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STRUCTURAL CONTROL OF ORE DEPOSITION IN THE RED MOUNTAIN, SNEFFELS, AND TELLURIDE DISTRICTS OF THE SAN JUAN MOUNTAINS, COLORADO[1]

by

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[1]Published by permission of the Director of the U. S. Geological Survey, in cooperation with the State of Colorado through the Colorado State Geological Survey Board and the Colorado Metal Mining Fund.

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Abstract

The main objectives of this report are (1) to present a preliminary geologic map of the Red Mountain, Sneffels, and Telluride districts of the western San Juan Mountains of Colorado, (2) to present conclusions on the origin and structure of the ore deposits in these districts, and (3) to indicate principles in the application of structural and other factors controlling ore deposition to prospecting.

The Silverton caldera, which is the major structural feature about and within which the ore deposits are localized, is a volcanic center and basin of late Tertiary age associated in origin with eruptions of the Silverton volcanic series. Areally and structurally the unit is only a minor part of the vast volcanic field of the San Juan Mountains, which has been described in Bulletin 843 of the United States Geological Survey, by Cross and Larsen. However the mineral productivity of the unit is relatively great compared to other parts of the San Juan, and is represented by complex ores of the base metals, gold ores, and silver ores.

The ancient volcanic plateau of the western mountains is now deeply entrenched by erosion, exposing a series of basement rocks ranging from pre-Cambrian to Tertiary in age. This series includes a maximum thickness of about 5,000 feet of Paleozoic and Mesozoic sedimentary rocks. After several periods of uplift and erosion in Paleozoic and Mesozoic time, the volcanic formations accumulated upon an early Tertiary erosion surface to a depth of nearly one mile.

In late Tertiary, probably late Miocene and Pliocene time, the Silverton caldera was formed by gradual downwarping and faulting of a large shield-shaped block of the crust about 8 miles in diameter. Radial and concentric dikes and fissures were formed in and around the caldera and provided the sites of deposition of the principal vein

deposits. Concentrations of volcanic pipes in places on the ring-fault margin of the caldera provided further sites for the localization of "chimney" ore deposits.

The development of the principal structural features of the caldera and the surrounding country is reviewed in historical order, and effects on localization of ore deposits discussed. The Red Mountain district, comprising the "chimney" deposits of the fault margin, is treated as one structural unit, and the Sneffels and Telluride districts together, comprising a swarm of northwest-trending veins, as a second unit.

The origin of the Red Mountain chimney ores is believed to be closely allied to fumarolic and geyser basin activity, and analogies between the area of these deposits and the Yellowstone basin are presented. Owing to the strong influence of fumarolic processes in the origin of the deposits, the chemical factors involved are correlated with the structural factors. It is concluded that the ore bodies, consisting locally of strongly "telescoped" chimneys of lead and silver-copper ores grading down to low-grade pyrite, were formed by evaporation of the ore-forming solutions in the throats of fumarolic channels. These channels were leached by attack of acid-sulphate solutions formed concurrently from vapors of the ore-forming solutions. A suggestion for prospecting based upon the structure and origin of the deposits is given.

The Sneffels and Telluride districts, which include the most productive vein deposits of the region, comprise a northwest-trending swarm of dikes, fissures, and veins at the northwest border of the caldera. Fissuring and tensional rupturing of the more competent formations took place concurrently with the formation of a northwest axis of downwarping exterior to the main caldera. This downwarp along the so-called Sneffels axis of sagging is interpreted to represent an initial stage in the formation of a graben.

The earlier dike-filled fissures are curved in strike and represent a simultaneous development of radial tension fissures about the main caldera and an outlying intrusive center situated 7 miles northwest of Red Mountain. With further downwarping, which followed the igneous cycle, tensional strains were formed along straight lines of N. 45° W. trend in the more competent members of the volcanic section. Owing to these strains the walls of the older dikes were reopened and new tensional fissures were produced by rupture of the competent body of the San Juan tuff-breccia. The younger fissures in places strike diagonally to the older sets of curved trend. The ores were concentrated at successive stages during which old fissures were reopened and new fissures were formed. Mineralization began with the deposition of base-metal ores and continued through intermediate stages in which gold and silver-gold ores were formed to a final stage in which only gangue minerals were formed.

