DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

MISCELLANEOUS FIELD STUDIES
MAP MF-1949
PAMPHLET

GEOLOGY, ALTERATION, AND VEINS OF THE REDCLOUD PEAK (LAKE CITY CALDERA) AND HANDIES PEAK WILDERNESS STUDY AREAS, HINSDALE COUNTY, COLORADO

By

Ken Hon

STUDIES RELATED TO WILDERNESS
Bureau of Land Management Wilderness Study Areas

The Federal Land Policy and Management Act (Public Law 94-579, October 21, 1976) requires the U.S. Geological Survey and the U.S. Bureau of Mines to conduct mineral surveys on certain areas to determine the mineral values, if any, that may be present. Results must be made available to the public and be submitted to the President and the Congress. This report presents the results of mineral surveys of the regions surrounding the Redcloud Peak (CO-030-208) Wilderness Study Area and the Handies Peak (CO-030-241) Wilderness Study Area, Hinsdale County, Colorado.

SUMMARY

The Redcloud Peak and Handies Peak Wilderness Study Areas are located within the San Juan volcanic field of southwestern Colorado. The geology of the two wilderness study areas is dominated by the 23.1-m.y.-old Lake City caldera and the surrounding 29-m.y.-old Uncompahgre-San Juan caldera complex. Mineralized veins occupy faults formed during resurgence of these calderas. In the Redcloud Peak Wilderness Study Area, most veins appear to have formed during the waning stages of emplacement of a large resurgent intrusion late in the Lake City caldera cycle. Veins within the Handies Peak Wilderness Study Area fill faults of the Eureka graben within the resurgent dome of the Uncompahgre-San Juan caldera complex, but mineralization in the Eureka graben did not occur until 5-10 m.y. after formation of this caldera complex. Several silicified breccia masses, which superficially resemble the surface expression of known breccia-pipe deposits in the western San Juan Mountains, were identified in the northwest corner of the Lake City caldera (within the Redcloud Peak Wilderness Study Area). Alteration possibly related to porphyry-type mineralization occurs in the same general area, but in rocks outside of the Lake City caldera. A quartz monzonite in the northeastern part of the Redcloud Peak Wilderness Study Area is associated with sparse quartz and potassium feldspar veinlets, magnetite veinlets, tourmaline breccias, and pebble dikes, which are all interpreted as characteristics of weak porphyry-type copper mineralization. However, no evidence of the strong hydrothermal alteration typical of this type of mineral deposit was found associated with the quartz monzonite intrusion.

INTRODUCTION

Mineral surveys were conducted on approximately 40,000 acres of the Redcloud Peak and Handies Peak Wilderness Study Areas, managed by the BLM (U.S. Bureau of Land Management), in Hinsdale County, southwestern Colorado. Throughout this report, "wilderness study area(s)" and "study area(s)" apply only to the areas where mineral surveys were conducted. The study areas lie within the western San Juan Mountains, a region that contains some of the most productive epithermal vein deposits in Colorado and that is considered to be one of the most mineralized volcanic terrains in the world. The purpose of this report is to briefly summarize the history of volcanic activity and mineralization in the study areas, as well as to present the results of recent geologic mapping that are important to the assessment of their mineral resource potential. Included within this report are new geologic, alteration, and vein maps of the Redcloud Peak study area (Lake City caldera), and a modified version of part of a published geologic map that includes the Handies Peak study area (Lipman, 1976a), which was revised in cooperation with D. J. Bove.

The terminology used for volcanic and plutonic rocks throughout this report is that recommended by the IUGS (International Union of

Geological Sciences) in reports by Le Maitre (1984) and Streckeisen (1975). Thus, the igneous rock names used differ slightly from those used by Lipman (1976a), Steven and Lipman (1976), and Lipman and others (1973); as well as from the names used by numerous other authors. The most significant difference in terminology is the replacement of the terms quartz latite (65-70 percent SiO_2) and rhyodacite (60-65 percent SiO_2) (as defined by Lipman (1975)) by high-K (high-potassium) dacite (63-69 percent SiO_2) and high-K andesite (57-63 percent SiO_2). For ease of discussion, the high-K modifier has been left out in much of the text and these rocks are referred to simply as dacite and andesite. However, the dacite and andesite of the San Juan volcanic field are not compositionally equivalent to the low-K orogenic andesite and dacite found in island arc settings.

Most K-Ar (potassium-argon) ages are from Lipman and others (1970) and Mehnert and others (1973), and have been recalculated by Hon and Mehnert (1983). Other sources of ages are referenced within the text.

GEOLOGIC SETTING

GEOLOGY OF THE WESTERN SAN JUAN VOLCANIC FIELD

The Redcloud Peak and Handies Peak Wilderness Study Areas are located in the western part of the mid-Tertiary San Juan volcanic field of southwestern Colorado (fig. 1). The western San Juan Mountains were the site of periodic volcanic and hydrothermal activity, from about 33 m.y. ago until about 5 m.y. ago (Lipman and others, 1970; Lipman and others, 1973; Lipman and others, 1976; Naeser and others, 1980). Andesitic to dacitic lava flows and pyroclastic breccias were erupted approximately 33-30 m.y. ago from several large stratovolcanoes in the area between Lake City and Silverton (Lipman and others, 1973; Lipman and others, 1976). Accumulations of these near-source facies rocks and composite intrusions mark the Larson, Lake Fork, Cimarron, and Carson centers in the vicinity of Lake City, whereas similar volcanoes in the Silverton area are thought to have been destroyed by later caldera collapses (fig. 1) (Lipman and others, 1973). Early intermediate-composition volcanic and volcaniclastic rocks related to these centers, as much as 5,000 ft thick in places, were deposited unconformably upon Mesozoic and Paleozoic sedimentary rocks and Precambrian metamorphic and igneous rocks. In the region surrounding the Redcloud Peak and Handies Peak study areas the underlying basement is composed entirely of Precambrian rocks because Phanerozoic sedimentary rocks were either not deposited or were removed by erosion during uplift of the area in the late Paleozoic and again in the Late Cretaceous (Burbank, 1940; Kelley, 1957; Lipman, 1976a).

