arsenic contents of less than 100 ppm (Hon, unpub. data), which contradicts the suggestion that arsenic is enriched in iron-manganese coatings. In addition, none of the samples collected by Fischer and others (1968) from within or adjacent to the study area contains greater than 200 ppm of arsenic (Hon, 1986, table 3). Because of the problems with the arsenic analyses in table 2 of Hon (1986), as discussed earlier, and because the high arsenic values in this data set were not confirmed by independent sampling (Hon, 1986, table 3), the arsenic anomalies defined by these samples (Hon, 1986, table 2) were not considered to be accurate or reliable indicators of mineralization.

Samples taken from the area immediately adjacent to the wilderness study area (Hon, 1986) show only scattered, weak geochemical anomalies that are similar in magnitude to those found within the study area. Many of these were taken along the faults that trend from the upper Bear Creek area into the study area or from the small faults just to the west of study area (fig. 3 and pl. 1) (Hon, 1986). One sample contained 300 ppm lead and 100 ppm copper (Hon, 1986, table 3, no. 715) and was the only sample that had even slightly elevated concentrations of more than one element associated with vein mineralization in the region. A copper value of 700 ppm was reported from another sample (Hon, 1986, table 3, no. 859), whereas three samples had copper values of 70 ppm (Hon, 1986, table 3, nos. 703, 716, and 861), which is not considered to be an anomalous amount. No other samples contained lead or copper in excess of 50 ppm. None of the reported zinc values were greater than 200 ppm (Hon, 1986, table 1-3). Small amounts of molybdenum were detected in four samples (Hon, 1986, table 3, nos. 703, 704, 705, and 863) and another sample contained detectable tin (Hon, 1986, table 3, no. 859). None of these concentrations are considered to be anomalous. Another sample reportedly contained detectable gold (no. 889, Fischer and others, 1968), but the absence of detectable silver, which is highly correlated with gold, suggests that this analysis was erroneous. Again arsenic was detected only in samples listed in table 2 of Hon (1986), and for the reasons discussed earlier, these values should be treated with skepticism.

In contrast to the samples taken from within and immediately adjacent to the study area, veins sampled from the surrounding region (table 2) display very anomalous to ore-grade concentrations of large suites of elements of economic interest. Analytical data from some altered rocks collected in the vicinity of mineralized veins (Fischer and others, 1968; Steven and others, 1977) contained similar assemblages of elements, although many of the altered rocks have little or no anomalous metal content. Where anomalies were present in the altered rock samples, they commonly contained more restricted suites and more subdued concentrations of ore-related elements than the associated mineralized rocks or veins.

GEOPHYSICS

Scope of Investigations

The American Flats Wilderness Study Area has been included in regional gravity (Plouff and Pakiser, 1972) and aeromagnetic surveys (Steven and others, 1977; U.S. Geological Survey, 1972). The study area also lies two much more detailed aeromagnetic and aeroradiometric survey (High Life Helicopters/QEB, 1981; 1983). The results from less detailed aeroradiometric and aeromagnetic surveys (Geometrics, Inc., 1979; Aero Service, 1979) are available for the area, but were not evaluated during this investigation. The details of the methodology used in collecting and processing the geophysical data for these surveys are given in the individual reports cited above. No additional geophysical studies were done during the course of this investigation.

