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D.A. Gonzales and R.A. Larson

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AN OVERVIEW OF THE MINERAL DEPOSITS OF THE RED MOUNTAIN MINING DISTRICT, SAN JUAN MOUNTAINS, COLORADO

David A. Gonzales[1] and Robert A. Larson[2]

[1]Fort Lewis College, Department of Geosciences, 1000 Rim Drive, Durango, CO 81310, gonzales_d@fortlewis.edu
[2]Monadnock Mineral Services, LLC, 342 7th Ave, Ouray, CO 81427

Abstract—The Red Mountain mining district in Ouray County represents one of the oldest and most famous districts in the western San Juan Mountains. Deposit types in the Red Mountain district include breccia pipes with ore chimneys that extend to depths of 1000 ft (~300 m) along the ring fractures of the Silverton caldera. These deposits formed by expulsion of acidic hydrothermal fluids in proximity to hypabyssal plutons causing extensive advanced argillic to argillic alteration in adjacent country rocks. Discontinuous shoots of ore define a crude zonation within these deposits that grade from Ag-Pb-Zn in the upper levels to Cu-Au in the lower zones. These high-grade breccia pipe deposits were initially explored and mined from 1874 to 1910 yielding immense production of precious (Au, Ag) and base metals (Pb, Zn, Cu), that provided incredible wealth. To the west and northwest of the Red Mountain breccia pipes, numerous fissures and veins formed in radial fractures that fan outward from the structural walls of the Silverton caldera. These high-grade veins were the focus of some of the most notable base and precious metal deposits in the region, such as the Idarado mine (including the Smuggler-Union, Black Bear, Argentine), the Camp Bird mine, and the Revenue-Virginius mine. Veins in this system sometimes extended for several kilometers on strike and hundreds of meters in depth, and were extensively mined from 1874 to the 1980's. Base metals dominated the veins at depth with increasing concentrations of gold at higher levels. The deposits in the Red Mountain mining district define a unique period of geologic history marked by widespread mineralization related to middle to late Cenozoic magmatism. The mining in this district also left an indelible mark on the human history of the area. Current mining at the Revenue-Virginius, just to the northwest of this district, marks the latest chapter in the history of mining in the area.

INTRODUCTION

The Red Mountain mining district (Figs. 1, 2) is one of the oldest and most recognized, of the many mining districts in the western San Juan Mountains. Dunn (2003) reported that the Red Mountain district was one of the original six districts established in Ouray County in 1882. Prospecting began in the mid 1870's, with the discovery of rich deposits at the Yankee Girl and Guston mines in 1881 which initiated a rush to the area and a "re-examination of existing discoveries which showed profitable amounts of silver, gold, lead and copper" (Dunn, 2003). This district is located between Silverton and Ouray with U.S. Highway 550, the Million Dollar Highway, traversing through the center. It extends both east and west with boundaries defined by ridgelines and topographic features (Fig. 2). Many of the mines in the Red Mountain district are situated at elevations between 10,000 and 12,500 ft. There are three dominant deposit types in the district: 1) breccia pipes; 2) veins; and 3) replacement-type deposits.