Andesitic volcanism gave way to eruptions of large volumes of dacitic to rhyolitic tuffs, which were accompanied by subsidence of the source areas to form calderas. The two oldest calderas in the western San Juan volcanic field, the Ute Creek and Lost Lake calderas, formed about 30 m.y. ago to the south of the earlier volcanic centers (Lipman and others, 1973; Steven and Lipman, 1976). Activity then shifted back to the cluster of stratovolcanoes, where the Uncompahgre and San Juan calderas collapsed contemporaneously 29 m.y. ago, during the eruption of the Sapinero Mesa Tuff (Lipman and others, 1973). Caving of large volumes of early intermediate-composition rocks from the oversteepened caldera walls enlarged the two calderas greatly beyond their structural boundaries (Lipman, 1976b). Only a narrow septum of Proterozoic granite, which was relatively resistant to slumping, remains between the Uncompahgre and San Juan calderas (fig. 2) (Lipman and others, 1973). The two calderas jointly resurged soon after their collapse and formed a broad elliptical dome, which extends from Lake City to Silverton (figs. 1 and 2) (Lipman and others, 1973; Steven and Lipman, 1976). Distensional faulting along the crest of the dome produced a complex northeast-trending graben, the Eureka graben, with numerous inwardly dipping normal faults (Luedke and Burbank, 1968; Steven and Lipman, 1976). Eruptions of postcollapse andesitic to dacitic lavas and deposition of related tuffaceous sediments (pyroxene andesite member, Burns Member, and Henson Member of the Silverton Volcanics) began soon after the onset of resurgence (Lipman and others, 1973). Although some of these rocks were deposited within the study areas, they are much thinner there than to the north and south where they filled the moat area surrounding the resurgent dome (Lipman, 1976a). Several ash-flow sheets, including the 27.8-m.y.-old Fish Canyon Tuff (Kunk and others, 1985), the Crystal Lake Tuff, and the Carpenter Ridge Tuff, also ponded within the Uncompahgre caldera during the late stages of resurgence (Lipman and others, 1973). The Crystal Lake Tuff was erupted from the Silverton caldera (fig. 1), whereas the other ash flows had sources in the central San Juan Mountains (Lipman and others, 1973; Steven and Lipman, 1976). After the completion of resurgent doming, postcollapse volcanism terminated in the Uncompahgre caldera with the eruption of the volcanics of Uncompahgre Peak (Lipman and others, 1973; Lipman, 1976a). The last phase of igneous activity related to the Uncompahgre caldera was the intrusion of 25- to 28-m.y.-old monzonitic stocks (Caskey, 1979; Slack, 1980; Lipman, 1976a) in the Capitol City area and in the southeast corner of the caldera (fig. 2). Similar rocks were intruded along the southeast margin of the San Juan and Silverton calderas and farther to the west near Ophir and Mount Wilson at about the same time (fig. 2) (Dings, 1941; Larsen and Cross, 1956; Bromfield, 1967; Lipman and others, 1970; Jackson and others, 1980).

Volcanic activity resumed in early Miocene time with the eruption of the 23.1-m.y.-old Sunshine Peak Tuff from the Lake City caldera (figs. 1 and 2) (Lipman and others, 1973; Hon and others, 1983). This younger caldera is nested within the Uncompahgre caldera and truncates many of the older structures, such as the Eureka graben (Lipman, 1976a; Steven and Lipman, 1976). The ash-flow tuffs and resurgent intrusions related to the formation of the Lake City caldera are mildly alkalic and petrologically distinct from the calc-alkaline rocks formed during earlier caldera eruptions (Lipman and others, 1978). At about the same time (24-22 m.y. ago), quartz- and sanidine-bearing, dacitic to andesitic intrusions were emplaced along a northeasterly trend from Red Mountain Pass to Engineer Pass (fig. 2) (Lipman and others, 1976; K. Hon, unpub. data). Later, porphyritic and aphyric high-silica rhyolites were intruded largely along the same linear trend between 19 and 10 m.y. ago, but extended further to the northeast toward Lake City (fig. 2) (Lipman, 1976a; Lipman and others, 1976; Maher, 1983).

GEOLOGY OF THE REDCLOUD PEAK WILDERNESS STUDY AREA (LAKE CITY CALDERA)

The Redcloud Peak Wilderness Study Area lies mostly within the 23.1-m.y.-old Lake City caldera (fig. 1; Map A), which collapsed in response to the eruption of the compositionally zoned Sunshine Peak Tuff (Map A). This ash-flow sheet consists of a high-silica rhyolitic lower member, a rhyolitic middle member, and a quartz trachytic upper member (Map A) (Hon and others, 1983). The three members interfinger with a caldera-collapse breccia member, which was produced by periodic landsliding of older rocks from the walls of the Lake City caldera (Lipman, 1976b). This caldera-fill sequence makes up the bulk of the rocks exposed within the Redcloud Peak study area (Map A), as well as in the eastern third of the Handies Peak study area (Map C) (Lipman, 1976a).