Gravity Survey

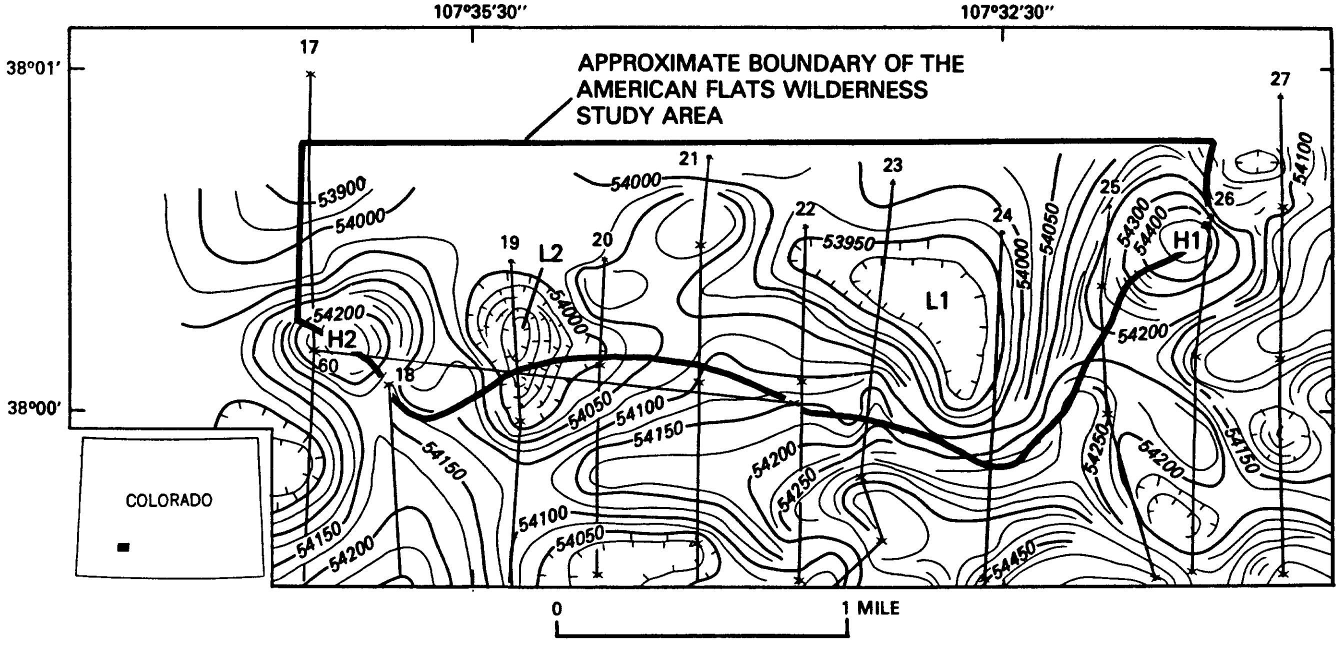
The study area lies along the northwestern edge of a large regional gravity low that probably reflects a major batholith underlying the San Juan Mountains (Plouff and Pakiser, 1972). The regional gravity low has no direct significance for the local evaluation of the resource potential of the study area. Although detailed gravity studies can be useful in detecting density differences that may help locate shallow unexposed plutons or other geologic features of possible significance to mineralization, available gravity data are too sparse to permit this type of interpretation within the study area. In fact, there are no gravity stations in or near the study area.

Aeromagnetic Survey

Aeromagnetic data were evaluated from two surveys (High Life Helicopters/QEB, 1981; 1983), which show very similar features. One survey was flown north-south at 1/3-mi spacings and the other was flown east-west at 1/4-mi spacings. Both were draped at an average of 400 ft above ground. Only the 1981 survey is shown in figure 4; anomalies determined from the 1983 data are so similar that they are not reproduced here.

The aeromagnetic map (fig. 4) shows a small high (H1) in the northeast corner of the study area, a broad boomerang-shaped low (L1) just to the west of H1, a small high (H2) in the southwest corner of the study area, a sharp low (L2) just to the east of this high, and a broad, aeromagnetically nondescript area in between the two lows. Although these features are correlated to some degree with the topography in the study area, the effects of topography alone are not considered sufficient to produce the observed aeromagnetic features. The aeromagnetic features (fig. 4) may be produced by rock units exposed either at the surface or present in the subsurface that are strongly magnetic in comparison to the surrounding units. Aeromagnetic lows L1 and L2 are probably caused by a polarity effect that occurs on the north side of the corresponding aeromagnetic highs (fig. 4) and by topographic effects due to the survey aircraft flying into a deep valley. The areas of irregular topography without strong aeromagnetic features between L1 and L2 (fig. 4) probably represent rocks that were originally only weakly magnetized or whose magnetic minerals were destroyed by later events, such as oxidation or hydrothermal alteration.

None of the aeromagnetic features observed in the study area can be attributed unambiguously to particular single geologic sources. Interpretation is hindered by the small scale of study, lack of conclusive rock-magnetic data for the various rock types, and nonuniform magnetic character within individual geologic units. The aeromagnetic highs in the northeast and southwest corners of the study area (H1 and H2, fig. 4) are tenatively attributed to buried dacite plutons; although the magnetic characteristics of these intrusions are not well known. The implications of this speculation are minor, in regard to the presence or absence of mineral deposits in the study area.



EXPLANATION

Magnetic contours—Contour interval 25 nanoteslas. Hachured in area of closed magnetic low

Flight line—Showing reference number and points on survey

L2 **Magnetic anomaly discussed in text**

Figure 4. Aeromagnetic map of the American Flats Wilderness Study Area, Quray and Hinsdale Countries, Colorado (modified from High Life Helicopters/QEB, 1981).