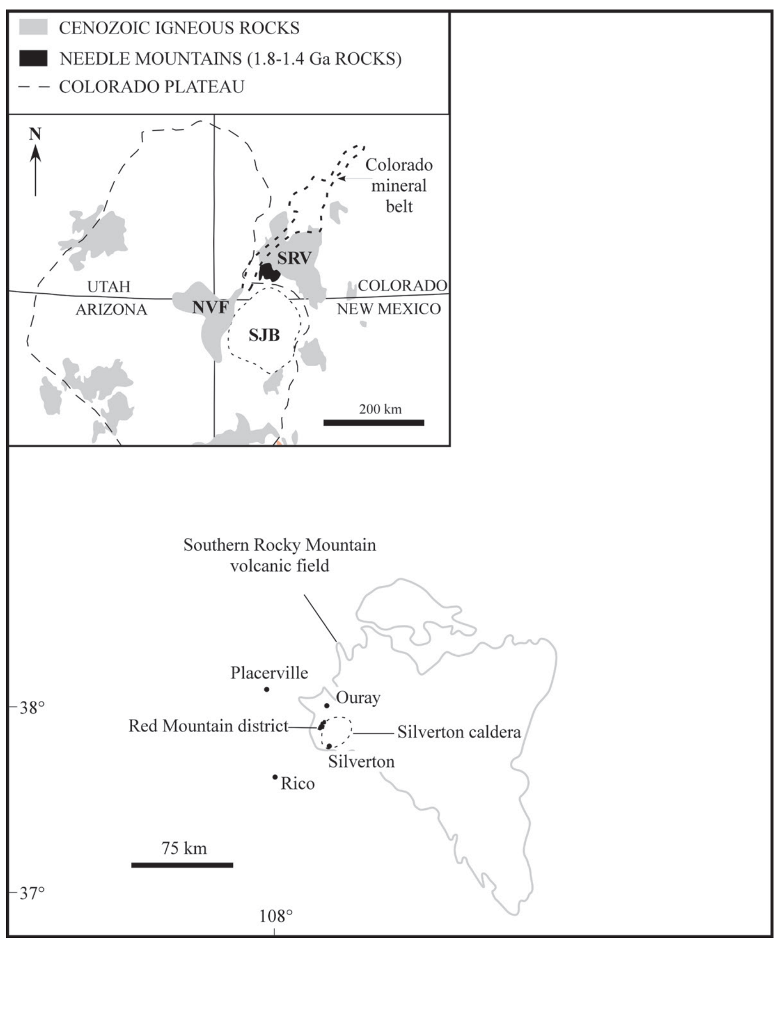

FIGURE 1. General map of the western San Juan Mountains showing the approximate location of the Red Mountain mining district on the northwestern margin of the ~27.6 Ma Silverton caldera (dashed line). Abbreviations in inset map: SRV (Southern Rocky Mountain volcanic field), SJB (San Juan Basin), and NVF (Navajo volcanic field). The Red Mountain district is located within the southern extent of the Colorado mineral belt.

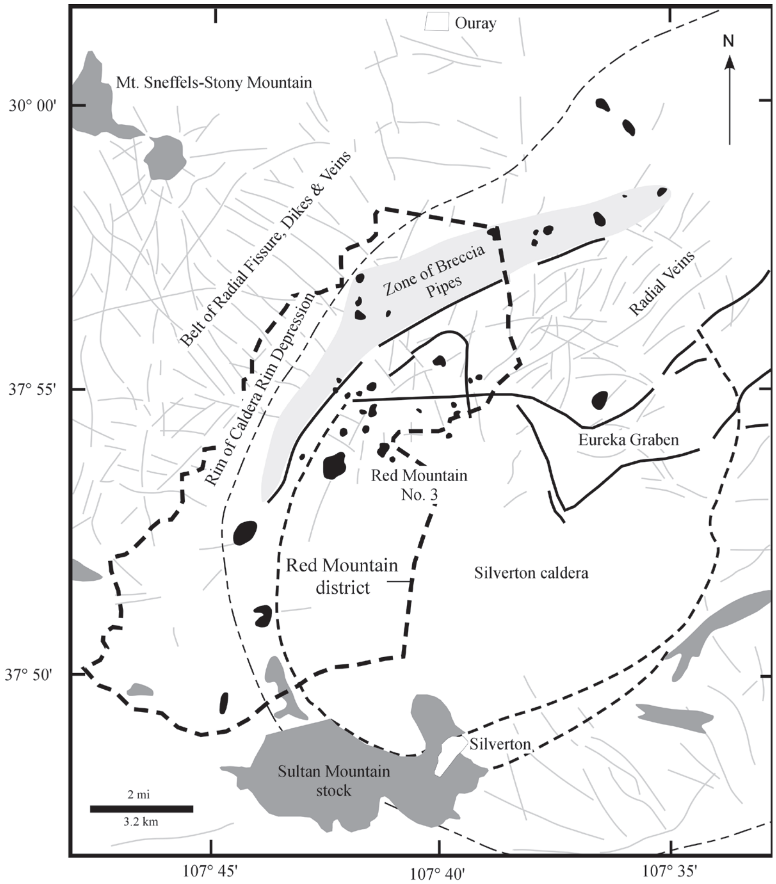

FIGURE 2. Simplified geologic map of the Silverton caldera and Red Mountain district. Oligocene plutons are shaded dark gray. Breccia chimney and related hypabyssal intrusive rocks are shown in black. Solid black lines indicate major faults. The zone of breccia pipes is transected by numerous vertical zones of stockwork breccia and ore chimneys.

The geology and mineral deposits of the Red Mountain mining district have been studied, defined, and recorded in previous publications and reports (e.g., Ransome, 1901; Bastin, 1922; Burbank, 1941; Hillebrand and Kelley, 1957; Burbank and Luedke, 1968; Mayor and Fisher, 1971; Nash, 1975; Fisher and Leedy, 1973; Fisher, 1990). In this contribution, we provide a summary of the key geologic aspects of the deposits in the district, using previous descriptions, tempered with experience and observations from geological studies, mineral exploration, and mining projects with which the authors have participated.

GEOLOGIC SETTING

Post-80 Ma magmatic events in the western San Juan Mountains span the boundary of the Colorado Plateau and Southern Rocky Mountains, and are broadly aligned with the southwestern extension of the Colorado mineral belt (CMB) (Fig. 1), a locus of recurrent magmatism with peak events at 75-65, 35-23 and 18-4 Ma (e.g., Tweto and Sims, 1963; Cunningham et al., 1977, Cunningham et al., 1994; Cappa, 1998; Chapin et al., 2004; Chapin, 2012). The Red Mountain mining district is situated in the western margin of the Oligocene Southern Rocky Mountain volcanic field on the edge of the Silverton caldera which was superimposed on the older San Juan caldera creating a complex system of fractures in the Red Mountain district (Figs. 1, 2). Oligocene magmatism, including widespread eruption of andesitic lavas and breccias, began by ~32.5 Ma in the western San Juan Mountains. Major ash-flow eruptions were produced by the San Juan-Silverton caldera complex from 28.2 to 27.6 Ma during the extensive Oligocene magmatic "flare up" (Lipman et al., 1973; Steven and Lipman, 1976; Lipman, 1989; Bove et al., 2001; summary in Lipman, 2007).