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

The rocks of the Lake City caldera can be divided into two distinct petrologic groups. The Sunshine Peak Tuff and the resurgent intrusive rocks define a mildly alkaline trend, whereas the dacite lavas and late intrusions are calc-alkaline (Map A). The alkaline rocks vary from quartz syenite or quartz trachyte to high-silica rhyolite (64-77 percent SiO_2) (Map A). Similar zonations within both the Sunshine Peak Tuff and the resurgent intrusion are thought to reflect their derivation from a single compositionally zoned magma chamber (K. Hon and Z. C. Peng, unpub. data). The calc-alkaline rocks include the dacite lavas of Grassy Mountain, the dacite of Red Mountain, and the quartz monzonite of Alpine Gulch, which are all confined to the eastern part of the Lake City caldera (Map A). In contrast to the alkalic rocks, the dacites and quartz monzonite have a narrower compositional range of 62-68 percent SiO_2 (Map A). Mineralogic, textural, chemical, and isotopic data indicate that the dacite porphyry of Red Mountain and the quartz monzonite of Alpine Gulch are nearly identical, which suggests that both were derived from the same underlying magma chamber. The dacite lavas of Grassy Mountain appear to represent a slightly earlier, but related phase of this magmatism (K. Hon and Z. C. Peng, unpub. data).

Geophysical studies also support the presence of two distinct plutonic bodies beneath the Lake City caldera. Both aeromagnetic and gravity anomalies (Grauch, in press; Grauch and Campbell, 1985; High Life Helicopters/QEB, 1981) roughly coincide with the mapped limits of the resurgent intrusion in the north-central part of the Lake City caldera. The resurgent intrusive rocks are denser than the surrounding tuff and have normal remanent magnetization in contrast to the reverse polarities of the Sunshine Peak Tuff (Map A) (Reynolds and others, 1986). These properties indicate that a large resurgent intrusion, underlying this part of the caldera, is the most probable cause of the observed gravity and aeromagnetic highs (Grauch, 1985). A more subdued pair of gravity and aeromagnetic highs in the eastern third of the Lake City caldera appears to represent a source at greater depth (High Life Helicopters/QEB, 1981; Grauch and Campbell, 1985; Grauch, 1985, in press). The latter anomalies are interpreted here as the crystallized magma body that was the source of the postcollapse calc-alkaline lavas and intrusions in this sector of the caldera. One of these intrusions, the quartz monzonite of

Alpine Gulch, has normal remanent magnetization (Reynolds and others, 1986) and is associated with a strong positive aeromagnetic anomaly (Grauch, in press). The presence of similar holocrystalline rocks at depth in the eastern part of the caldera could account for the less pronounced aeromagnetic high in the eastern third of the caldera. Exposures of the postcollapse lavas and late intrusions are all peripheral to the geophysical expression of this postulated calc-alkaline magma chamber, probably because their high-level emplacement was controlled by the ring fault of the Lake City caldera.

A few small areas of volcanic rocks, which are dominantly Uncompahgre caldera fill outside of the Lake City caldera, lie within the boundaries of the Redcloud Peak Wilderness Study Area (Map A). These include the intracaldera Sapinero Mesa Tuff and related caldera-collapse breccias (Eureka and Picayune Members), lenses of postcollapse lavas and sediments (Burns and Henson Members of the Silverton Volcanics), and thin sheets of the Fish Canyon and Crystal Lake Tuffs, which were deposited on the margin of the resurgent dome of the Uncompahgre caldera.

Late monzonitic intrusions related to the Uncompahgre caldera are also present in the northwestern and southeastern corners of the study area (Map A) (Lipman, 1976a). Intrusions in the Capitol City area, near the northwestern corner of the study area, range from monzodiorite to granite (59-72 percent SiO_2), whereas the intrusion near Williams Creek in the southeastern corner of the study area (Map A) grades from equigranular monzodiorite or monzonite (59 percent SiO_2) inwardly to porphyritic quartz monzonite (Larsen and Cross, 1956; Lipman, 1976a; K. Hon, unpub. data). The southeast body is associated with a strong aeromagnetic high, and a positive aeromagnetic anomaly of similar size and strength underlies the scattered outcrops of monzonitic intrusions in the Capitol City area (High Life Helicopters/QEB, 1981; Grauch, in press). The intrusions in the Capitol City area have normal magnetic polarity (K. Hon and R. L. Reynolds, unpub. data), suggesting that the observed aeromagnetic high could be produced by a large monzonitic intrusion underlying the area.

Structures within the Redcloud Peak Wilderness Study Area are closely related to volcanic processes, particularly formation of the Lake City caldera. Major episodes of faulting and doming are directly attributable to catastrophic ash-flow eruptions, followed by the emplacement of an intrusive body of near-batholithic dimensions.

The most prominent structure is the ring fault of the Lake City caldera, which is typically vertical or dips steeply (greater than 70°) inward toward the center of the caldera (Map A) (Lipman, 1976a). The ring fault bounds a deeply subsided block marked by the accumulation of more than 5,000 ft of Sunshine Peak Tuff. During resurgence of the Lake City caldera, differential upward movement occurred along the ring fault due to the asymmetric emplacement of the quartz syenite intrusion within the north-central part of the caldera. The northern sector of the ring fault was uplifted more than 4,000 ft, and displacements gradually decrease in a counterclockwise direction along the ring fault.

Stratigraphic relations also indicate the presence of a major fault in the drainage of Alpine Gulch. Maximum displacement of more than 4,000 ft along this fault coincides with the area of greatest uplift on the ring fault (Map A), and displacement diminishes rapidly toward the interior of the caldera. The Alpine Gulch fault marks the northeastern limits of quartz syenite intrusions and apparently formed during resurgent doming of the caldera.

Faulting within the center of the caldera is also related to resurgent doming and the emplacement of quartz syenite intrusions into the caldera-fill sequence. The faults are concentrated above the quartz syenite intrusions and have a dominant northeast trend (Maps A and B), suggesting that they represent the root zone of an extensional graben that formed on the crest of the resurgent dome. Displacements on these faults are generally less than 100 or 200 ft, although offsets of as much as 600 ft have been documented. Many of the faults are marked by conspicuous outcrops of quartz veins or fault breccias, but some are covered or have little surface expression and are only reflected by stratigraphic displacements (Maps A and B).