The control of the competent San Juan tuff on the spacing of new tensional ruptures of different stages is discussed on the basis of Becker's partial theory of the spacing of fissures. This theory accounts for the observed relations, and hence is applicable in prospecting.

Factors controlling ore deposition and their application in prospecting are discussed separately for different parts of the districts. These factors include the relations between wall-rock control and regional structure, the influence of different ages and kinds of fissures, the effects of transverse faults, feeding channels in depth, volcanic and breccia pipes, effects of temperature and pressure, and chemical factors.

STRUCTURAL CONTROL OF ORE DEPOSITION IN THE RED MOUNTAIN, SNEFFELS, AND TELLURIDE DISTRICTS OF THE SAN JUAN MOUNTAINS, COLORADO

INTRODUCTION

Geologic studies of mining districts in the western San Juan Mountains were started at Ouray during the summer of 1929, by the Geological Survey, Department of Interior, in cooperation with the State of Colorado and the Colorado Metal Mining Fund. Since that time the field work has been divided between several mining districts in order to coordinate the structural features of the local areas and to formulate a more or less comprehensive picture of the regional control of mineralization. Until 1938 most of the field work was carried out by one party, but in that year another party under J. S. Vhay started work in the Silver Mountain area south of Telluride, and in 1940 a party under V. C. Kelley worked in the Uncompahgre Canyon and Poughkeepsie Gulch south of Ouray.

This paper presents essentially final conclusions on the structural control of ore deposition in the Red Mountain, Sneffels, and Telluride mining districts in Ouray and San Miguel Counties. The conclusions supplement those presented in three reports and several shorter papers covering the regional geologic settings of the districts and local details in the Uncompahgre and Arrastre Basin districts.[3]

[3]Burbank, W. S., Revision of the geologic structure and stratigraphy of the Ouray district of Colorado, and its bearing on ore deposition: Colorado Sci. Soc. Proc., vol. 12, pp. 151-232, 1930.
———, Vein systems of the Arrastre Basin, and regional geologic structure in the Silverton and Telluride quadrangles: Colorado Sci. Soc. Proc., vol. 13, no. 5, 1933.
———, The manganese minerals of the Sunnyside veins, Eureka Gulch, Colorado: Am. Mineralogist, vol. 18, pp. 513-527, 1933.
———, Geologic guides are sought for ore development: Eng. and Min. Jour., vol. 136, no. 8, pp. 386-392, 1935.
———, Structural control of ore deposition in the Uncompahgre district, Ouray County, Colorado: U. S. Geol. Survey Bull. 906-E, 1941.

In carrying out the local projects the author has become much indebted for the aid and valuable suggestions of those associated with him in the field parties, and whose names appear on the legend of the map. The mining men, companies, county surveyors, and other residents in the several districts have been fully cooperative and uniformly helpful to our field parties in providing facilities for work and in furnishing essential information on mining properties, without which the project obviously would not have been practicable. It is regrettable that some of the older valuable maps have become unavailable, because they were either filed in unknown places, or were lost or destroyed. This matter is mentioned in this preliminary report in the hope that some reader may know of the existence of old or new maps of mines that would add to and complete information before issuance of the final report. A request is made that those knowing of or possessing such maps correspond with the author or with Mr. Charles W. Henderson of the United States Bureau of Mines in Denver. Dr. Henderson has maintained constant and invaluable contact between the mining industry of Colorado and the cooperating geologic agencies.

The author wishes to express his appreciation to his colleagues, G. F. Loughlin for the critical revision of the original manuscript, and C. S. Ross for the reading and criticism of the section on origin of the Red Mountain ore bodies.

The issuance of a preliminary geologic map, plate 1, in three colors and without a topographic base leaves much to be desired in some areas of more complex geology. However, with the aid of the accompanying topographic base maps, and the geologic cross-sections (pl. 2), the general features of the structure may be readily understood. In the Telluride and Sneffels areas the vein structures are the most critical geologic features and at least for local use in these districts the map is believed adequate.

Geography

The Telluride, Sneffels, and Red Mountain mining districts lie within the western San Juan Mountains in parts of San Miguel, Ouray, and San Juan Counties. The nearest towns and shipping points include Telluride on the Rio Grande Southern branch line, a narrow-gage road connecting with the Denver and Rio Grande Western railroad at Montrose; Ouray on a narrow-gage branch line of the latter road, and Silverton on another narrow-gage branch that connects with the Denver and Rio Grande Western at Durango on the southern border of the mountains.