The Silverton caldera is approximately 8 miles (~13 km) in diameter (Figs. 1, 2) within an area of positive uplift that subsided following tectonism and deposition of the Silverton volcanic series. The caldera has been referred by some as a "hinged-caldera" with Lipman et al. (1973) describing the intracaldera rocks being tilted in "trapdoor" style with little displacement on the north and maximum displacement on the south. The caldera margins are defined by numerous radial and concentric faults and fractures that provided avenues for emplacement of shallow plutons and hydrothermal fluids that would give rise to the Red Mountain breccia pipes (Figs. 3, 4, 5) and veins (Fig. 6). The northwestern caldera boundary, in the center of the Red Mountain mining district, is characterized by fissures and clusters of volcanic pipes and chimneys (Figs. 2, 3). Radial structures extending to the northwest of the caldera boundary form the famous vein deposits of the Red Mountain and adjacent districts. The significant vein-type mineralization in these structures is within an area described by Burbank (1941) as the "Sneffels Sag".

The intensely altered zone between Red Mountain No. 1 and No. 3 (Fig. 3) is interpreted as another possible area of subsidence (Burbank and Luedke, 1964). Subsequent geologic mapping and sampling (Fisher and Leedy, 1973) revealed that the high degree of alteration in this area made stratigraphic and structural interpretations difficult, if not impossible. These Red Mountains, however, may be considered a "mineralization center" with lead-silver-copper rich zones extending outward into base metal veins and then into precious metal veins to the northwest (e.g., Burbank, 1941; Burbank and Luedke, 1964; Herness, 1966).

The breccia deposits in the Red Mountain mining district are hosted by andesitic to dacitic flows and tuffs, flow breccia, and volcaniclastic sediments of the ~27 Ma Burns Member of the Silverton volcanic series (Burbank and Luedke, 1964; Luedke and Burbank, 2000). Below the Burns Member is the Oligocene San Juan Formation which is widespread in the western San Juan Mountains, and is the dominant host rock for the extensive vein deposits. Although Oligocene to Pleistocene volcanic rocks dominate the landscape there are exposures of Proterozoic Uncompahgre Group and Paleozoic to Cenozoic sedimentary rocks in the area, especially to the north in Ironton Park and the gorge of the Uncompahgre River.

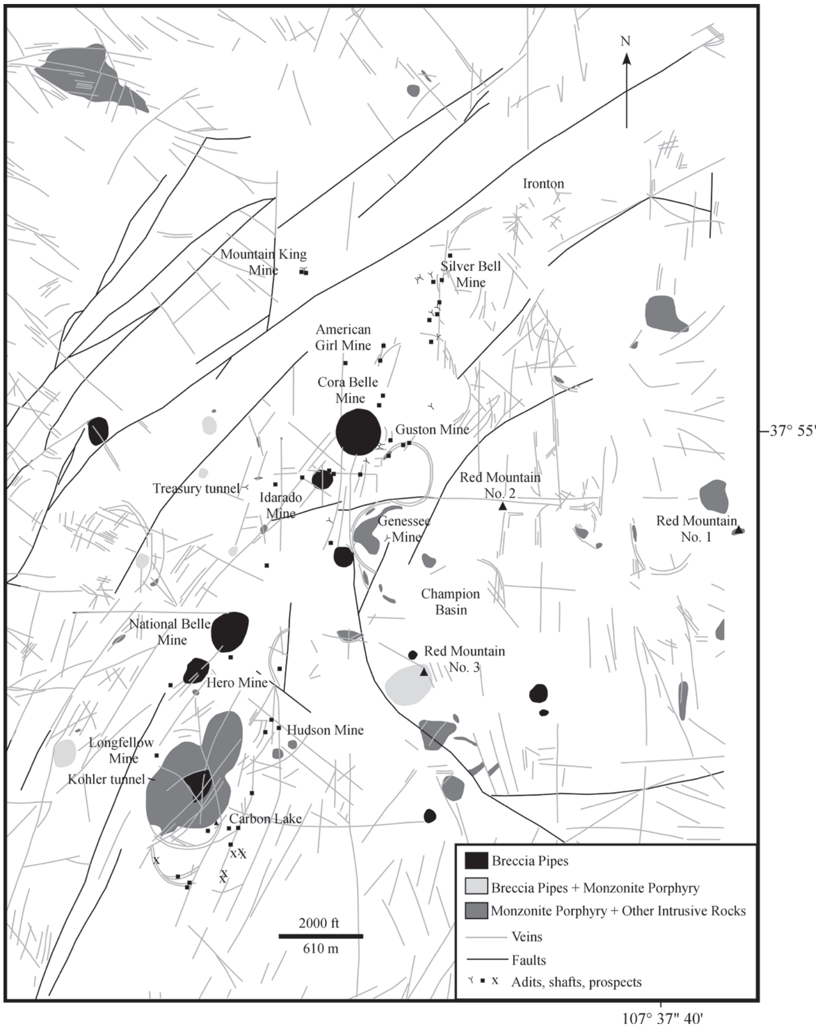

FIGURE 3. Breccia pipes deposits of the Red Mountain district shown with related plutons and fissure veins. Note the strong northeast structural fabric along which the pipes are developed. Figure modified after Burbank and Luedke (1964).