Faults within the caldera rarely cut or offset the resurgent intrusions, but the faulted and displaced rhyolite porphyry bodies west of Cooper Lake are an exception to this. At this locality, rhyolite porphyry was probably intruded early and was subsequently faulted during later high-level emplacement of nearby quartz syenite (Map A). In contrast, the well-developed fault breccias and shearing found within the quartz syenite in Owl Gulch and the late quartz monzonite of Alpine Gulch, respectively, must have formed long after solidification of these holocrystalline intrusions. Thus, some minor amount of faulting appears to have occurred after the main episode of intrusive activity ceased within the caldera.

Mineralization within the Redcloud Peak study area appears to have occurred mainly during the Lake City caldera cycle, but some precaldera mineralization and alteration took place in the northwest corner of the study area. Quartz veins occupy many faults within the core of the Lake City caldera, and the intensity of the alteration associated with these mineralized structures is zoned about the resurgent intrusion (Map B). These veins and the associated widespread alteration appear to have formed by convection of meteoric water during cooling of the resurgent intrusion. A few veins cut intrusions within the caldera, and some of these may have formed after the Lake City caldera cycle. Evidence of weak porphyry-type mineralization is associated with both the quartz monzonite of Alpine Gulch and the dacite of Red Mountain, the latter of which lies outside of the study area. Several small bodies of silicified breccia, thought to be of hydrothermal origin, were identified in the northwestern part of the Lake City caldera. Although these can be no older than the caldera, it is not known if they formed during or after hydrothermal activity associated with formation of the caldera. Precaldera mineralization is confined to the northwestern part of the study area, where altered rock and possible porphyry-type mineralization are associated with 25- to 28-m.y.-old monzonite intrusions near Capitol City (fig. 2).

Most of the well-developed quartz veins and associated alteration within the Redcloud Peak study area are hosted by the ash-flow members of the Sunshine Peak Tuff. Where quartz veins extend into the caldera-collapse breccia member, they generally become small limonite-stained slips. Although veins cutting the collapse breccias have little surface expression, similar structures in the Burrows Park area of the Lake City caldera are mineralized (Woolsey, 1907; Krasowski, 1976). Veins that contain moderate-tonnage silver and base-metal (Pb, Zn, Cu) deposits are present north of the Lake City caldera (Irving and Bancroft, 1911; Slack, 1980), 1-2 mi outside of the study area. These veins also are postulated to be related to the emplacement of the resurgent intrusion within the Lake City caldera (Slack, 1980). If true, then similar veins might be expected to occur at depth along the periphery of the resurgent intrusion within the study area.

Approximately 100 quartz veins were mapped within the Redcloud Peak study area (Map B) and more than one third of these exceed 1,000 ft in length. The most continuous veins within the area are slightly longer than 1 mi and some of the veins are exposed over vertical intervals in excess of 1,000 ft (Map B). The veins are typically between 1 and 3 ft in width, but can be as much as 10-20 ft wide. The structure of the veins varies from massive quartz to zones of smaller sheeted or anastomosing veins and silicified wallrock. Vein filling is generally milky-white to light-gray, aplitic or coxcomb quartz that can contain finely disseminated pyrite. On the ridge dividing Silver and Cooper Creeks, several distinctly different veins consist of medium- to dark-gray breccias of "cherty" silica. The breccias are composed of small (less than 1 in.) angular fragments, which are generally pyritic, but are not replacements of the surrounding wallrocks.

Base-metal sulfides, such as galena, sphalerite, and chalcopyrite, are sparse in the veins within the Redcloud Peak study area and are generally only exposed in small adits and prospects. Sulfosalt minerals, such as tetrahedrite or tennantite, are rarely identifiable in hand specimen samples of veins. Many veins contain platy pseudomorphs or casts that appear to have formed by replacement or dissolution of earlier barite. Wallrock immediately adjacent to the veins is commonly strongly silicified and surrounded by quartz-sericite-pyrite alteration, although a few veins have margins of gouge, which may be due to argillic alteration. Krasowski (1976) also noted the presence of weak argillic alteration further out from the veins in Burrows Park, and this zonation may occur elsewhere in the caldera as well. Large areas of the Sunshine Peak Tuff have been affected by quartz-sericite-pyrite alteration of varying intensity (Map B), and quartz veins too small to be mapped commonly form networks along fractures and joints within the more strongly altered areas (Map B). Even the smallest of these veinlets (less than 0.2 in.) are composed of vuggy coxcomb quartz, indicative of formation by open-space filling.

Minor mineralization also occurred along the faults that apparently formed after the Lake City caldera cycle. A small mineralized shear (not mapped) cuts the quartz monzonite of Alpine Gulch at about 10,200 ft on the ridge nearest the ring fault (Map A). This fault probably formed during postcaldera(?) movement along the Alpine Gulch fault and contains a distinctive assemblage of carbonate, specular hematite, and base-metal sulfide minerals. The fault displacing the quartz syenite intrusion on the west side of Owl Gulch (Map A) is composed largely of brecciated rock, but in places this has been cemented by coxcomb quartz.