The mining districts occupy portions of a rugged mountainous country underlain mainly by volcanic rocks and rising abruptly from the Colorado plateau on the west. As shown on the inset map of plate 1, the country lies only 10 to 15 miles northwest of the continental divide. The altitudes range from 8,700 feet in the San Miguel valley near Telluride to a maximum of 13,790 feet on Potosi Peak at the northern edge of the area. Most of the mines are at altitudes of 10,000 to 12,500 feet. The mountains are drained locally by the San Miguel River, which flows west from Telluride to the Uncompahgre and Colorado Rivers, and by Red Mountain and Canyon Creeks, which flow north and northeast to the canyon of the Uncompahgre. The divide between these creeks and Mineral Creek, which flows south to the Animas River at Silverton, lies at the extreme southern edge of the area mapped (pl. 1).

These main valleys were occupied by trunk glaciers during Pleistocene time, and the surrounding mountains were nearly covered with tributary ice sheets. The topography, therefore, has been strongly sculptured by ice erosion, which resulted in oversteepened cliffs and U-shaped valleys and basins. Oversteepening of the slopes and saturation of the surface rocks from heavy rains and snows has resulted in large numbers of landslides in the San Juan Mountains. Those landslides within the areas of more massive volcanic bedrock, as represented by the area under discussion, are small. One of the larger areas of supposed landslide topography, however, has proved to contain only small superficial slides. This area, in the Red Mountain district, consists mostly of topographic features that closely simulate landslides but have been produced by glacial abrasion of highly faulted and tilted rocks. The interpretation of these peculiar pseudo-landslide features is pertinent to the geology of the Red Mountain district and will be considered farther on in this text.

General Geology

The general geology of the Silverton and Telluride quadrangles has already been reviewed by the author in an earlier number of the Colorado Scientific Society proceedings[4] and that of the San Juan Mountains as a whole by Cross and Larsen.[5] For the purposes of this text only a brief resumé of the general geology and description of rock formations will be given.

The main structural feature of the Silverton quadrangle as shown on the inset map (pl. 1) and accompanying generalized cross-section is that of a large volcanic basin or caldera of subsidence. The volcanic formations underlie all except the deeper valleys of the area. Around the western and southern border of the area the volcanic rocks rest upon a basement of Paleozoic and Mesozoic sedimentary formations, which dip west and northwest away from ancestral uplifts of the San Juan Mountains. In the central and eastern parts of the area the volcanic rocks rest mainly on the pre-Cambrian rocks.

Historically the present mountain structure began in late Paleozoic and late Mesozoic times with the development of ancestral uplifts. During the periods of erosion that followed each of these stages of uplift portions of the sedimentary formations were swept away, and by early Tertiary time the pre-Cambrian rocks had become exposed over a large area in the central part of the San Juan.

[4]Colo. Sci. Soc. Proc., vol. 13, no. 5, 1933.

[5]Cross, W., and Larsen, E. S., A brief review of the geology of the San Juan region of southwestern Colorado: U. S. Geological Survey Bull. 843, 1935.

The volcanic eruptions followed in middle and late Tertiary time, and breccias and flows accumulated to a thickness of more than a mile. During latest Tertiary time renewed volcanic action produced intrusive stocks and central volcanic vents in these older volcanic formations. The Silverton basin or caldera formed gradually during the accumulation of the Silverton volcanic series of the western mountains. As downwarping of the basin became accentuated with the thickening of the series, ring faults and associated radial fractures developed. Intrusive bodies forced their way upward along certain more strongly accentuated regional rifts, and great numbers of smaller intrusive bodies and volcanic pipes penetrated the broken rocks of the fault ring.

The structural features of greatest economic importance have so far proved to be the radial systems of dikes and fissures that surround the down-faulted basin. These have been the loci of the most productive vein deposits of the several districts. Owing to the concentrations of the vein systems along certain main trend or rift lines, some sectors outside the basin have been more productive than others.

The most productive veins of the late Tertiary epoch of mineralization are found in the volcanic formations. The sedimentary formations that underlie the western part of the area affected have not yet proved to contain oreshoots of as great continuity as those in the younger rocks. Recent deep developments in some mines have shown however that shoots of ore do extend at least to moderate depths into sedimentary rocks, especially where structural disturbances have favored the development of trunk feeding channels, and where favorable kinds of rocks immediately underlie the volcanic capping.

