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RECONNAISSANCE GEOLOGY AND ECONOMIC SIGNIFICANCE OF THE PLATORO CALDERA, SOUTHEASTERN SAN JUAN MOUNTAINS, COLORADO*

by

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Recent U.S. Geological Survey investigations of volcanic rocks of the San Juan Mountains have led to recognition of numerous caldera-collapse structures (fig. 1) related to eruption of voluminous ash-flow tuffs in Oligocene time (Luedke and Burbank, 1968; Steven and Ratté, 1965; Steven and Lipman, 1968). It has also become clear that most major ore deposits of the San Juan Mountains, such as those near Creede, Silverton-Telluride-Ouray, and Lake City, are closely associated with calderas (Burbank and Luedke, 1968; Steven, 1968). An apparent exception to this association between mineralization and caldera structure seemed until recently to be the Summitville-Platoro district in the southeastern San Juan Mountains (Steven and Ratté, 1960; Steven, 1968). This paper gives a preliminary description of the newly recognized Platoro caldera and the associated mineral deposits, including those in the Summitville district.

GEOLOGIC SETTING

The San Juan volcanic field, which covers about 25,000 km^2 in southwestern Colorado and adjacent parts of New Mexico (fig. 1), is the largest erosional remnant of a once nearly continuous volcanic field that extended over much of the southern Rocky Mountains in Oligocene and later time (Steven and Epis, 1968). Throughout the San Juan remnant of this field, the general volcanic sequence was relatively simple: initial intermediate lavas and breccias, followed closely in time by more silicic ash-flow tuffs, and ending with a compositionally bimodal association of basalt and rhyolite (Lipman and Steven, 1969).

In the San Juan field voluminous early intermediate-composition lavas and breccias—mainly alkali andesite, rhyodacite, and mafic quartz latite—were erupted from numerous scattered central volcanoes onto an eroded tectonically stable terrane. They formed mostly during the interval 35-30 m.y. (million years) ago (Lipman and others, 1970).

About 30 m.y. ago, major volcanic activity changed to explosive ash-flow eruptions of quartz latite and low-silica rhyolite that persisted until about 26 m.y. ago. Source areas for the ash flows are marked by large calderas. Two groups of lavas and associated rocks of intermediate composition intertongue with the ash-flow sequence: (1) quartz latitic lavas that were erupted in and adjacent to caldera structures and are genetically related to the ash-flow activity, and (2) other generally more mafic lavas and related rocks that are widely distributed without evident structural relation to the ash-flow eruptive centers. The second group apparently represents a continuation of the early intermediate activity into the period of major ash-flow eruption.

In Early Miocene the character of volcanism changed notably. Whereas the Oligocene volcanics are predominantly intermediate lavas and related silicic differentiates, the younger rocks are largely a bimodal association of basalt and high-silica alkali rhyolite. Basalt and minor rhyolite were erupted intermittently through the Miocene and Pliocene, and at one time formed a widespread veneer over the older volcanic terrane.

ROCK UNITS

The stratigraphy of the Platoro caldera area is most readily summarized in terms of (1) precaldera intermediate-composition lavas and related rocks of the Conejos Formation, (2) ash-flow sheets of the Treasure Mountain Tuff erupted from the Platoro caldera, (3) lavas and intrusions related to the Platoro caldera, (4) younger ash-flow sheets from calderas farther northwest, and (5) basalt and rhyolite of the Hinsdale Formation.

CONEJOS FORMATION

All pre-caldera rocks in the Summitville-Platoro area are parts of the Conejos Formation (Larsen and Cross, 1956). This unit consists largely of lava flows and breccias that range in composition from calc-alkalic andesite to mafic quartz latite, and also contains varied volcaniclastic rocks, mainly of mudflow origin. Most rocks of the Conejos Formation were erupted in middle Oligocene time from numerous widely scattered central volcanoes, at least three of which contributed to the accumulation within the area of Figure 2. Conejos rocks in the east half of the mapped area are predominantly lavas and flow breccias, whereas the bulk of the formation southwest of the Platoro caldera consists of bedded breccias and conglomerates with minor intercalated flows.

TREASURE MOUNTAIN TUFF

The Treasure Mountain Tuff is here redefined from the Treasure Mountain Rhyolite (Larsen and Cross, 1956) to