MINERAL DEPOSITS

Breccia pipes and ore chimneys

The breccia pipes (zones of stockwork breccia) with associated ore chimneys and veins have yielded rich deposits of lead + copper + zinc + silver + gold since the 1880s, and are significant features of the Red Mountain mining district (Figs. 2, 3, 4, 5). These deposits are concentrated in a zone about 2 km wide and 8 km long that trends approximately 025 along the northwestern margin of the San Juan Silverton caldera complex (Fig. 1). Bastin (1922) noted that the zone of breccia pipes is situated in two "near vertical" and "highly fractured" zones that are subparallel. Ransome (1901) reported that most of these mines were not operating at the time he examined them, so the mining period at that time was short lived but lucrative. Exploration and mining have been cyclical since that time based upon economic conditions and the price of metals, but there is no current mining focused on the breccia deposits.

Some of the more noted mines developed in breccia pipes are the Longfellow (Koehler and Carbon Lake), National Belle, Genessee-Vanderbilt, Yankee Girl, Guston-Robinson, Silver Belle, and Red Mountain No. 3. Other mines include the Hero, Hudson, and American Girl mines (Fig. 3). The Genessee-Vanderbilt workings were first developed in the 1890's from the Vanderbilt shaft with 6 levels having a vertical distance of 370 ft (115 m). The Genessee tunnel was then driven at a lower elevation for 800 ft (244 m) to intersect these workings, and ore was mined that contained 35% copper and 27 ounces per ton silver (Warren C. Prosser, unpublished report for Baumgartner Companies, 1968). Further development in the 1940's and 1950's extended these workings under Red Mountain No. 3 and crosscuts were driven under the western and eastern sides of the pipe by American Smelting and Refining Company (AS&R). Diamond drilling was done from the crosscuts along the sides and toward the center of the Red Mountain No. 3 pipe (Fig. 3). Some mineralized rock was penetrated in the drilling and crosscuts; however, no production of ore is recorded (Fisher and Leedy, 1973, p. 10). Warren Prosser stated in conversations in the 1960's that beautiful specimens of covellite were found during this exploration phase. Some of these can still be observed today in various mineral collections or museums.

The Yankee Girl mine (Fig. 5) was discovered in 1881 and in 1882 was opened by two 50-foot-deep shafts (Ransome, 1901). The mine operated until 1896 producing an average ore grade in various zones as high as 242 opt silver, 36% lead, and 29% copper. Ransome (1901) commented on the demise of the mine, "But it was an expensive mine to operate on account of the irregular form of its large ore bodies, the abundance and corrosive activity of its waters, and the necessity of hoisting and pumping through deep shafts." This mine was one of the premier breccia pipes as outlined and summarized by Herness (1966) (Fig. 5). The Yankee Girl shaft reached 1100 ft (326 m) in depth and provided extremely rich ore within a unique hydrothermal mineral assemblage. Total value at the time of production was estimated at $4.7 million from 1881 to 1896. The Yankee Girl headframe, visible from Highway 550, remains a notable vestige of mining in the Red Mountain district.

The Guston and Robinson shafts (Fig. 4) were developed in the Guston breccia pipe in 1882 and closed in 1897 (Ransome, 1901). It was reported that some "carloads" of ore carried 600 to 1,400 opt silver. Ransome (1901) also noted from field notes of S.M. Emmons taken in 1888 from the third level of the Guston mine the occurrence of a "solid mass of chalcopyrite mixed with tetrahedrite and galena carrying up to 750 ounces per ton." Continued mining activities were documented by Warren C. Prosser (unpublished report for Baumgartner