To the north of the Silverton center there are older ore deposits of late Mesozoic or early Tertiary age that are found entirely in sedimentary and intrusive rocks.[6] These were formed in an entirely different structural en-

[6]Burbank, W. S., U. S. Geol. Survey Bull. 906-E, 1941.

vironment and consequently comparisons with them are untrustworthy in predicting deeper aspects of mineralization of the younger epoch.

Rock Formations

The sedimentary rock formations of the area are shown in the accompanying table. These have been described sufficiently heretofore and need little additional mention. Owing to a recently discovered error in the correlation of the Upper Jurassic sandstones between the La Plata Mountains and the Telluride district, further revision of the nomenclature of beds forming the lower part of the Morrison formation has been undertaken.[7] It may be noted that the Wanakah member of the Morrison formation as now defined has been restricted to the shale unit of the member as recently described by the author in the Uncompahgre report.[8] The Bilk Creek sandstone member of the Morrison formation is a new name applied by Goldman and Spencer to the upper sandstone of Cross' La Plata sandstone as defined in the Telluride folio,[9] because this sandstone is not the equivalent of the upper La Plata sandstone of the La Plata Mountains.

The igneous rocks of the region are divisible into two principal groups according to age. The older group is of late Cretaceous or early Tertiary age, and is represented on plate 1 by only one body exposed near Canyon Creek at the northern edge of the area. Most of these older rocks are quartz monzonite or granodiorite porphyry, and, although they are unrelated to the structural features described in this paper, their existence should be kept in mind as they might be encountered in unexpected places in sedimentary rocks beneath the volcanic capping.

[7]Goldman, M. I., and Spencer, A. C., Correlation of La Plata sandstone, southwestern Colorado, (in preparation).

[8]U. S. Geol. Survey Bull. 906-E, pp. 194, 195.

[9]Cross, W., and Purington, C. W., U. S. Geol. Survey Geol. Atlas, Telluride folio (no. 57), 1899.

TABLE 1. SEDIMENTARY FORMATIONS OF THE RED MOUNTAIN, TELLURIDE, AND SNEFFELS DISTRICTS

Era	Age	Names used locally	Names and symbols used in this report and on geologic map		Symbol	Thickness (feet)		Character
Tertiary	Oligocene (?)	Telluride conglomerate	Telluride conglomerate		Tt	0 - 300		Mostly coarse conglomerate and arkosic sandstone, containing pebbles and boulders of granite, schist, quartzite, porphyritic igneous rocks and older sedimentary rocks. Locally near base thin limestones, lime-pellet beds, and sandy shale.
Mesozoic	Upper Jurassic	†McElmo formation	Shale and sandstone (undivided)	Morrison formation	Jm	500 - 700		Upper part mainly variegated shales in green and red colors, and yellowish to gray sandstone; also porcelainic beds, possibly of altered volcanic ash. Sandstone beds with chert pebbles at top. Lower part mainly sandstone beds with interbedded red and green shales, and a few limestones. Massive 30 foot sandstone at base.
Mesozoic	Upper Jurassic	†McElmo formation	Wanakah marl member	Morrison formation	Jw	85-125	50 - 70	Mainly green and chocolate brown sandy marls, with chert layers or concretions, and nodular limy concretions; thin interbedded sandstones more prominent in upper part.
Mesozoic	Upper Jurassic	†La Plata sandstone	Bilk Creek[a] sandstone member	Morrison formation	Jw	85-125	25 - 30	Sandstone, soft and friable becoming silty in upper part; at top thin ledge-forming sandstone with chert concretions; locally marly beds interbedded with hard sandstones at top.
Mesozoic	Upper Jurassic	†La Plata sandstone	Pony Express[a] limestone mem.	Morrison formation	Jw	85-125	10 - 25	Dark bituminous shaly limestone, limestone breccia, and bedded or nodular limestone.
Mesozoic	Upper Jurassic	†La Plata sandstone	Entrada sandstone		Je	45 - 80		Massive white sandstone, distinctly cross-bedded in upper part; commonly more even bedded in lower part.
Mesozoic	Jurassic (?) and Upper Triassic	Dolores formation	Dolores formation		℞d	40 - 300		Brownish sandstones, bright red sandy marls and shales, and beds of limestone pebbles; commonly at base 5 to 30 feet of coarse quartz sandstone and conglomeratic beds with chert pebbles.
Paleozoic	Permian	Cutler formation	Cutler formation		Cc	2,000 - 2,400		A series of maroon sandstones, grits, and conglomerates, alternating with sandy shales and earthy red marls.
Paleozoic	Pennsylvanian	Hermosa formation	Hermosa formation		Ch	1,400 - 1,600		In middle and upper parts, thicks beds of arkosic sandstones, with interbeds of fossiliferous shale and limestone. Lower part greenish sandstones, and dark marine shales with fossiliferous limestones.
Paleozoic		Molas formation	Molas formation			40 - 60		Red calcareous shale, sandstone with pebbles of quartzite and chert, and interbedded conglomerates with many chert pebbles.
Paleozoic	Mississippian	Ouray limestone	Leadville limestone		CD	180 - 230		Upper part mostly coarse textured clastic limestone with interbeds of reddish shale; locally thin-bedded cherty and ferruginous limestone at top; lower part dark-blue-gray or brownish gray limestone with sandy layers near base. Fossiliferous.
Paleozoic	Upper Devonian	Ouray limestone	Ouray limestone			65 - 75		Mainly gray, buff, white, fine-textured, dolomite or dolomitic limestone; layers of pinkish clastic limestone with flossils locally.
Paleozoic	Upper Devonian	Elbert formation	Elbert formation			35 - 50		Thin-bedded buff dolomitic limestones, with interbedded sandstones and calcareous shale.
	Pre-Cambrian	Uncompahgre quartzite and slate	Uncompahgre formation		unq	5,000 - 8,000		Massive to thin-bedded quartzite with minor shale or slate partings; occurs in wide bands alternating with slate bands. Quartzites, white, pink, and brownish; slates, rusty brown, or black. Local narrow bands of schistose beds.