Aeroradiometric Survey

The results of the regional aeroradiometric survey by High Life Helicopters/QEB (1981) have been previously interpreted by Pitkin and Duval (1982). Results of a later survey (High Life Helicopters/QEB, 1983) are nearly identical to those of the earlier investigation. No significant anomalies of any type were detected within the boundaries of the study area by either aeroradiometric survey, although subdued equivalent uranium and thorium anomalies are associated with exposures of biotite dacite outside of the study area to the northeast of Wildhorse Peak (High Life Helicopters/QEB, 1983). The lack of strong anomalies indicates that none of the units exposed within the study area contain significantly elevated concentrations of uranium, thorium, or potassium compared to the surrounding rocks. The absence of anomalies confirms the geologic mapping (pl. 1) (Lipman, 1976a), which shows neither uranium-enriched rhyolites (pl.1, unit Tir) nor evidence for their presence in the shallow subsurface. No potassium-rich zones were detected during this study that might indicate the presence of regional alteration related to widespread disseminated mineralization of rock in the study area. Surface radiometric traverses of the study area also failed to detect any material above background.

The strong anomalies in the area around the study area are attributable to the rhyolite dome complexes on Dolly Varden Mountain and north of Engineer Pass, and the rhyolite intrusion near Mary Alice Creek (fig. 3). These rocks show as pronounced highs on the equivalent uranium maps (High Life Helicopters/QEB, 1981, 1983; Pitkin and Duval, 1982). The high silica rhyolites at Dolly Varden Mountain and Mary Alice Creek are defined by especially strong anomalies, but these rocks also display elevated concentrations of equivalent thorium. This is in agreement with geochemical data from samples of three of these complexes (K. Hon and R. A. Zielinski, unpub. data), which show that they contain up to an order of magnitude more uranium than the surrounding rocks. Samples collected from the rhyolites near Dolly Varden Mountain and Mary Alice Creek also have nearly twice the thorium content of other rocks found in the region, which accounts for the associated anomaly on the equivalent thorium map.

FAVORABILITY FOR UNDISCOVERED RESOURCES WITHIN THE STUDY AREA

Vein Deposits

Polymetallic veins of the western San Juan Mountains have produced large quantities of base and precious metals during the last century and constitute a future source of these metals (Burbank and Luedke, 1968). Vein deposits found in the vicinity of the wilderness study area contain variable amounts of silver, gold, lead, zinc, and copper; and they may also contain enough bismuth, cadmium, uranium, and tungsten to be recoverable as byproducts.

Productive mid- to late-Tertiary veins in the western San Juan Mountains are commonly hosted by either early intermediate-composition volcaniclastic conglomerates or dacite lavas (Burns Member of the Silverton Volcanics) (Purington, 1898; Burbank, 1941; Bejnar, 1957; Varnes, 1963; Burbank and Luedke, 1969). However, in the Engineer Pass area the principal mineralized veins occur within the tuffaceous sandstone (Henson Member) or the porphyritic andesite (pyroxene andesite member) of the Silverton Volcanics (Kelley, 1946). The intracaldera facies of the Sapinero Mesa Tuff (Eureka Member) and quartz monzonite intrusions are locally important hosts in veins along the south fork of Henson Creek and at Capitol City (fig. 3). The lithologic and physical characteristics of the host rocks play an important role in the determination of the size and style of open structures suitable for mineralization (Bejnar, 1957). Doe and others (1979) demonstrated that no significant metallic component of the veins was derived from the immediately surrounding wall rocks.

The most important criterion for precious- and base-metal mineralized vein systems is the presence of large regional structures that were open during the time of mineralization. The highly productive veins of the western San Juan Mountains occupy extensive and complex fault zones that are generally related to caldera formation (Steven, Luedke, and Lipman, 1974), although, in most cases, mineralization postdated formation of the structures (Lipman and others, 1976). Spectacular examples of this type of mineralization occur in the Sneffels-Telluride district, where some veins were mined continuously for as much as 8,000 feet horizontally and 3,000 feet vertically (Burbank, 1941). Around the wilderness study area, however, even the largest and most continuous of the structures contain only sporadic intervals of mineralized vein material.

Lipman and others (1976) have shown a close relationship between major mineral deposits and Miocene intrusive rocks, particularly quartz-bearing in the western San Juan Mountains. Both Kelley (1946) and Maher (1983) noted the presence of altered Miocene rhyolite intrusions associated with veins in the Mineral Point and Engineer Pass areas (fig. 3) to the south of the study area. Near Capitol City (fig. 3), it is possible that some or all of the veins could be related to the alteration and weak disseminated mineralization that was probably produced by late Oligocene quartz monzonite intrusions (Steven and others, 1977; Lipman and others, 1976).