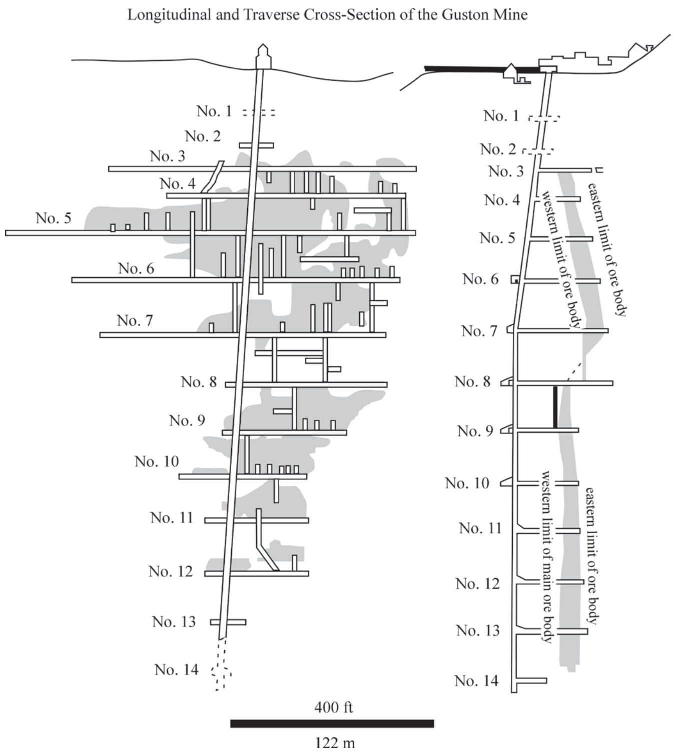

FIGURE 4. A schematic cross section of the Guston mine illustrating the mine workings in relation to the ore deposits (gray). Modified from Ransome (1901).

Companies, 1967). According to Prosser "The Yankee Girl and Guston mines contained ore richer in silver than any other mines found in the Red Mountain area". Ralph Stebens, Ouray resident and mineral collector, in the 1960s, displayed a specimen from the Robinson mine that was one-half native silver and one-half native gold.

The Silver Bell mine (Fig. 3) was also developed by a shaft. Ransome (1901) noted that this deposit "Produced large amounts of ore carrying from 500 to 1,000 ounces of silver per ton". The shaft was reported to be 700 ft (214 m) in depth and contained water, "strongly impregnated with sulfuric acid generated from the pyrites in the ore bodies". As with most of the Red Mountain area, sulfuric acid is generated naturally by the oxidation of pyrite, providing the coloration that is prevalent. Flowing springs exist in areas above any mining activity and are extremely acidic, with pH in the range of 2 to 3. It has been determined by extensive water sampling and analyses that the coloration and heavy metal content in Red Mountain Creek is due to approximately 50% natural conditions and approximately 50% mining related activities. The reclamation efforts in the Red Mountain area have been outlined to improve the man-caused portion of the above, knowing that naturally occurring acidic waters will continue to be generated.

The Longfellow mine (Fig. 3), is located adjacent to a large quartz monzonite hypabyssal intrusive. The adjoining San An-