[a]Goldman, M. I., and Spencer, A. C., unpublished manuscript.
†Names abandoned in official usage of U. S. Geological Survey.

The younger Tertiary igneous rocks are separable into two main groups on the basis of their mode of occurrence. The bedded volcanic formations include the tuffs, breccias, and lava flows of the Tertiary eruptions, extending from the San Juan tuff at the base to the Potosi volcanic series at the top of the sequence. A tabular summary is given in table 2. The intrusive group includes dikes, stocks, and rocks associated with the volcanic pipes. A complete description of these will be reserved for the final report. Brief descriptions are given in table 3.

Structure

General features

The Silverton volcanic basin comprises two major structural provinces—(1) an interior down-faulted block, which may be further subdivided into a hub of tilted and moderately disturbed formations, and an enclosing ring of highly faulted rocks, and (2) an exterior province of relatively undisturbed but fissured rocks. Although structural studies of the interior block have only begun, the rocks of the hub or down-faulted core of the caldera are irregularly tilted and locally fissured and faulted; in contrast, the rocks of the marginal zone of ring faults are highly faulted, fractured, and more steeply tilted. The rocks exposed in the hub are mainly the Burns latite and pyroxene andesite of the Silverton volcanic series; those exposed in the ring-fault zone comprise a greater proportion of older formations, owing partly to their higher structural position, and partly to erosion along the valleys that outline the caldera. This zone is characterized also by numerous small intrusive bodies, breccia pipes, and volcanic necks, which afford evidence of relatively intense volcanic activity. Over a width ranging from several thousand feet to several miles the rocks have been highly altered by chemical action of fumarolic emanations and hot mineralizing waters. Both the rock alteration and the concentration of intrusive bodies suggest that at moderate depths below the surface