Several silicified and brecciated masses of rock are present in the northwestern part of the caldera and appear to be of hydrothermal origin (Map B). Three of these breccias are so strongly silicified that their outcrops stand 5-15 ft above the surrounding rocks. The fourth (the body at 11,400 ft on the ridge immediately east of Lee Smelter Gulch) is not silicified, and may only be shattered, altered rock within the caldera-collapse breccia. The breccia mass on the 13,484-ft peak east of Cooper Lake is localized at the intersection of several major quartz veins cutting the lower Sunshine Peak Tuff (Map B) and is clearly not an altered mass of precaldera rock incorporated within collapse breccia. Rare fragments of highly altered Sunshine Peak Tuff were found within the southwestern silicified body, but the clasts within the northwestern body are so completely silicified that no original textures could be identified. Fragments within the breccias are generally small (1-3 in.) and angular to subrounded in shape. The three silicified bodies contain variable amounts of pyrite, but no other minerals could be identified in hand specimen. The silicified breccia on the 13,484-ft peak appears to be surrounded by 5-10 ft of argillized rock; however, poor exposures prevent similar observations at the other localities. Although these breccia bodies superficially resemble the silicified cap rock associated with breccia-pipe deposits elsewhere in the western San Juan Mountains (Maher, 1983; Fisher and Leedy, 1973; Burbank, 1941), it is unclear if they are of similar origin.

Both the quartz monzonite of Alpine Gulch (Map B) and the dacite of Red Mountain, which lies just to the east of the study area, display some characteristics of weak Cu-Mo (copper-molybdenum) porphyry-type mineralization (Bove, 1984, unpub. data). The quartz monzonite body contains abundant miarolitic cavities and is cut by rare veinlets of graphically intergrown quartz and potassium feldspar near the top of the intrusion. Magnetite veinlets were found in float near the base of the exposed pluton, and a zone of tourmaline breccias and fragmental dikes cut collapse breccia roofing the intrusion (Maps A and B). No indications of strong hydrothermal alteration, such as the sericitic or potassic alteration halos typical of Cu-Mo porphyry-type mineralization, were observed in association with the quartz monzonite intrusion. The dacite of Red Mountain is spatially and temporally associated with extensive hydrothermal breccias and 23.1-m.y.-old alunite alteration, which formed in a very near surface environment (Bove, 1984, unpub. data; Mehnert and others, 1979). The intense advanced argillic alteration on Red Mountain grades downward into argillic and potassic zones, both of which are cut by microveinlets of quartz, sericite, and pyrite. Anomalous amounts of lead, zinc, copper, and molybdenum were detected in samples from these zones (Map B) (Bove, 1984, unpub. data). No similar widespread alunitization occurs within the Redcloud Peak study area and, because deposits of this type form close to the surface, none are expected within the study area. However, it is geologically possible that other Cu-Mo mineralized calc-alkaline stocks occur at depth along the eastern margin of the study area, if the pluton inferred from geophysical data does indeed exist. No geologic evidence of any porphyry-type mineralization was found associated with the resurgent quartz syenite or rhyolite intrusions.

In the northwest corner of the study area, alteration and widely disseminated porphyry-type mineralization associated with monzonitic rocks in the Capitol City area (Slack, 1980; Steven and others, 1977) predated formation of the Lake City caldera, as shown by the incorporation of altered rock locally within the megabreccia of the Lake City caldera (Lipman and others, 1976). No altered or mineralized rock was found associated with the monzonitic intrusion near Williams Creek inside of the study area (Map B). However, some altered and pyritized rock occurs to the south of this intrusion in Cascade Gulch around a small plug (Lipman, 1976a).

GEOLOGY OF THE HANDIES PEAK WILDERNESS STUDY AREA

The Handies Peak Wilderness Study Area encompasses part of the San Juan caldera, as well as the southwestern edge of the Lake City caldera (fig. 1). The area between these two calderas is marked by faulted blocks of Proterozoic granite (Map C) (Lipman, 1976a), which represent the remnants of the septum dividing the San Juan and Uncompahgre calderas (fig. 2) (Lipman and others, 1973).

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

Only one intrusive body, a small dike southeast of Handies Peak (Map C), was identified within the study area. The dike is a quartz- and sanidine-bearing dacite, similar to dacites dated between 22 and 24 m.y. in the vicinity of Red Mountain and Engineer Passes (Lipman and others, 1976).

Northeast-trending faults of the Eureka graben dominate the structure within the Handies Peak study area (Map C) (Lipman, 1976a). These faults are truncated by the ring fault of the younger Lake City caldera on the eastern side of the study area. On the southern side of the study area, many of the faults trend northwest, perpendicular to the orientation of the Eureka graben. These faults are probably related to extension parallel to the longitudinal axis of the Uncompahgre-San Juan caldera resurgent dome and are best developed on the flanks of this structure (Map C) (Lipman, 1976a). With the exception of the ring fault, no large faults were identified in the part of the Lake City caldera inside of this study area.

Drainages within the Handies Peak study area define a circular pattern, which extends along the Lake Fork Gunnison from Burrows Park up through American Basin and down Boulder Gulch, and then along Campbell Creek until it reconnects with the Lake Fork (Map C). Structural and stratigraphic evidence indicate that the fill of the Lake City caldera within the Handies Peak study area has been domed upwards separately from the main resurgent dome. In this area the lower member of the

Sunshine Peak Tuff is tilted toward the Lake Fork Gunnison River, which follows the axis of a structural terrace in Burrows Park southward into a well-defined synclinal axis (Map A and B). These structures may result from a zone of flexure between block uplift along the ring fault and doming within the interior of the Lake City caldera during resurgence. The large fault blocks of the granite of Cataract Canyon were uplifted significantly either late in the resurgence of the Uncompahgre-San Juan caldera or afterwards, because the bounding faults truncate postcollapse lavas within the Eureka graben (Map C) (Lipman, 1976a). However, relationships within the fill of the San Juan caldera in the study area show no conclusive evidence for significant faulting or doming unrelated to resurgence of the Uncompahgre-San Juan caldera complex (Map C) (Lipman, 1976a).