The criteria used to assess the likelihood for vein deposits within the study area were the presence of (1) suitable host rocks, (2) well-developed fault or fracture zones, (3) quartz veins or mineralized rock, (4) hydrothermally altered rock, (5) geochemical anomalies, and (6) intrusions or geophysical evidence of their presence.

Many of the rock units that are the most favorable host rocks for vein deposits in the region are present within the study area. However, the southern 20-30 percent of the study area is covered by the Fish Canyon Tuff (pl. 1), which is not a favorable host for vein deposits. Where similar outflow sheets are present above productive veins elsewhere in the western San Juan Mountains, the mineralized structure splays upward into thin weakly mineralized fractures (Purington, 1898; Burbank, 1941). Nowhere in the western San Juan Mountains are these rocks known to host ore deposits. However, the outflow-facies ash-flow tuffs that cap the major veins of the Sneffels-Telluride district are commonly weakly mineralized and extensively altered above the deposits (Burbank, 1941), as is the Fish Canyon Tuff that crops out above and adjacent to the Frank Hough deposit on Engineer Pass (Maher, 1983). Although the Fish Canyon Tuff might prevent veins developed in the underlying units from being exposed at the surface within its outcrop area, alteration associated with any such veins would still be expected to be conspicuous.

The dacite intrusions exposed within the study area are not the type that are known to be associated with mineralization elsewhere in the western San Juan Mountains. Although the general trend of Miocene intrusions projects through the study area, there is no evidence that any of the quartz-bearing dacite and andesite or high-silica rhyolite intrusions crop out or underlie the study area.

Faults exposed within the wilderness study area are not well developed and are defined either by small stratigraphic offsets or by zones of weak hydrothermal alteration. None of these faults or fractures has the size or continuity necessary to host a major polymetallic vein deposit, such as those found at the Sunnyside, Idarado, Camp Bird, or Shenandoah-Dives mines (fig. 2) (Ransome, 1901; Varnes, 1963; Casadevall and Ohmoto, 1977; Mayor, 1978). However, the structures are of sufficient size to contain smaller vein deposits similar to those found in the vicinity of the study area. The principal products of these veins were silver and gold because the concentrations of the base-metals within most of the deposits were generally low.

No mineralized vein material has been found within the study area either along or away from mapped faults (pl. 1). The only known mineralized structures that trend into the study area are those found in the upper Bear Creek drainage basin (fig. 3), and although they have been prospected fairly extensively, they have not produced any ore. Samples taken from these faults within 1 mile of the study area do not show any geochemical anomalies. Faults that host the productive deposits of the Engineer Pass area trend parallel to the study area boundary and die out as they get closer to the study area. Similarly, the veins found along the South Fork of Henson Creek are confined to the Eureka graben zone and are oriented parallel to the study area.

Traces of hydrothermal alteration found in the study area consists of weak, patchy silicification associated with bleaching of the wall rock; the bleached appearance of the rocks was probably produced by minor argillic alteration. Silicification and bleaching were found only along the small, discontinuous faults and fractures on the western edge of the study area. No altered rocks were observed along the larger northeast-trending faults that cut the Fish Canyon Tuff and that appear to be extensions of the structures in the Bear Creek area. Only a few geochemical anomalies, which are defined by single metallic elements, were detected from samples within and immediately adjacent to the American Flats study area. None of the samples displays the suites of elements that were found to be characteristic of the productive vein deposits outside the study area, nor did the stream-sediment samples show any indication of mineralized areas.

Breccia-Pipe Deposits

Breccia-pipe deposits in the western San Juan Mountains have produced a moderate amount of rich silver-copper-lead ore. Minor amounts of the elements tin, uranium, and bismuth are also associated with these ores (Pierson and others, 1958; Fischer and others, 1968; Burbank and Luedke, 1969). Very little gold was produced from these deposits.

All of the productive breccia-pipe deposits are in a belt that extends from Red Mountain Pass to Ironton, and their emplacement appears to be controlled by ring faults related to the Silverton and San Juan calderas (Burbank, 1941). In contrast, the breccia pipe just south of the study area boundary near Engineer Pass (fig. 3) does not appear to be associated with any regional structures (Maher, 1983). In general, the breccia pipes consist of a silicified and brecciated core surrounded by argillic and phyllic alteration assemblages in the wall rocks. The deposits are commonly zoned from lead-silver to rich copper-silver to pyritic ore with depth (Burbank, 1940). The absence of copper in the breccia pipe near Engineer Pass (Maher, 1983) is probably the result of supergene leaching, because copper is highly mobile under the acidic conditions of the upper, near-surface portions of these breccia pipes (Fisher and Leedy, 1973). Altered rocks around these deposits are commonly enriched in lead and contain small, erratic anomalies of arsenic, bismuth, and silver. Gold and arsenic are the best pathfinder elements within the silicified cores of mineralized pipes, but significant amounts of silver are present as well (Fisher and Leedy, 1973). Intrusive quartz-bearing andesite to dacite porphyries and aphyric rhyolites are intimately associated with most of the mineralized breccia pipes (Burbank, 1941; Maher, 1983). However, the relationship of these intrusions to formation of the breccia pipes and their associated ore deposits is not understood.