TABLE 2. BEDDED VOLCANIC FORMATIONS OF THE RED MOUNTAIN, TELLURIDE, AND SNEFFELS DISTRICTS

Age		Series, group, or formation		Names and symbols used in this report and on geologic map		Thickness (feet)	Character
Tertiary	Miocene	Potosi volcanic series	Treasure Mountain quartz latite	Quartz latite and rhyolite known locally as "Potosi rhyolite"	Tpt	1,000	A series of flows and tuffs of quartz latite and rhyolite. Lower part (500-600 ft.), mainly quartz latites or plagioclase rhyolites, with bouldery tuff locally at base. Upper part, mainly rhyolites, welded rhyolitic tuffs, and rhyolite tuff, with thin layers of andesitic tuffs containing fossil plant remains.
		(?)	(?)	Quartz biotite latite	Tpl	200-400	A complex of biotite latite flows, and rhyolitic tuffaceous flows containing abundant inclusions of quartzite; there are beds of steeply inclined andesitic tuffs and breccias, and associated andesitic intrusive bodies. Complex rests against steep cliffs of latite of Picayune volcanic group near Full Moon Gulch. Mainly an intra-caldera formation. Age relation to upper Silverton formations not known.
		Silverton volcanic series	Pyroxene andesite	Pyroxene andesite	Tsa	500-800	Dark colored pyroxene andesites in flows and breccia beds; some flows of latitic character. Occupies higher ridges of Red Mountains, and southern part of Brown Mountain Ridge. Appears to be confined mainly to interior block of caldera in this area.
			Burns latite	Burns latite	Tsb	500-1,000	Fine-textured dark greenish hornblende or pyroxene-bearing latites. Tuff and breccia beds commonly present at bottom and top of formation, but are only locally recognizable near western border of caldera. In this area Burns latite appears to be confined mainly to interior block of caldera.
			Picayune volcanic group	Hornblende latite and rhyolite flows and tuffs	Tsl	200-800	Upper part, mainly massive flows and flow-breccias of latite or quartz latite; contains beds of autoclastic breccias associated with more massive and fluidal flow material; at base there is locally a conglomeratic bed of latite boulders. Lower part (100-150 ft.) thin rhyolitic flows with prominent fluidal texture, and greenish lentiles of chloritic material (flattened vesicles); some beds contain many inclusions of foreign andesitic material.
				Pyroxene andesite flows and breccias	Tsp Tspl	100-500	Flows and breccias of dark colored pyroxene andesites, and amygdaloidal andesites. In Red Mountain Valley latitic flows or tuffs appear in lower part of section (Tspl). There are also beds of tuff-breccia like San Juan tuff in lower part of formation.
	Miocene (?)	San Juan tuff		San Juan tuff	Tsj	1,800-3,000	Bedded tuff, tuff-breccia, and tuff-conglomerate, made up of andesitic and latitic material. A few dense flows in upper part on Hayden Mountain; and lenses of latitic tuff near top.

TABLE 3. INTRUSIVE ROCKS OF THE RED MOUNTAIN, TELLURIDE, AND SNEFFELS DISTRICTS

AGE		NAMES AND SYMBOLS USED IN THIS REPORT, AND ON GEOLOGIC MAP		CHARACTER
Tertiary	Miocene or Pliocene (?)	Clastic dikes (not shown on map)		Bodies of clastic material consisting of fragments and rounded pebbles of volcanic, sedimentary, and pre-Cambrian rocks; mostly as dikes, but also in irregular bodies of various attitudes, and as pipes. The material composing some dikes in the Red Mountain district must have been injected upward more than 3,000 feet from its source.
		Intrusive rhyolite	Tir	Glassy, devitrified, or fluidal textured rhyolite; occurs in dikes, irregular bodies, and as the latest intrusive bodies in volcanic pipes; associated with breccia in pipes and occurs as fragments in such breccias.
		Quartz latite porphyry	Tql	Conspicuously porphyritic rocks containing phenocrysts of quartz, plagioclase, and sodic orthoclase; also contain biotite and hornblende. Found mostly in volcanic pipes, but also as dikes. Locally the phenocrysts of feldspar attain a size of 1 to 2 inches.
		Intrusive latite	Til	Fine to medium textured latite, in part with many inclusions; texture fluidal; found in a volcanic pipe on the west slope of Mount Abrams, but may possibly occur elsewhere either as dikes or in pipes.
		Intrusive andesite	Tia	Mainly dark colored rocks of andesitic composition; some conspicuously porphyritic, others fine grained or amygdaloidal; in dikes and irregular intrusive bodies. Most of the andesitic dikes belong to the northwest swarm between Stony Mountain and Red Mountain.
		Gabbro-diorite of Stony Mountain	Tgd	Composite stock of gabbro and diorite, with small salic bodies of quartz monzonite; locally contains immense blocks as well as numerous small fragments of quartzite, possibly of pre-Cambrian age.
		Rhyolite of Gray Copper Gulch	Trh	Fluidal rhyolite, exposed beneath the Burns latite of Gray Copper Gulch; age relations not definite. Possibly a pre-Burns volcanic neck. Flow lines are steeply inclined at many places.
Cretaceous or Tertiary	Late Cretaceous or early Tertiary	Quartz monzonite porphyry	TKm	Quartz monzonite porphyry, containing altered hornblende and biotite; a laccolithic body associated with the intrusive center of the Uncompaghre Valley near Ouray. The body is overlain unconformably by the Telluride conglomerate and San Juan tuff.