A large gravity high covers much of the Handies Peak study area, although it is poorly constrained by the available data (Sanford and others, in press). The geometry of this anomaly suggests the presence of a shallow source with a density somewhat greater than 2.40 g/cm^3 (the value used to reduce the data) in the vicinity of Handies Peak (Sanford and others, in press; Grauch and Campbell, 1985). The thick section of Picayune Megabreccia Member of the Sapinero Mesa Tuff, which is exposed on Handies Peak, is composed of large blocks of dense andesitic lavas (as much as 1 mi long) (Lipman, 1976a, b) that could easily account for the observed density contrast. Although there are some topographic, geologic, and geophysical suggestions that the Handies Peak area was domed upward independently of caldera related processes, no unambiguous geologic or geophysical evidence substantiates this hypothesis.

Quartz veins occur along faults throughout the Handies Peak Wilderness Study Area (Map C). Most veins lie within the Eureka graben and represent the continuation of a vein system that is highly mineralized 5 mi to the southwest of the study area (Burbank and Luedke, 1969; Casadevall and Ohmoto, 1977). Although most of these faults were formed during resurgence of the Uncompahgre-San Juan caldera cycle, mineralization did not occur until 5-10 m.y. after the Lake City caldera cycle (Lipman and others, 1976). This interpretation is supported by results of this study, as no vein material was found within the collapse breccias in the western part of the Lake City caldera adjacent to the Eureka graben. In addition, a mineralized vein within the Lake City caldera south of Burrows Park appears to extend across the ring fault as a set of weakly mineralized fractures cutting the granite of Cataract Canyon (Map C).

The Eureka and Picayune Megabreccia Members of the Sapinero Mesa Tuff host most major veins within the study area. A few veins continue into the granite of Cataract Canyon or occur adjacent to mafic dikes cutting this unit (Map C) (Lipman, 1976a). Discontinuous mineralized intervals are also present along the ring fault of the Lake City caldera. Dacite lavas of the Burns Member of the Silverton Volcanics, which host all of the large polymetallic vein deposits within the San Juan and Silverton calderas (fig. 2) (Varnes, 1963; Burbank and Luedke, 1969; Casadevall and Ohmoto, 1977), occur only within small downfaulted blocks in the Handies Peak study area (Map C) (Lipman, 1976a).

Nearly 50 veins were identified within the Handies Peak study area (Map C). Most veins are less than 2,000 ft long, although about one quarter of them are longer and several can be traced for almost 1 mi (Map C). Vein widths are commonly 5-10 ft, but range from 1 to 30-40 ft. The structure and quartz filling of these veins is similar to that in the Redcloud Peak study area, although many of the veins have been rebrecciated (Korzeb, 1986). Almost all of the veins within the Handies Peak study area are pyritic, and many contain disseminated base-metal sulfides. Barite occurs in some veins and tetrahedrite was identified at a few localities by Korzeb (1986). Hydrothermal alteration is generally confined to narrow (less than 5-10 ft) envelopes around the veins, although silicification is widespread around veins in the saddle between Whitecross Mountain and Handies Peak (Map C).

Dikes of 17.5-m.y.-old high-silica rhyolite are associated with mineralized pebble dikes and uranium-mineralized fractures 1 mi south of the study area (Map C). Similar rhyolite and unmineralized pebble dikes also occur farther to the south along Cuba Gulch (A. R. Kirk, unpub. data). The rhyolite dikes are typically strongly hydrothermally altered, as is the surrounding granite, and are cut by thin (less than 0.05 in.) veinlets of microaplitic quartz, pyrite, and sericite. These rocks have many of the characteristics of mineralized molybdenum porphyry systems elsewhere (White and others, 1981). However, similar intrusions or pebble dikes are not thought to occur within the study area.

CONCLUSIONS

Mineralizing processes operated throughout the Redcloud Peak and Handies Peak Wilderness Study Areas. Numerous quartz veins and areas of hydrothermally altered rock occur in both study areas (Maps B and C), and areas with geologic characteristics of porphyry-type and possibly breccia-pipe deposits were identified within the Redcloud Peak study area. Although a large alunite deposit is present within 2 mi of the Redcloud Peak study area (Map B), similar alunitization is absent in the study area.

REFERENCES CITED

Bove, D. J., 1984, Geology and hydrothermal alteration of the Red Mountain alunite deposit, Lake City, Colorado [abs.]: Geological Society of America Abstracts with Programs, v. 16, no. 4, p. 216.

Bromfield, C. S., 1967, Geology of the Mount Wilson quadrangle, western San Juan Mountains, Colorado: U.S. Geological Survey Bulletin 1227, 100 p.

Burbank, W. S., 1940, Structural control of ore deposition in the Uncompahgre district, Ouray County, Colorado, with suggestions for prospecting: U.S. Geological Survey Bulletin 906-E, p. 189-265.

Burbank, W. S., 1941, Structural control of ore deposition in the Red Mountain, Sneffels, and Telluride districts of the San Juan Mountains, Colorado: Colorado Scientific Society Proceedings, v. 14, no. 5, p. 141-261.

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

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

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

Dings, McClelland, 1941, Geology of the Stony Mountain stock, San Juan Mountains, Colorado: Geological Society of America Bulletin, v. 52, p. 695-720.

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

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

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

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

High Life Helicopters/QEB, 1981, Contour maps of uranium, uranium/thorium ratio, and total field magnetics, Lake City area, San Juan Mountains, Colorado: U.S. Geological Survey Open-File Report 81-568, 22 p.

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

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

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

Jackson, S. E., Harmon, R. S., Lux, D. R., Rice, C. M., and Ringrose, C. R., 1980, Isotope geochemistry and chronology of porphyry-style mineralization near Ophir, San Juan Mountains, Colorado [abs.]: Geological Society of America Abstracts with Programs, v. 12, p. 454.

Kelley, V. C., 1957, General geology and tectonics of the western San Juan Mountains, Colordo: New Mexico Geological Society Guidebook, 8th Field Conference, p. 154-162.