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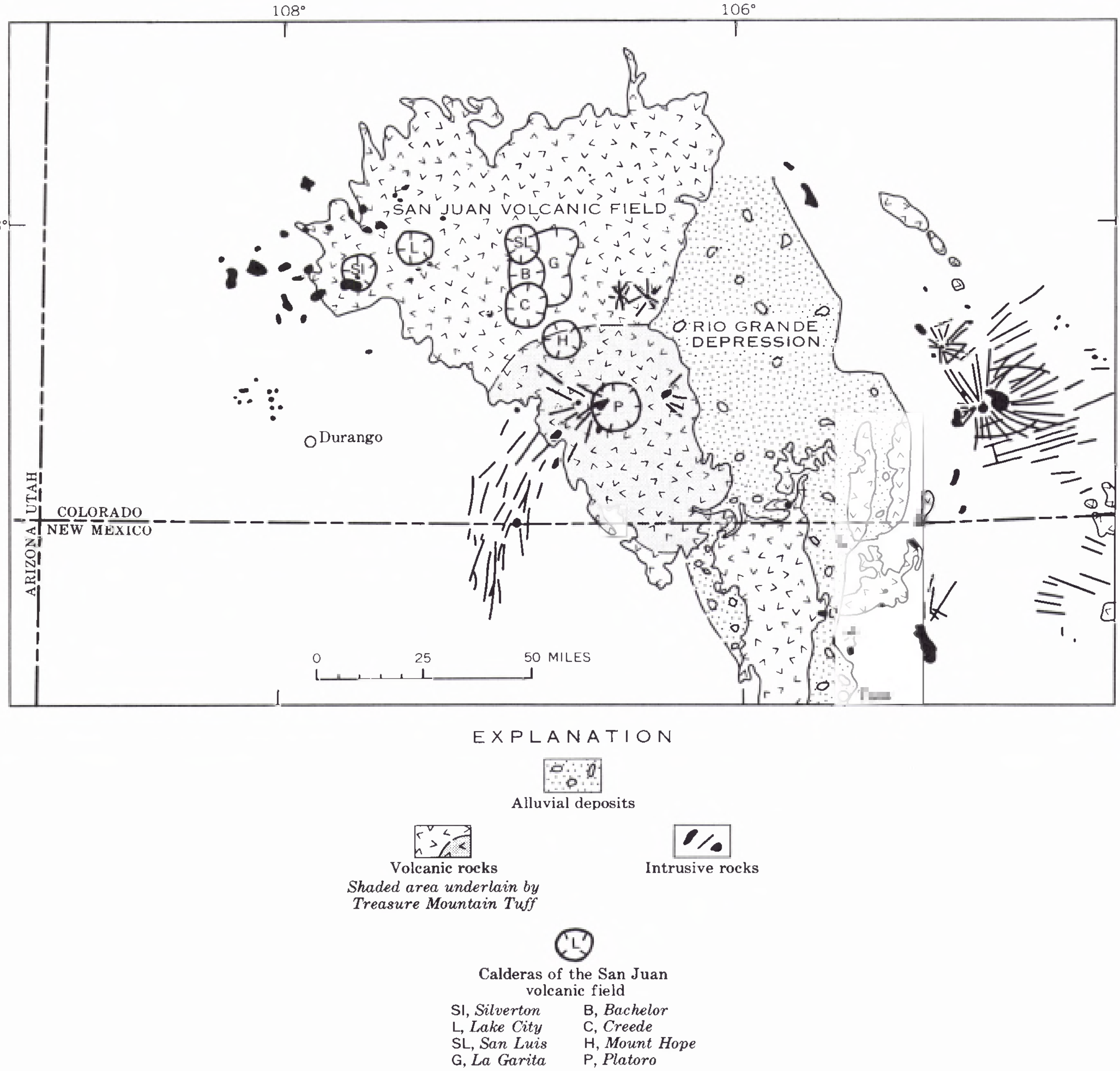
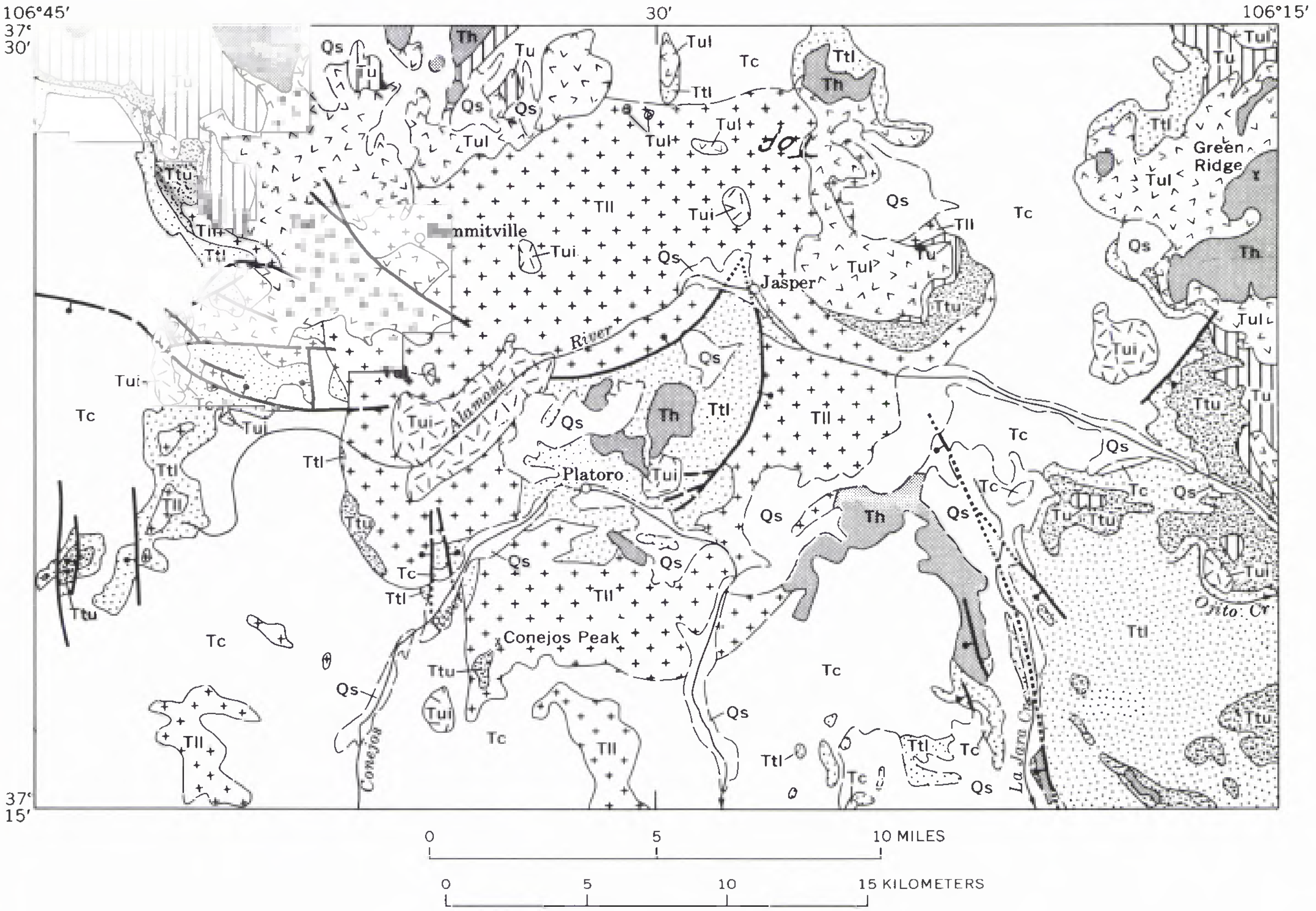


FIGURE 1.

Index map showing location of the San Juan volcanic field, calderas of the San Juan Mountains, and distribution of ash-flow tuffs erupted from the Platoro caldera. In part modified from Cohee (1961).

include only the units present at the type locality at Treasure Mountain, approximately 20 km west of Summitville, Colo., plus additional intertonguing tuffs farther to the south. Excluded from the Treasure Mountain Tuff are thick sections of other welded ash-flow tuffs that were mapped as Treasure Mountain Rhyolite in the western and central San Juan Mountains by Larsen and Cross (1956, pl. 1). The largest body of these in the western San Juan Mountains was designated the Gilpin Peak Tuff by Luedke and Burbank (1963). As redefined, the Treasure Mountain Tuff is a coextensive assemblage of ash-flow tuffs, largely or entirely related to the Platoro caldera. Three large ash-flow sheets in the Treasure Mountain Tuff that have been mapped over nearly 5,000 km^2 are formally designated members in this report: the La Jara Canyon, Ojito Creek, and Ra Jadero Members, in ascending order. Less widespread air-fall and ash-flow tuffs below the La Jara Canyon Member, between the La Jara Canyon and Ojito Creek Members, and above the Ra Jadero Member are informally designated the lower, middle, and upper tuffs, respectively.