the margin of the caldera is underlain by a more or less continuous ring of intrusive rock, the protuberances of which have forced their way up through the highly faulted and shattered volcanic formations. Another local but characteristic feature of this zone is the tendency for the rock formations on the inner part of the ring-fault zone to tilt outward whereas those along the outer part tilt inward, forming a circumferential sag or depression. This kind of structure appears to be more highly developed in wide marginal zones of particularly intense rock alteration.

The exterior province of the Silverton basin surrounding the down-faulted block comprises relatively undisturbed formations, which are cut by numerous dikes and fissures of radial trend, and by a lesser number that are diagonal to the principal radial and concentric structure lines. In this province the basement rocks beneath the volcanic accumulations are exposed locally along some of the deeper valleys draining the mountains and continuously farther west at the border of the Colorado Plateau. Some of the volcanic formations thicken toward the center of the Silverton basin; others present in the interior are absent or unrecognizable in parts of the exterior province. These relations suggest that sinking of the basin through faulting was in part concurrent with eruptions of the lava flows, an inference that is strengthened by structural evidence along the faulted border between the two provinces.

Within the outer province of the basin there are many larger outlying or exterior intrusive centers that perhaps lie along certain main structural trends or rifts of the region. These exterior centers of intrusion lie mostly to the northwest, west, and southwest of the basin. Some of them are connected with the main center by swarms of curved and straight fissures and dikes, along which many of the principal vein deposits of the region are found.

Relation to ore deposits

The forms of the ore deposits directly reflect the degree of structural complexity of the different provinces. First, with reference to simple forms of structure, there is a close parallel between the form of intrusive bodies and the shape of ore bodies. Intrusive bodies of the ring-fault zone include many plugs or necks, associated closely with volcanic breccia pipes of nearly cylindrical shape, whereas dikes are obscure geologic features, and, where present, are discontinuous. The principal oreshoots of this province, typified by those of Red Mountain, are the so-called chimney deposits of the miners. These are cylindrical upright bodies, a few feet to a few tens of feet in diameter, and have been mined to depths of generally less than 1,000 feet. Some true veins occur in this zone, but like the dikes, the oreshoots are comparatively short and discontinuous.

As contrasted to this, the intrusive igneous rocks of the Telluride district in the exterior province assume the form of dikes that are essentially continuous for many miles; the main ore bodies, in conformity to this structural change, are fissure veins of great continuity. Near Telluride, some 5 to 8 miles from the fault margin, veins have been stoped for lengths of 4,000 to 8,000 feet and to depths of 2,000 to 3,000 feet.

Vein deposits between these extremes of structural form are represented in zones near the outer margin of the ring-fault zone. The oreshoots are less continuous, and their vertical dimensions more closely approach or may even exceed their length. These changes result in part from an increasing number of crisscrossing fractures and faults that interrupt the continuity of the main radial vein systems. Dikes likewise are faulted into segments or end abruptly as they enter the fault belt.

Although there is obviously a tendency for the ore bodies of the two contrasted provinces to approach one another in shape, the vein and chimney deposits, like the dikes and volcanic pipes, owe their distinctiveness to quite marked differences in mode of origin. The two forms do not exhibit complete gradational features, though they may be closely associated in space. The form of the dike and the filled fissure vein is produced by a simple mechanical breaking apart of rocks, but the cylindrical form of the volcanic pipe and the chimney ore body evidently results from more complex but narrowly circumscribed processes, induced by combined chemical and mechanical disintegration of the rocks. The general form of the chimney ore bodies resembles most closely that of the fumarolic vent, and there is some evidence that the open spaces partly occupied by ore in such bodies may indeed be the actual roots of geysers or fumaroles. Hydrothermal replacement processes have played some part in the origin of the chimney ore bodies, but with respect to general form the chimney ore bodies are closely allied to the central type of volcanic and fumarolic vent, with which they are associated.