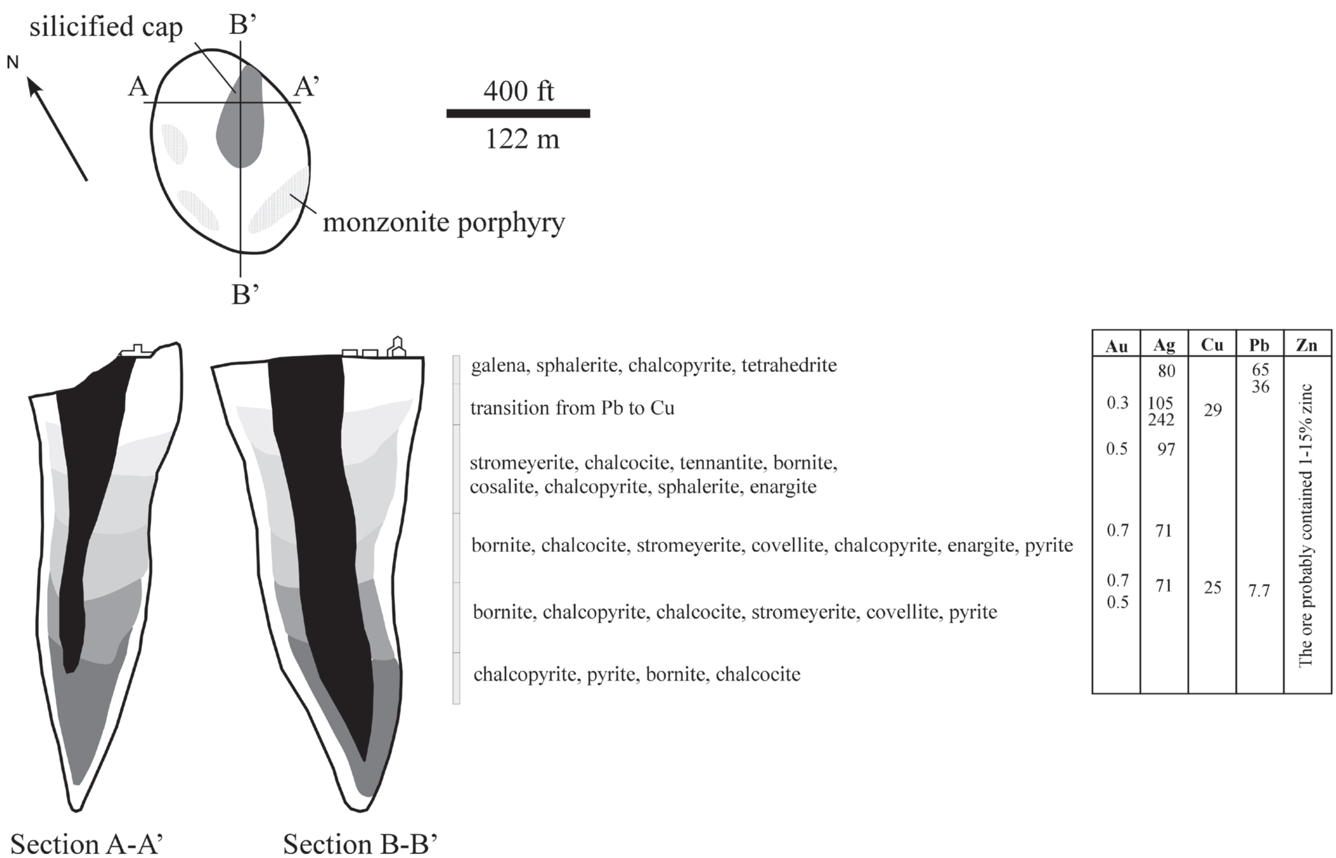

FIGURE 5. A schematic reproduction of the Yankee Girl breccia deposit in plan and sectional views illustrating the general zonation, mineral associations, and general grades of Ag, Au, Pb, Zn, and Cu. Note the overall decrease of Ag and Pb at depth, and the general increase in Cu and Au. Reproduced from Herness (1966). Gold and silver grades are in ounces per ton and Pb, Cu, and Zn concentrations are in percent.

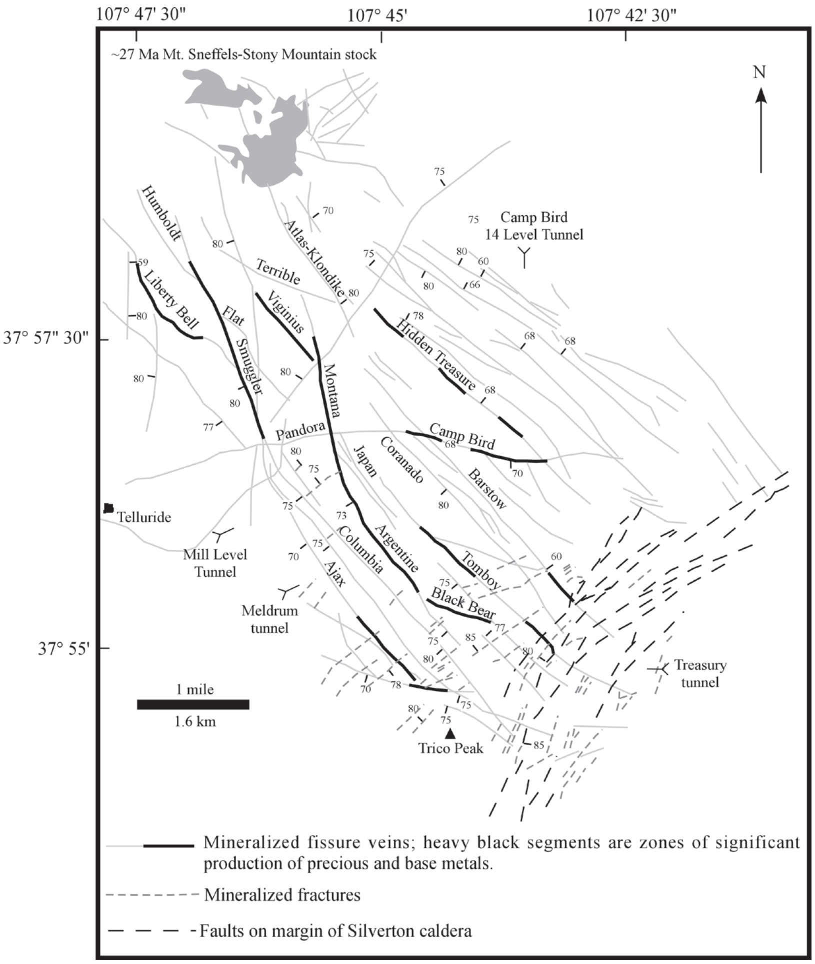

FIGURE 6. Some of the major veins and structures that dominate the region to the northwest of the boundary of the Silverton caldera. The veins are deposits in the Red Mountain, Sneffels-Telluride, and Camp Bird mining districts. Numbers on the veins indicate the dip. Modified from Fisher (1990). Some of the more lucrative veins mined via the Treasury tunnel included the Tomboy, Black Bear, Argentine, Montana, and Japan.

tonio, Carbon Lake and Congress mines were developed in the early 1900's. The Longfellow deposit was not discovered until the mid-1950's when the Highway Department was excavating fill material for highway construction. One of the ore chimneys was uncovered under the talus and the Longfellow mine was subsequently explored and mined. Extensive and beautiful enargite crystals were found within the ore chimneys that are a part of this breccia pipe system. Although the old mine dumps of the Longfellow have been sampled a great deal, collectors still find beautiful specimens of enargite at a few locations.