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

Krasowski, D. J., 1976, Geology and ore deposits of Burrows Park, Hinsdale County, Colorado: Fort Collins, Colo., Colorado State University, M.S. thesis, 111 p.

Kunk, M. J., Sutter, J. F., and Naeser, C. W., 1985, High-precision $^{40}Ar/^{39}Ar$ ages of sanidine, biotite, hornblende, and plagioclase from the Fish Canyon Tuff, San Juan volcanic field, south-central Colorado [abs.]: Geological Society of America Abstracts with Programs, v. 17, no. 7, p. 636.

Larsen, E. S., and Cross, Whitman, 1956, Geology and petrology of the San Juan region, southwestern Colorado: U.S. Geological Survey Professional Paper 258, 303 p.

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

Lipman, P. W., 1975, Evolution of the Platoro caldera complex and related volcanic rocks, southeastern San Juan Mountains, Colorado: U.S. Geological Survey Professional Paper 852, 128 p.

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

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

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

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

Lipman, P. W., Steven, T. A., Luedke, R. G., and Burbank, W. S., 1973, Revised volcanic history of the San Juan, Uncompahgre, Silverton, and Lake City calderas in the western San Juan Mountains, Colorado: U.S. Geological Survey Journal of Research, v. 1, no. 6, p. 627-642.

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

Luedke, R. G., and Burbank, W. S., 1968, Volcanism and cauldron development in the western San Juan Mountains, Colorado, in Epis, R. C., ed., Cenozoic volcanism in the southern Rocky Mountains: Colorado School Mines Quarterly v. 63, no. 3, p. 175-208.

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

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

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

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

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

Sanford, R. S., Grauch, R. I., Hon, Ken, Bove, D. J., Grauch, V. J. S., and Korzeb, S. L., in press, Mineral resources of the Redcloud Peak and Handies Peak Wilderness Study Areas, Hinsdale County, southwestern Colorado: U.S. Geological Survey Bulletin 1715-B.

Slack, J. F., 1980, Multistage vein ores of the Lake City district, western San Juan Mountains, Colorado: Economic Geology, v. 75, no. 7, p. 963-991.

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

Steven, T. A., Lipman, P. W., Fisher, F. S., Bieniewski, C. L., and Meeves, H. C., 1977, Mineral resources of study areas contiguous to the Uncompahgre primitive area, San Juan Mountains, southwestern Colorado: U.S. Geological Survey Bulletin, 1391-E, 126 p.

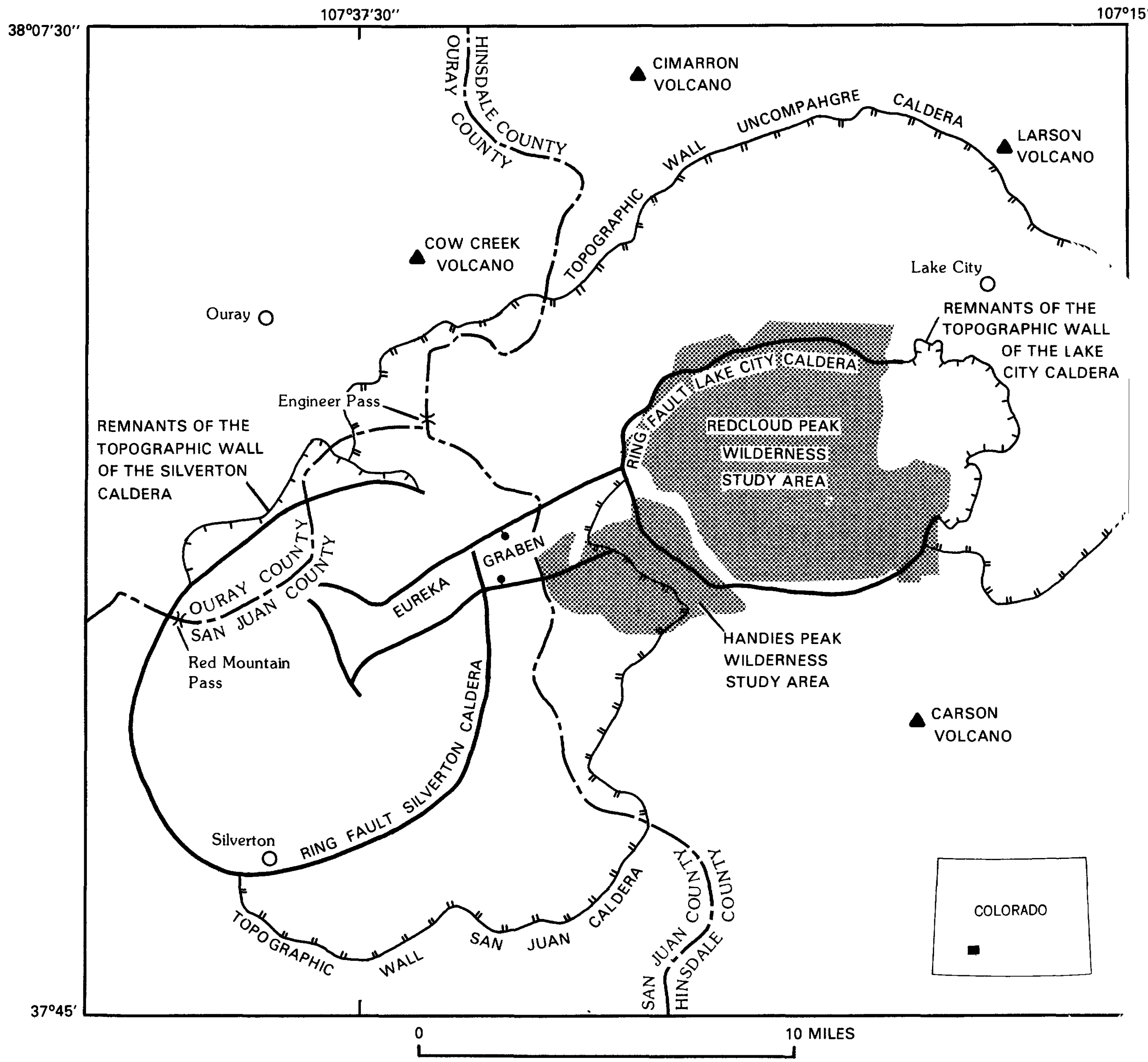
Steven, T. A., Lipman, P. W., Hail, W. J., Jr., Barker, Fred, and Luedke, R. G., 1974, Geologic map of the Durango quadrangle, southwestern Colorado: U.S. Geological Survey Miscellaneous Investigations Map I-764, scale 1:250,000.