While the forms of openings and their relations to the major structural pattern constitute the most fundamental relations between structure and ore deposition, deep-seated processes in the formation of the subsided basin have localized igneous and fumarolic activity and the migration of ore-forming solutions, so as to produce a mineralogic zoning of the ore deposits in relation to the structure. In fissure veins that radiate out from the marginal faults. complex base-metal (polymetallic) ores predominate areally in the inner part of the exterior province, though restricted amounts of higher-grade precious-metal ore are found. In the outermost part of the exterior province the dominant ores are those of silver and gold with only minor local concentrations of the base-metal ores. In the Red Mountain district of the ring-fault belt the chimney ores are strongly zoned, from high-grade lead-silver-copper ore near the surface, to pyritic ore in depth. Zoning in depth is much less pronounced in the exterior provinces where the larger mineral deposits have vertical extents 3 to 5 times those in the Red Mountain district. Although in the latter district the pre-heating of the channel-ways by igneous matter and fumarolic emanations ascending along the volcanic pipes may account for some restriction of the vertical zone favorable to commercial mineralization, other factors are believed to be equally responsible. Dikes of the exterior province fail to show any pronounced or at least apparent effect upon the vertical limits of favorable conditions, for fissures along dikes in places contain rich ore to as great a depth as fissures that do not follow dikes.

Main fissure systems

Classification.—The main directions of fissuring in the different districts offer a strong argument in themselves against a classification based upon compass bearings.[10] A number of prominent dike and fissure systems, represented by the Smuggler-Union-Ajax and the Montana-Argentine veins, are curved in strike from N. 45° W. to N. 10° W. Furthermore, from place to place the directions of fissuring are slightly divergent, and there appears to be no limit to the number of arbitrarily defined sets that could be recognized. The fissures of the different districts, therefore, are better classified into a smaller number of main systems, based not so much upon trend as upon their structural setting, general form, and inferred geologic relations. Unless otherwise stated the fissures are classified according to the presence or absence of curvature along their strikes, and not according to a three-dimensional form for which evidence may be lacking. It is to be understood, therefore, that reference to a fissure as straight will refer only to its average trend or strike, and does not preclude many minor irregularities in form, or a curvature in depth. The structural settings are based upon major structural features, such as the down-faulted block of the caldera or the intrusive centers. The inferred geologic conditions under which the several systems were formed are necessarily subject to errors inherent in any genetic interpretation.

The main systems that have been defined are as follows: (1) a ring-fault, or concentric, system of the caldera; (2) radial systems of the caldera; (3) "spiral" and cone-fracture systems of the caldera; (4) radial systems of the Stony Mountain (and Mt. Sneffels) center; and (5) "spiral"

[10]See, for example, C. W. Purington's classification, Mining industries of the Telluride quadrangle: U. S. Geological Survey, 18th Ann. Rept., pp. 764-767, 1898.

and cone-fracture systems of the Stony Mountain center. Subdivisions and subsidiary systems of those enumerated above will be considered in connection with structural interpretations that follow.

Form and relations.—The ring system (1) that encircles the main down-faulted block of the caldera is illustrated to the extent now known on the inset map of plate 1. The curvature of the system as a whole is attained partly by actual curvature of individual faults, and partly by irregular or systematic branching of the faults. The dips of the main faults are nearly vertical or slightly inward toward the down-faulted block. Main faults are commonly marked by wide zones of brecciated or crackled rocks, though locally faults of apparent large displacement are inconspicuous. In the Red Mountain district the faults and subsidiary fissures of this system range in strike from N. 25° E. to N. 65° E.

There are numerous subsidiary systems within the ring-fault belt, some of which may be related in origin to stresses within the walls of the main faults, and others to stresses produced by later deformation superimposed upon the faulting, but related to the ring-fault belt. Still others appear to represent traces of regional trends or rifts. The belt is also affected by fissuring of the radial systems.

One system most critical to an understanding of the later stages of deformation in the Red Mountain district is represented by fissures and faults that roughly parallel the ring faults but dip at moderate to low angles both eastward and westward. These faults resulted from the subsidence that formed a sag or graben along the Red Mountain Valley. This sag is emphasized in belts along which the rocks are so highly altered by volcanic emanations that the less massive of them have undergone "plastic" deformation. The faults produced are normal faults (see fig. 2. p. 165), and are of much shallower origin than the main ring faults.

The radial fissure systems of the caldera (2) and the Stony Mountain center (4) are of much economic importance, because many of them are occupied by the more