The La Jara Canyon Member is a multiple-flow, compound cooling unit of phenocryst-rich quartz latite that



EXPLANATION

Qs — Quaternary surficial deposits

Miocene and Pliocene

Th — Hinsdale Formation

Oligocene — TERTIARY

Tu — Undifferentiated younger ash-flow sheets

Tul, Tui — Upper lavas and intrusives
Tul, *quartz latite and rhyolite flows*
Tui, *quartz monzonite and granodiorite intrusives*

Treasure Mountain Tuff

Ttu — Upper Part
Ra Jadero Member, middle tuff, and Ojito Creek Member

Tll — Lower lavas
Andesite and rhyodacite; underlie and overlie upper part (Ttu)

Ttl — La Jara Canyon Member

Tc — Conejos Formation
Andesitic and rhyodacitic lava

Contact
Dashed where approximately located

Fault
Dashed where approximately located; dotted where covered. Bar and ball on downthrown side

FIGURE 2.

Generalized geologic map of the Platoro caldera area.

makes up the first widespread ash-flow sheet in the eastern and central San Juan Mountains; eruption of these ash-flows resulted in the first major collapse of the Platoro caldera. At its type locality in La Jara Canyon (37°10′ N., 106°20′ W.), about 27 km southeast of Platoro, this sheet is about 100 m thick (fig. 3), and its maximum thickness outside the Platoro caldera is about 300 m. Within the caldera it is much thicker; near Jasper (fig. 2), where its top is eroded and its base is not exposed, it is more than 800 m thick. The original total volume of the La Jara Canyon Member was more than 500 km^3 and possibly more than 1,000 km^3.

Tuff in the La Jara Canyon Member contains 20-40 percent phenocrysts, mostly plagioclase, accompanied by some biotite, augite, and opaque oxides. Silica content is 65-70 percent. La Jara Canyon within the Platoro caldera is somewhat different from the outflow tuffs that occur outside the caldera: it is lower in silica, contains more phenocrysts, and is propylitically altered. The K-Ar radiometric age of the La Jara Canyon Member at Treasure Mountain is 29.8 m.y. (mean of biotite and plagioclase; Lipman and others, 1970, table 3, No. 1). The tuff is everywhere characterized by reversed magnetic polarity, as indicated by about 25 field determinations.

Outside the Platoro caldera the La Jara Canyon Member is generally separated from the Ojito Creek Member by

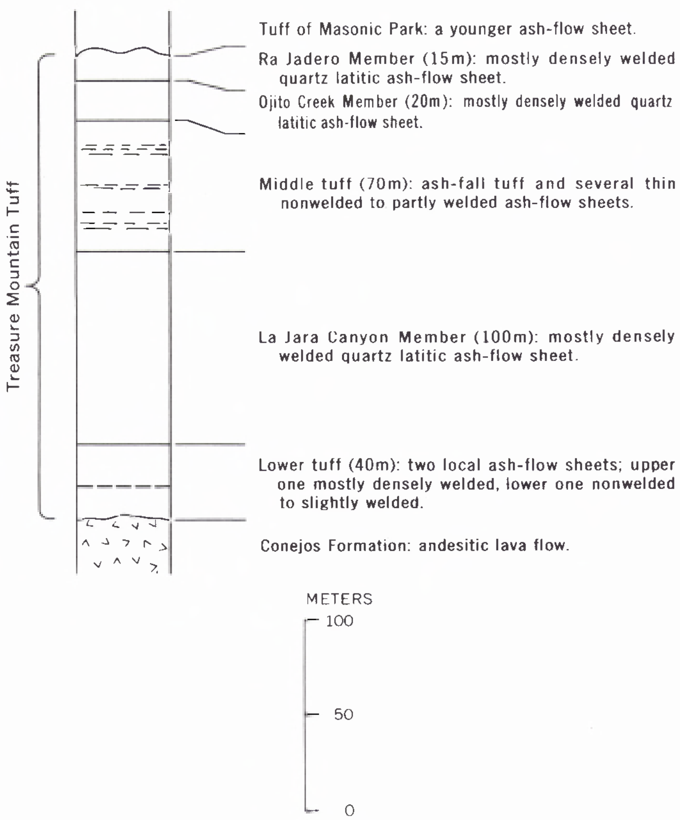


FIGURE 3.

Columnar section of the Treasure Mountain Tuff at La Jara Canyon.

the middle tuff, consisting of 10-70 m of ash-fall and weakly welded ash-flow tuff that is almost everywhere poorly exposed.[1]

The Ojito Creek and Ra Jadero Members are relatively thin widespread ash-flow sheets of similar petrography and megascopic appearance; accordingly, they are described together and combined with the middle tuff in Figure 2. Each is typically 10-20 m thick (fig. 3), dark brown where densely welded, and quartz latitic in composition. The initial volume of the two sheets together was probably about 100 km^3. The Ra Jadero Member is virtually coextensive with the La Jara Canyon Member; the Ojito Creek Member does not extend as far north and is missing from the type section of the formation at Treasure Mountain. Both members are well exposed together in their respective type localities: at the head of Ojito Creek (37°20′ N., 106°17′ W.), about 22 km east of Platoro, and in the Ra Jadero Canyon (37°14′ N., 106°16′ W.), about 26 km miles southeast of Platoro.

The Ojito Creek and Ra Jadero Members contain 10-15 percent phenocrysts, and are distinctly less crystal rich than the La Jara Canyon Member. Plagioclase is the major phenocryst constituent in both, accompanied by augite and opaque oxides. The Ra Jadero Member, unlike other tuffs in the Treasure Mountain, contains fairly abundant sanidine. The Ojito Creek Member has normal magnetic polarity; the Ra Jadero Member is reversed. These rocks have not yet been dated radiometrically, but relations to other dated units in the area suggest that they are no more than about 1 m.y. younger than the La Jara Canyon Member (29.8 m.y.).

LAVAS AND INTRUSIONS OF THE CALDERA

Lavas related to the Platoro caldera are generally divisible into two groups: older nonporphyritic dark-gray to black andesite and rhyodacite (lower lavas, fig. 2), and younger more silicic lavas (upper lavas, fig. 2), mostly light-gray rhyodacite and quartz latite that characteristically contain large feldspar phenocrysts as well as biotite and augite or hornblende.