The characteristics of breccia-pipe deposits that were used to assess likelihood for their occurrence within the American Flats Wilderness Study Area were (1) evidence of massive silicification and brecciation of country rock or widespread argillic and phyllic alteration, (2) geochemical anomalies similar to those found around known breccia pipes in the region, and (3) the presence of intrusive rocks commonly associated with the breccia pipes near Engineer and Red Mountain Passes.

As was discussed in the preceding section on vein deposits, the altered zones found within the study area are very restricted in size and are not associated with any significant geochemical anomalies. Because of the intense alteration and fracturing that are characteristic of these pipe deposits, it is unlikely that they would occur without some surface expression in the area. In addition, the intrusions exposed within the study area are not of the type known to be associated with breccia pipes in the western San Juans and there is no indication that favorable intrusive rocks might exist at depth.

Porphyry-Type Molybdenum and Copper Deposits

Two environments with characteristics of porphyry-type molybdenum deposits with or without copper are present in the vicinity of the study area. Calc-alkaline monzonitic intrusions near Capitol City, the Iron Beds, and Matterhorn Peak (fig. 3) are associated with anomalous amounts of molybdenum, copper, and several other elements indicative of disseminated mineralization (Steven and others, 1977). The association of molybdenum with copper and the chemistry of the related plutonic rocks the possibility of weakly developed granodiorite-type molybdenite deposits at these localities, similar to those found in the Canadian Cordillera (Soregaroli and Sutherland Brown, 1976). The high-silica rhyolite associated with the breccia pipe near Engineer Pass could represent the surface expression of a granite or "Climax-type" molybdenite deposit (Mutschler and others, 1981; White and others, 1981). This complex bears striking similarity to the composite breccia pipe and related high-silica rhyolite intrusion above the Redwell Basin porphyry-type molybdenum deposit , which is adjacent to the Mount Emmons ore body (Sharp, 1978; Thomas and Galey, 1982) The intrusion on Engineer Pass contains elevated concentrations of molybdenum; however, no molybdenum-mineralized clasts were recognized within the associated breccia pipe (Maher, 1983). The uranium-enriched, high-silica rhyolites also are petrologically similar to the intrusions associated with "Climax-type" deposits (White and others, 1981; Burt and others, 1982) and contain elevated initial concentrations of molybdenum (Steven and others, 1977). However, none of these rhyolites in the vicinity of the study area appears to have caused hydrothermal alteration indicative of porphyry-type mineralization (Steven and others, 1977).

Because pervasively altered rocks typical of porphyry-type deposits have not been recognized within or adjacent to the study area, any potential deposits would have to be at relatively great depths. Commonly, the only indication of these deposits are surface exposures of igneous and clastic dikes, the latter of which can carry fragments of mineralized rock. Although no clastic dikes were found, several small plugs of dacite are present along the southwestern side of the study area; however these are unaltered and are not the same type of intrusions known to be associated with disseminated mineralization elsewhere in the region. None of the available geophysical data shows any clear indication either of widespread alteration or of plutons, which might be associated with porphyry-type mineralization within the study area.

Uranium Deposits

Uranium occurs as concentrations at the margins of high-silica rhyolite intrusions east of the study area, which contain elevated magmatic concentrations of uranium, fluorine, beryllium, lithium, and molybdenum (Steven and others, 1977). These rhyolites and similar rocks elsewhere were referred to as "topaz" rhyolites by Burt and others (1982), who noted their relationship to deposits of uranium, beryllium, tungsten, tin, and molybdenum. In the region including the study area, the only likelihood for uranium deposits is associated with rhyolites of this type. Although two of these rhyolite-related uranium occurrences outside of the study area have been drilled rather extensively, no significant uranium deposits have been delineated. There is no geological or geophysical evidence to suggest the presence of similar rhyolite intrusions within the study area. However, none of the geophysical data available for the study area was adequate to determine if similar intrusions are present at any great depth beneath the surface.

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