Streckeisen, Albert, 1975, To each plutonic rock its proper name: Earth Science Reviews, v. 12, p. 1-33.

Varnes, D. J., 1963, Geology and ore deposits of the South Silverton mining district, San Juan County, Colorado: U.S. Geological Survey Professional Paper 378-A, 56 p.

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

Woolsey, L. H., 1907, Lake Fork extension of the Silverton mining area, Colorado: U.S. Geological Survey Bulletin 315, p. 26-30.



EXPLANATION

Fault—Bar and ball on downthrown side

FIGURE 1.--Index map showing location and geologic setting of the Redcloud Peak and Handies Peak Wilderness Study Areas, western San Juan Mountains, Colorado. (Modified from Lipman, 1976a.)

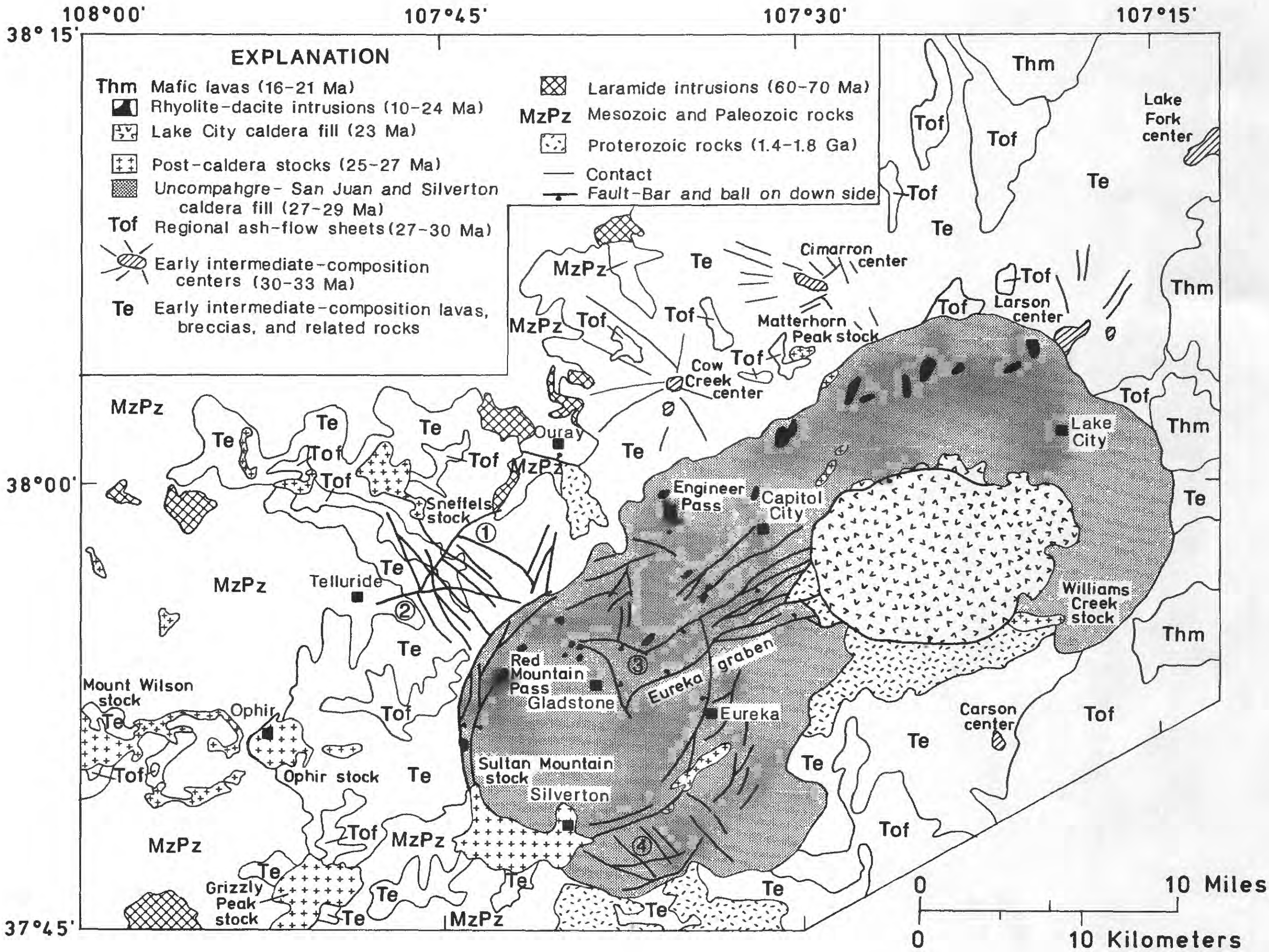


FIGURE 2.--Generalized geologic map of the western San Juan Mountains, Colorado. Numbered localities are principal mines: 1, Camp Bird; 2, Idarado; 3, Sunnyside; 4, Shenandoah-Dives. (Modified from Burbank and Luedke, 1969; Steven and others, 1974, 1977; Casadevall and Ohmoto, 1977.)