Mineralization within the National Belle (Fig. 3) was found in cavernous chimneys with associated clay minerals. The silicified cap rock of the pipe provides a distinct topographic feature that defines all of the mineralized breccia pipes. Fisher and Leedy (1973) provided evidence of the similar geochemical characteristics of the National Belle pipe and the Red Mountain No. 3 pipe to the east. This association led to the concerted mapping and sampling efforts conducted during the 1970's, under the direction of S. Kermit Herness, Baumgartner Companies. The exploration led to the discovery of the large-tonnage, low-grade gold deposit that still exists on Red Mountain No. 3. The efforts of Baumgartner Companies and subsequent joint-venture partners, to explore and develop this mineralized breccia pipe, have defined 12 million tons of 0.027 opt gold (Behre Dolbear, unpublished Technical Review for Osiris Gold Corporation 1994). Burbank (1941) and Fisher and Leedy (1973) indicate that the south and west slopes of Red Mountain No. 3 present favorable exploration targets at depth. The question still remains as to the potential of deep-seated sulfide mineralization associated with the feeders of the defined near-surface oxide ore. As for the National Belle, "The sulfide ore deeper in the mine occurred as irregular masses in altered rock and consisted mainly of enargite with lesser amounts of chalcopyrite, galena, sphalerite, and tetrahedrite. The ore was generally argentiferous and also contained some free gold" (Fisher and Leedy, 1973, p. 10).

The breccia pipes in the Red Mountain district have similar geometry and dimensions (Figs. 4, 5). The pipes are cone-shaped, having diameters at the surface up to 500 ft (153 m) across with depths up to 1000 ft (305 m) (more typically 500 to 700 ft) (Ransome, 1901; Burbank, 1941). The breccia pipes at the level of exposure are hosted by propylitically altered rocks of the Burns Member. The "cones" of stockwork breccia are spatially related to, and often intruded by, irregular plugs, stocks, and dikes of quartz-feldspar monzonite porphyry ("latite" of Burbank and Luedke, 1964). The largest pluton is exposed at the Koehler mine (Fig. 3). The monzonite porphyry is distinguished by quartz phenocrysts that are partially resorbed, and the perthitic orthoclase exhibits pronounced zoning. The monzonite porphyry varies from unaltered to extremely altered with feldspar replaced by kaolinite and other clays.

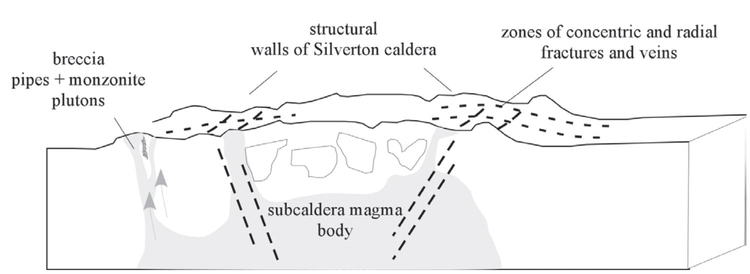

FIGURE 7. A general model of magmatism and ore formation on the margins of the Silverton caldera. Following caldera eruption and collapse of the Silverton caldera at ~27.6 Ma there was emplacement of intermediate to felsic plutons along the ring fracture system. The Red Mountain breccia pipes developed in a highly-fracture zone on the western margin of the caldera as hydrothermal-magmatic fluids were transported to levels where hot, mineral-laden and acidic fluids caused extensive alteration and deposition of metals in ore chimneys, probably at ~24 Ma. Further to the west, hydrothermal fluids moved along radial fractures creating the extensive network of lode veins that formed around 17 and 10 Ma (Fisher, 1990).

Previous K-Ar analyses constrained the timing of emplacement of the plutons from 24 to 22 Ma with alunite alteration occurring around the same time (Lipman et al., 1976; Bove et al., 2001). A new U-Pb zircon analysis constrains the timing of emplacement for the stock related to the Yankee Girl pipe at 24.03±0.14 Ma. These data illustrate that the plutons associated with mineralization were emplaced about 3 million years after caldera eruptions. Burbank (1941) noted that pieces of the porphyry were found in the National Belle breccia indicating gas-charged eruptions subsequent to emplacement and crystallization of the intrusive rocks.

Propylitic alteration (epidote + calcite + chlorite + albite) is dominant in the volcanic rocks outside the zones of mineralization, but within and adjacent to the pipes there was extensive sulfotaric action (advanced argillic to argillic alteration) that led to the formation of alteration assemblages that include quartz (silicification), kaolinite, dickite, and alunite with lesser pyrophyllite, diaspore, rutile, barite, leucoxene, and zunyite (Fisher and Leedy, 1973). Pyrite in the rocks has been extensively oxidized to produce the distinctive red and orange outcrops in the district.