The dark older lavas flooded the caldera moat to overflowing shortly after the core of the caldera was resurgently domed; they are more than 700 m thick at Conejos Peak in the southern part of the caldera. The obscurity of contacts at caldera walls between these flows and petrographically similar lavas of the Conejos Formation has contributed to the delayed recognition of the Platoro caldera. Although the dark lavas were correctly described as overlying the Treasure Mountain Rhyolite in the Platoro-Summitville area by Patton (1917, p. 36), who designated them the Summitville Andesite, they were mistakenly assigned to the Conejos Formation by Larsen and Cross (1956, p. 36), who also considered the Treasure Mountain Tuff inside the Platoro caldera to represent an older part of the Conejos Formation (p. 101-102). Steven and Ratté (1960)

[1]The lower and upper tuffs, of similar lithology, are not well developed within the area of Figure 2. Thick lower tuffs are present a few kilometers to the south, at La Jara Canyon (fig. 3).

and Calkin (1967) followed Larsen and Cross in assigning the dark lavas, including those at Conejos Peak, to the Conejos Formation.

The younger porphyritic lavas occur in a broad zone along the north side of the Platoro caldera from Summitville to Green Ridge (fig. 2); they are remnants of a partial ring of caldera-margin lava domes. The lavas at Summitville were, until recently, assigned to the Fisher Quartz Latite (Larsen and Cross, 1956, p. 172; Steven and Ratté, 1960), but Steven and Ratté (1965, p. 43-44) later restricted use of this formational name to late lavas and breccias localized around the Creede caldera. The Summitville-Green Ridge assemblage occupies a similar position with respect to the Platoro caldera, and was erupted independently of the type Fisher Quartz Latite. K-Ar ages of porphyritic lavas of the Summitville-Green Ridge zone range from 27.8 to 20.2 m.y., but the distribution of certain younger ash-flows tuffs suggests that most of these lavas were erupted in a relatively brief interval close to the older date (Lipman and others, 1970), and are largely Oligocene in age.

Several fine- to medium-grained granodioritic to quartz monzonitic stocks within and near the Platoro caldera appear to be genetically related to the lava-flow activity at this center. The largest granitic body, the Alamosa River stock, intrudes the dark lavas that filled the moat of the resurgent Platoro caldera, but relations with its alteration halo indicate that at least some of the upper lavas are younger (Steven and Ratté, 1960, p. 38). Dikes that are petrographically similar to the porphyritic lavas define an incomplete radial pattern around this stock (fig. 4), indicating closely associated activity. The Alamosa River stock has yielded a K-Ar age of 29.1 m.y., in good agreement with the other geologic relations (Lipman and others, 1970).

Undivided younger ash-flow sheets

Younger ash-flow sheets that were erupted from calderas farther north in the San Juan volcanic field (fig. 1) are present within the mapped area (fig. 2) around the north side of the Platoro caldera and locally within the caldera. Units present but not shown separately include the tuff of Masonic Park (Lipman and others, 1970) erupted from the Mount Hope caldera (fig. 1), Fish Canyon Tuff (Olson and others, 1968) erupted from the La Garita caldera, Carpenter Ridge Tuff (Olson and others, 1968) erupted from the Bachelor caldera, Wason Park Rhyolite (Ratté and Steven, 1967) erupted from the Creede caldera area, and Snowshoe Mountain Quartz Latite (Ratté and Steven, 1967) erupted from the Creede caldera.

Hinsdale Formation

The last volcanic activity in the Summitville-Platoro area is represented by the Hinsdale Formation, which consists of alkalic olivine basalt, basaltic andesite, and small scattered plug domes of silicic alkali rhyolite. These rocks probably range widely in age and are not closely related in origin to the Platoro caldera. Basalt and rhyolite from Beaver Creek, just north of the area of Figure 2, have yielded K-Ar ages of 23.4 and 21.9 m.y., respectively, but other Hinsdale basalts in the southeastern San Juan Mountains are as young a 5 m.y. (Lipman and others, 1970).

STRUCTURAL EVOLUTION OF THE PLATORO CALDERA

Before ash-flow eruptions began in the southeastern San Juan Mountains, the central volcanoes of the Conejos Formation had been extensively eroded and the intervening basins filled with the resultant detritus, producing a widespread surface of low relief. As a result, phenocryst-rich quartz latitic ash-flows from sources in the Summitville-Platoro region were able to spread 30-40 km in all directions, depositing the La Jara Canyon Member of the Treasure Mountain Tuff.

Collapse of a subcircular block about 20 km in diameter began before completion of these eruptions, with the result that the later ash-flows of the Jara Canyon Member were ponded and accumulated to a thickness in excess of 800 m within the caldera. These later tuffs were somewhat more mafic and phenocryst rich than the initially erupted tuff of the widespread thin outflow sheet, reflecting differentiation in the source magma chamber similar to that described for other ash-flow deposits in the San Juan Mountains and elsewhere (Ratté and Steven, 1964; Lipman and others, 1966). The concurrent eruption and collapse at the Platoro caldera clearly differ from those of some other carefully studied areas such as the Valles caldera in New Mexico, where the last erupted units are no thicker inside the caldera than outside, demonstrating that eruption was virtually complete before major subsidence occurred (Smith and Bailey, 1968, p. 638). Other calderas in which thick intracaldera accumulations of ash-flow tuff demonstrate collapse contemporaneous with eruption have been recognized in the San Juan Mountains (Steven and Ratté, 1965, p. 59) and in southern Nevada (Christiansen and others, 1965; Byers and others, 1969). Collapse probably occurs concurrently only with ash-flow eruptions of very large volume; in some such eruptions initial collapse appears to have coincided approximately with abrupt compositional changes in the zoned ash-flow sheets (Lipman and others, 1966, p. F24-F25; Byers and others, 1969, p. 86).

The thick tuffs of the La Jara Canyon Member within the Platoro caldera are topographically and structurally high as a result of resurgent doming (Smith and Bailey, 1968) shortly after collapse. Early resurgence is demonstrated by the presence of monolithologic talus breccias of the La Jara Canyon that intertongue with the caldera-filling moat lavas adjacent to the resurgent block. This block dips homoclinally to the southwest and is bounded on its north and east sides by normal faults of large displacement. Prior to disruption by these faults there may have existed a more complete structural dome such as characterizes most resurgent cauldrons (Smith and Bailey, 1968).

The dark andesitic lavas (lower lavas of fig. 2) within the Platoro caldera filled the moat after resurgence was virtually complete, and they lap unconformably onto the uplifted central block. A minimum figure for the amount of collapse

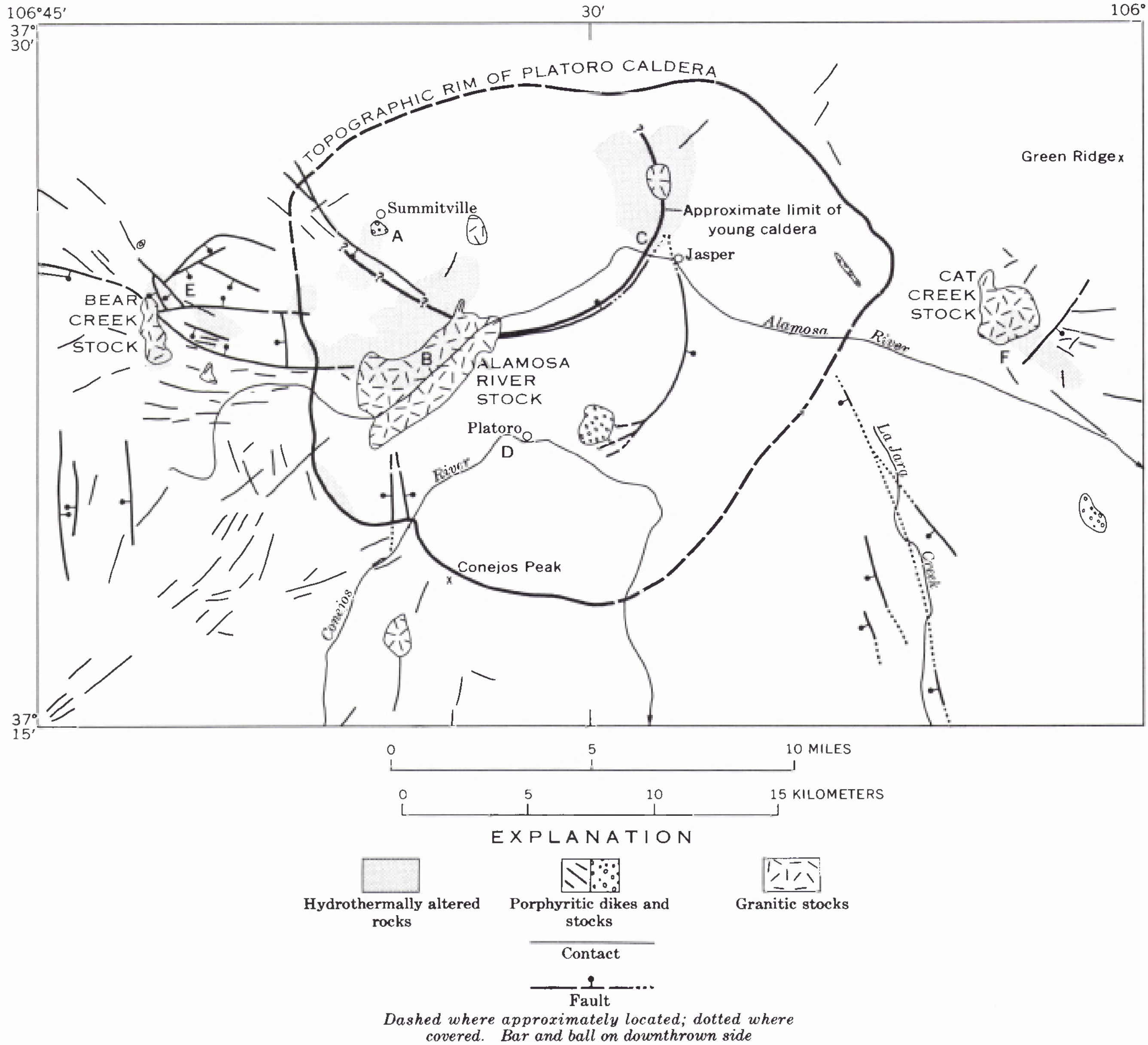


FIGURE 4.

Map showing stocks, dikes, faults, and areas of extensive hydrothermal alteration in the vicinity of the Platoro caldera. A—Summitville district; B—Stunner and Gilmore districts; C—Jasper district; D—Platoro district; E—Crater Creek area; and F—Cat Creek area.

of the Platoro caldera is 1,500 m, as shown by the thickness of these lavas in the caldera moat (about 700 m on Conejos Peak) and the thickness of the La Jara Canyon Member within the caldera (about 800 m with the top eroded and the base not exposed). These andesitic lavas, in essence, represent a continuation of the same type of volcanic activity that characterized the Conejos Formation, with which they are readily confused in the field. Continued andesitic volcanic activity during ash-flow eruptions characterizes other portions of the San Juan volcanic field as well, and this relation is significant in reconstructing the petrologic evolution of the volcanic field (Lipman and Steven, 1969).

Upper tuffs of the Treasure Mountain, including the Ojito Creek and Ra Jadero Members, were erupted after the moat of the early, resurgent part of the Platoro caldera was nearly completely filled by andesitic lavas, as these tuffs are found within the caldera only in a few places above thick accumulations of andesitic lavas (fig. 2). The Ojito Creek and Ra Jadero tuffs are nearly coextensive with the La Jara Canyon Member and must have been erupted from the same general area. Although the volumes of these upper two members are much less than the La Jara Canyon, on the order of 50 km^3 each, they are sufficiently large to indicate the likelihood of associated caldera collapse (Smith, 1960, fig. 3). Several features suggest the probability of late collapse related to these tuffs within the northwestern part of the Platoro caldera (fig. 4), although this extensively altered area is not fully understood at the present preliminary stage of study. In this area the arcuate northeast-trending fault that truncates the central resurgent block of La Jara Canyon Tuff (fig. 4) has a displacement of more than 800 m in a direction plausible as a younger caldera-margin fault. The andesitic lavas inside the proposed late caldera differ somewhat from those in other parts of the Platoro caldera: as noted by Steven and Ratté (1960, p. 11), they are exceptionally thick, poorly stratified, and highly brecciated. Although not differentiated on the preliminary map (fig. 2), these flows are probably younger than andesitic lavas in other parts of the Platoro caldera and postdate late collapse related to eruption of the upper two members of the Treasure Mountain Tuff.

Extrusion of the porphyritic (upper) lavas and intrusion of dikes and granitic stocks following collapse and filling of the younger caldera constitute the last phase of igneous activity related to the compound Platoro caldera. The existing area of porphyritic lavas represent remnants of an arc of lava domes around the north side of the Platoro caldera. These lavas may originally have been widely distributed farther to the south as well, having been fed by the numerous dikes and stocks southwest and east of the Platoro caldera (fig. 4), but now completely removed by erosion. Many of the stocks and dikes are petrographically similar to the porphyritic lavas, and they appear to have been emplaced at about the same time. The radiometric age of the Alamosa River stock (29.1 m.y.) is only slightly younger than the La Jara Canyon Member (29.8 m.y), even though this stock is clearly later than the boundary fault of the late caldera. The Bear Creek stock in the western part of the mapped area (fig. 4) is petrographically similar to the Alamosa River stock, but is later than some of the porphyritic lavas, inasmuch as it intrudes a complex graben of several faults which displace these lavas (fig. 2). This structure is clearly a radial graben related to the Platoro caldera.

MINERALIZATION RELATED TO THE PLATORO CALDERA

Recognition of the Platoro caldera, and of the general sequence of igneous events related to its development, has provided at least partial answers to many puzzling questions of long standing concerning the localization of the mineral deposits in the Summitville mining district and nearby mineralized areas. Earlier studies either were done before the concepts of ash-flow tuffs and associated calderas were developed (Patton, 1917) or were too limited in scope for the regional picture to be discerned (Steven and Ratté, 1960; Calkin, 1967). The preliminary summary by Steven (1968, p. 712-713) clearly reflects the uncertainties concerning localization both of the igneous centers and of related hydrothermal activity in the Summitville area.

We now know that the mineralization at Summitville and in certain nearby areas is closely related to intrusive and extrusive centers localized along margin ring structures formed during compound subsidence of the Platoro caldera, and outlying mineralization was controlled mainly by outward-extending fracture zones. The localization is thus closely comparable to that of other highly mineralized areas in the central and western San Juan Mountains (Steven, 1968; Burbank and Luedke, 1968), and it is instructive to consider other possibly analogous features that may bear on the mineral potential of this generally poorly explored area.

SUMMITVILLE AND JASPER DISTRICTS

As described by Steven and Ratté (1969), gold-silver-copper ore in the Summitville district was deposited in a very shallow volcanic environment within a then recently erupted volcanic dome of coarsely porphyritic quartz latite. The ore occurs in intensely altered pipes and irregular tabular masses of quartz-alunite rock that replaced the quartz latite along northwest-trending fracture zones. Metallic minerals, chiefly pyrite and enargite, fill irregular vugs that formed by local intense leaching of the quartz-alunite rock. The quartz-alunite masses are surrounded successively by soft argillically altered envelopes (illite-kaolinite zone) and by pervasively propylitized rock (montmorillonite-chlorite zone). The alteration was interpreted to have resulted from shallow solfataric activity similar to that associated with recent volcanic activity.

The alteration and mineralization at Summitville represents a late stage of a sequence of related igneous and hydrothermal episodes along the southwest margin of the younger collapse structure within the compound Platoro caldera (fig. 4). To the south and southeast, along the Alamosa River, a composite granodioritic to quartz monzonitic stock was intruded somewhat earlier, and much rock adjacent to the north margin of this stock was intensely altered. Calkin (1967, p. 123; 1968) noted that a small intrusive body (which he called the Alum Creek Porphyry) within the northern part of the Alamosa River stock is a focus of intense hydrothermal alteration. The subsidiary body contains locally anomalous quantities of several metals (Calkin, 1967, p. 144-146) and in places is cut by numerous closely spaced quartz veinlets containing abundant pyrite and sparse molybdenite (p. 146-147). As described by Patton (1917, p. 98-101), quartz-pyrite veins with ore shoots containing gold and silver tellurides were deposited locally in the Stunner and Gilmore districts within this mass of altered rock. According to W. N. Sharp of the U.S. Geological Survey (oral commun., 1969), these veins strike generally north-northwest and dip steeply. They are largely limited to the south side of the Alamosa River and do not penetrate the most intensely altered rock north of the river.

Some dikes and plugs of coarse porphyry similar to that in the quartz latite dome at Summitville cut both the intrusive mass and the adjacent altered rock, and these in turn were altered in various degrees (Calkin, 1967, p. 74). Sharp and Gualtieri (1968) described zoned anomalous concentrations of lead, copper, molybdenum, and zinc near one of these porphyry dikes.

The Jasper district, about 12 km east of Summitville, is a comparable area of intensely altered rock associated with a granitic stock. The district is localized along the east margin of the same younger collapse structure within the compound Platoro caldera, as are the Summitville, Stunner, and Gilmore districts. Quartz-pyrite veins with ore shoots containing gold and silver (Patton, 1917, p. 105-108) are localized along the south margin of the highly altered rocks.

The whole area from Summitville south across the Alamosa River and east to Jasper thus marks an area of recurrent intrusion, extrusion, and hydrothermal alteration and mineralization along a cauldron ring fault. The environment is similar to that in the intensely altered and mineralized Red Mountain district along the northwest margin of the Silverton cauldron in the western San Juan Mountains (Burbank, 1941; Burbank and Luedke, 1968). The analogy is even closer when the ores in the Summitville and Red Mountain districts are compared: pyrite and enargite are common in both districts, although numerous other ore minerals, including abundant sulfosalts of copper and silver, are present at Red Mountain. The gangues consist of pipelike masses of strongly leached silicified rock that formed by replacement of preexisting volcanic or shallow intrusive rocks in shallow solfataric environments.

PLATORO DISTRICT

Most veins in the Platoro district are persistent north-northwest-trending quartz-pyrite veins in the thick mass of La Jara Canyon Member within the early, resurgent part of the Platoro caldera. Local ore shoots on these veins containing gold telluride and silver sulfosalt minerals (Patton, 1917, p. 89-96) supplied most of the ore produced in early mining in the district. Most of the La Jara Canyon tuff exposed within the caldera is propylitically altered, apparently unrelated to the later ore deposition. Alteration related to mineralization is restricted to local argillic selvages along the quartz-pyrite veins.

The veins in the Platoro district are about on strike with some of the stronger veins in the Stunner district along the Alamosa River to the north, and the vein mineralogy in the two areas is closely similar. W. N. Sharp (oral commun., 1969) believes that the veins in the two districts are along the same fracture zone. The Platoro veins thus appear to follow radial fractures extending outward from the younger collapse structure in the compound Platoro caldera, and may be only incidentally located within the resurgent dome of the earlier cauldron. Ore deposits are uncommon within resurgent cores of other calderas in the San Juan Mountains, and the closest structural analogy to the Platoro district—the Creede district within the resurgent Bachelor caldera (fig. 1)—is primarily related to radial graben faults of the younger Creede caldera (Steven and Ratté, 1965).

CRATER CREEK AREA

Several conspicuous faults comprising a complex radial graben extend westward from the Platoro caldera (figs. 2, 4) and converge toward the north end of the Bear Creek granodioritic stock. Hydrothermally altered rock is apparent at places along these faults, and some rather extensive areas within the faulted zone and around the stock are pervasively altered. Numerous dikes of coarsely porphyritic quartz latite similar to the rock in the plug dome at Summitville fill subparallel fissures within and near the graben.

Shallow prospect pits are scattered through the faulted and discontinuously altered area, and the Crater Creek drainage area near the north end of the Bear Creek granodioritic stock is currently being explored (1967-70). According to Mr. William Ellithorpe of Monte Vista, Colo. (oral commun., 1969) and Mr. Harry V. Ellithorpe, Pueblo, Colo. (written commun., 1970), by the fall of 1969 this exploration had disclosed several veins ranging in width from less than a foot to more than 10 feet that contain significant quantities of lead, zinc, and silver. Through the courtesy of Mr. William Ellithorpe, we examined several selected high-grade samples of the vein consisting almost wholly of galena and sphalerite. As of October 1969, only a limited lateral extent of the vein had been explored.

A close analogy exists between the environment of the lead-zinc-silver vein along Crater Creek and that of the major producing base-metal veins in radial faults around the margins of the Creede caldera (Steven and Ratté, 1965) and the Lake City and Silverton cauldrons (Burbank and Luedke, 1968).

CAT CREEK AREA

An outlying stock of monzonite (Larsen and Cross, 1956, p. 110) is exposed in the Cat Creek drainage basin about 5 km east of the Platoro caldera (fig. 4). An extensive area including the southeastern part of the stock and adjacent volcanic rocks is pervasively altered. Numerous prospect pits and small shafts were noted during reconnaissance mapping, but the altered rock was not examined closely. We know of no recorded production from this area, but its possible mineral potential is not known.

CONCLUSIONS AND ECONOMIC SIGNIFICANCE

The altered and mineralized areas near Summitville and Platoro in the southeastern San Juan Mountains are localized within and adjacent to a compound cauldron subsidence structure that we have called the Platoro caldera. Foci of hydrothermal alteration and mineralization seem to be along the ring-fracture zone of the younger collapse structure in the northern part of the compound caldera, which was the locus of repeated intrusion of equigranular quartz monzonite and coarsely porphyritic quartz latite in stocks, plugs, dikes, and volcanic necks. Radial fracture zones extending outward from the younger subsidence structure localized numerous coarsely porphyritic dikes, as well as hydrothermal alteration and local ore deposition. The older larger cauldron structure apparently exerted little control on either exposed hypabyssal intrusions or related hydrothermal activity.

The areas of most widespread and intense alteration between Summitville and the Alamosa River show evidence of repeated intrusion and hydrothermal activity. The composite granodioritic-quartz monzonitic Alamosa River stock apparently was intruded first, and a large block of rock along its northern margin was pervasively altered. Alteration was in part localized around a subsidiary intrusion in the northern part of the Alamosa River stock, and anomalous concentrations of metals were introduced locally (Calkin, 1967, p. 144-147). These altered rocks are overlain by unaltered quartz latitic lavas that were erupted from the vicinity of Summitville to the north (Steven and Ratté, 1960, p. 38) and are locally cut by similar coarsely porphyritic quartz latitic dikes and plugs. Some of the quartz latitic lavas at Summitville were in turn altered and mineralized, and ores from this center have provided most of the metals produced from the Platoro caldera area. Related porphyry dikes and plugs to the south also are altered in various degrees, and at least one area containing anomalous metal concentrations is localized near one of these later dikes (Sharp and Gualtieri, 1968).

The whole environment, with repeated hypabyssal intrusion of differentiated granodioritic to quartz monzonitic (quartz latitic) plutons, widespread and intense hydrothermal alteration, and local anomalous concentrations of gold, silver, copper, and molybdenum, is similar to that in which "porphyry-type" disseminated deposits of copper and molybdenum occur throughout western North America. Presently exposed levels are relatively shallow within the volcanic pile (Steven and Ratté, 1960, p. 51-52), whereas porphyry-type deposits appear to have formed in lower volcanic levels, or in the upper part of the basement beneath the volcanic pile. Favorable zones for exploration thus still exist at depth.

The granodioritic and quartz monzonitic compositions of the known intrusive bodies in the Summitville-Alamosa River area are more common for predominantly copper-bearing porphyry deposits (Stringham, 1966) than for the predominantly molybdenum-bearing deposits such as those at Climax, Colo. (Wallace and others, 1968), or Questa, N. Mex. (Carpenter, 1968), where mineralization is related to relatively silica-rich rhyolite and granite porphyry. The abundance of copper and the dearth of molybdenum in the known ores at Summitville further suggest this association. Molybdenum and copper, however, both are present in the areas with anomalous metal content south of Summitville described by Calkin (1967, p. 144-147) and by Sharp and Gualtieri (1968).

Mineral deposits in the outward-extending radial fracture zones range from quartz-pyrite veins with shoots of gold and silver tellurides with associated silver and copper sulfosalt minerals in the Stunner, Gilmore, and Platoro districts to a silver-bearing galena-sphalerite vein in the Crater Creek area. The Crater Creek area is appreciably farther from the apparent focus of intrusion and hydrothermal activity between Summitville and the Alamosa River than are the Stunner, Gilmore, and Platoro areas. Although the data are too sparse to be very significant, this general distribution of gold, silver, and copper relatively near the source and of silver, lead, and zinc more distant is reminiscent of the metal zoning around many western mining districts, as previously suggested by Calkin (1967, p. 154). The outward-extending fracture zones have been poorly explored, and would seemingly deserve more attention.

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REFERENCES

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

Burbank, W. S., and Luedke, R. G., 1968, Geology and ore deposits of the western San Juan Mountains, Colorado, *in* Ridge, J. D., ed., Ore deposits of the United States, 1933-1967 (Graton-Sales volume), v. 1: Am. Inst. Mining, Metall., and Petroleum Engineers, Rocky Mtn. Fund Ser., p. 714-733.

Byers, F. M., Jr., Carr, W. J., and Orkild, P. P., 1969, Volcano-tectonic history of southwestern Nevada caldera complex, U.S.A. [abs.], p. 84-86 *in* Symposium on volcanoes and their roots: Oxford, England, Internat. Assoc. Volcanology and Chemistry of the Earth's interior, v. abs., 281 p.

Calkin, W. S., 1967, Geology, alteration, and mineralization of the Alum Creek area, San Juan volcanic field, Colorado: Colorado School of Mines unpub. Ph.D. thesis, 177 p.

——— 1968, Geology and petrology of the Alum Creek area, San Juan Mountains, Colorado, *in* Abstracts for 1967: Geol. Soc. America Spec. Paper 115, p. 410.

Carpenter, R. H., 1968, Geology and ore deposits of the Questa molybdenum mine area, Taos County, New Mexico, *in* Ridge, J. D., ed., Ore deposits of the United States, 1933-1967 (Graton-Sales volume), v. 2: Am. Inst. Mining, Metall., and Petroleum Engineers, Rocky Mtn. Fund Ser., p. 1328-1350.

Christiansen, R. I., Lipman, J. W., Orkild, P. P., and Byers, F. M., Jr., 1965, Structure of the Timber Mountain caldera, southern Nevada, and its relation to basin-range structure, *in* Geological Survey Research 1965: U.S. Geol. Survey Prof. Paper 525-B, p. B43-B48.

Cohee, G. V., chm., and others, 1961, Tectonic map of the United States, exclusive of Alaska and Hawaii: U.S. Geol. Survey and Am. Assoc. Petroleum Geologists, scale 1:2,500,000. [1962]

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

Lipman, P. W., Christiansen, R. L., and O'Connor, J. T., 1966, A compositionally zoned ash-flow sheet in southern Nevada: U.S. Geol. Survey Prof. Paper 524-F, 47 p.

Lipman, P. W., and Steven, T. A., 1969, Petrologic evolution of the San Juan volcanic field, southwestern Colorado [abs.], p. 254-255 *in* Symposium on volcanoes and their roots: Oxford, England, Internat. Assoc. Volcanology and Chemistry of the Earth's Interior, 281 p.

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: Geol. Soc. America Bull. [In press]

Luedke, R. G., and Burbank, W. S., 1963, Tertiary volcanic stratigraphy in the western San Juan Mountains, Colorado: Art. 70, *in* U.S. Geol. Survey Prof. Paper 475-C, p. C39-C44.

——— 1968, Volcanism and cauldron development in the western San Juan Mountains, Colorado, p. 175-208 *in* Epis, R. C., ed., Cenozoic volcanism in the southern Rocky Mountains: Colorado School Mines Quart., v. 63, no. 3, 287 p.

Olson, J. C., Hedlund, D. C., and Hansen, W. R., 1968, Tertiary volcanic stratigraphy in the Powderhorn-Black Canyon region, Gunnison and Montrose Counties, Colorado: U.S. Geol. Survey Bull. 1251-C, 29 p.

Patton, H. B., 1917, Geology and ore deposits of the Platoro-Summitville mining district, Colorado: Colorado Geol. Survey Bull. 13, 122 p. [1918]

Ratté, J. C., and Steven, T. A., 1964, Magmatic differentiation in a volcanic sequence related to the Creede caldera, Colorado: Art 131 *in* U.S. Geol. Survey Prof. Paper 475-D, p. D49-D53.

——— 1967, Ash flows and related volcanic rocks associated with the Creede caldera, San Juan Mountains, Colorado: U.S. Geol. Survey Prof. Paper 524-H, 58p.

Sharp, W. N., and Gualtieri, J. L., 1968, Lead, copper, molybdenum, and zinc geochemical anomalies south of the Summitville district, Rio Grande County, Colorado: U.S. Geol. Survey Circ. 557, 7 p.

Smith, R. L., 1960, Ash flows: Geol. Soc. America Bull., v. 71, No. 6, p. 795-842.

Smith, R. L., and Bailey, R. A., 1968, Resurgent cauldrons, p. 613-662 *in* Coats, R. R., Hay, R. L., and Anderson, C. A., eds., Studies in volcanology—A memoir in honor of Howel Williams: Geol. Soc. America Mem. 116, 678 p.

Steven, T. A., 1968, Ore deposits in the central San Juan Mountains, Colorado, *in* Ridge, J. D., ed., Ore deposits of the United States, 1933-1967 (Graton-Sales volume), v. 1: Am. Inst. Mining, Metall., and Petroleum Engineers, Rocky Mtn. Fund Ser., p. 706-713.

Steven, T. A., and Epis, R. C., 1968, Oligocene volcanism in south-central Colorado, p. 241-258 *in* Epis, R. C., ed., Cenozoic volcanism in the southern Rocky Mountains: Colorado School Mines Quart., v. 63, no. 3, 287 p.

Steven, T. A., and Lipman, P. W., 1968, Central San Juan cauldron complex, Colorado [abs.], p. 209 *in* Epis, R.C., ed., Cenozoic volcanism in the southern Rocky Mountains: Colorado School Mines Quart., v. 63, no. 3, 287 p.

Steven, T. A., and Ratté, J. C., 1960, Geology and ore deposits of the Summitville district, San Juan Mountains, Colorado: U.S. Geol. Survey Prof. Paper 343, 70 p.

——— 1965, Geology and structural control of ore deposition in the Creede district, San Juan Mountains, Colorado: U.S. Geol. Survey Prof. Paper 487, 87 p.

Stringham, Bronson, 1966, Igneous rock types and host rocks associated with porphyry copper deposits, p. 35-40 *in* Titley, S. R., and Hicks, C. L., eds., Geology of the porphyry copper deposits, southwestern North America: Tucson, Ariz., Arizona Univ. Press, 287 p.

Wallace, S. R., Muncaster, N. K., Jonson, D. C., Mackenzie, W. B., Bookstrom, A. A., and Surface, V. E. 1968, Multiple intrusion and mineralization at Climax, Colorado, *in* Ridge, J. D., ed., Ore deposits of the United States, 1933-1967 (Graton-Sales volume), v. 1: Am. Inst. Mining, Metall., and Petroleum Engineers, Rocky Mtn. Fund Ser., p. 605-640.