In general, the breccia pipe deposits at Red Mountain are similar in structure (Fig. 5), but the ore deposits vary in size, shape, and dimensions. Ore chimneys within the breccia pipes formed in near-vertical, "irregularly lenticular or spindle-shaped bodies" composed essentially of ore minerals surrounded by altered and fractured rock (Ransome, 1901; Burbank, 1941). Some are concentrated on a zone of fractures that trends 020 to 030 (Ransome, 1901; Bastin, 1922). Near vertical fracture zones along which mineralization was focused were referred to as "ore breaks" (Ransome, 1901). The ore shoots extended vertically up to several hundred feet, and in plan view ranged from circular to elliptical (dimensions up to 15 x 50 ft or 5 to 25 m) elongated to the northeast (Fig. 3). Burbank (1941) commented that these breccia pipes resembled "fumarolic vents" and that the "caves" and vugs in the pipes might be the roots of "geysers or fumaroles". Ore shoots in the pipes were often linked by barren fissures. The fractures along which the breccia pipes formed were conduits for mineral-laden hydrothermal fluids to move to zones of favorable deposition. Explosive release of hydrothermal fluids led to acidic alteration of country rocks and caused hydrothermal brecciation (Burbank and Luedke, 1968). In the deepest levels of the mines the breccia zones typically graded into north-trending veins.

The mineral deposits that formed in the breccia pipes on Red Mountain defined a general zonation from the surface to depth (Ransome, 1901; Bastin, 1922; Burbank, 1941; Burbank and Luedke, 1968) (Fig. 5). The surface exposures of most pipes are expressed by highly altered, silicified and vuggy caps. In the National Belle mine the upper levels of mineralization in "caves" consisted of oxidized assemblages containing cerussite, anglesite, malachite, and iron oxides. In most other mines, the upper zones of the pipes (75 to 300 ft depth or 23 to 100 m) were dominated by silver-bearing galena ± tetrahedrite ± chalcocite. These zones usually graded into ore masses containing stromeyerite + galena + argentite + chalcopyrite + pyrite (300 to 400 f or 100 to 122 m). At the deeper levels of each pipe the ore was described as "peacock copper", composed mostly of argentiferous bornite and chalcopyrite + pyrite + chalcocite + covellite + enargite. Gold was mostly recovered from the deeper copper-rich deposits in auriferous pyrite. Pyrite dominated the deepest barren levels of the mines. Bastin (1922) argued that primary sulfide minerals (pyrite, chalcopyrite, sphalerite, galena, enargite, cosalite, argentiferous tennantite-tetrahedrite, bournonite, and bornite) in some of the breccia deposits (Yankee Girl, Robinson, Genesee mines) were overprinted and replaced by secondary supergene minerals that included 1) stromeyerite replacement of sphalerite, galena, and tennantite-tetrahedrite; 2) chalcocite replacement of enargite; 3) covellite replacement of enargite, famatinite, sphalerite, tennantite-tetrahedrite, stromeyerite, cosalite, and galena; 4) proustite and pyrargyrite replacement of galena; and 5) secondary argentite and native silver. Burbank (1941), however, argued that the telescoping of ore minerals and ore enrichment in the breccia pipes was not likely caused by supergene action. He noted that "the origin of the ores may be accounted for satisfactorily by processes likely to occur down to depths of several thousand feet in belts of fumarolic alteration." He contended that the actions of hydrothermal fluids at depth and "shallow vaporization of hot solutions under pressure" were responsible for the intense leaching at upper levels of the pipes and the progressive deposition of hypogene ore minerals (Burbank, 1941, p. 203).

Veins and stratigraphic replacement deposits

Northwest-trending veins (315 to 295) and related replacement deposits extend about 12 km from the western structural margin of the Silverton caldera to the region north of Telluride (Fig. 6). The width of the vein belt varies from 3,000 m near the caldera rim to 1,200 m near Telluride. Base and precious metal veins and stratigraphic units in this zone were mineralized from hydrothermal solutions originating in the Red Mountain area. These deposits extend beyond the Red Mountain mining district into the Upper San Miguel and Sneffels mining districts. Mineral zonation has been identified within these veins that is similar to many mining districts throughout the world. Near the center of the Red Mountains (Fig. 2) copper mineralization is prevalent. Extending outward from this center, lead and zinc base metal mineralization becomes more prominent. Farther to the northwest and higher in the system, precious metal mineralization predominates. Fisher (1990) reports that veins and replacement deposits in this area collectively produced 6,200,000 ounces of gold with "approximately 22 million tons of ore exceeding $300 million in value at the time of production".

The Proterozoic Uncompahgre Group in this vein zone is overlain in places by a succession of Paleozoic to Mesozoic sedimentary rocks and the Oligocene Telluride Conglomerate, capped by Oligocene volcanic rocks. Radial fractures (Figs. 2, 6) developed in these rocks provided pathways for igneous intrusions and mineralizing hydrothermal fluids. Veins achieved thicknesses up to 8 m but are typically about 2 m and in some instances were mined for thousands of meters on strike to depths of 900 m. Fisher (1990) noted that the veins in the southern part of this zone of fissures produced base and precious metals (e.g., Argentine-Black Bear-Barstow veins) whereas to the north the veins produced mostly gold and silver (e.g., Pandora-Camp Bird veins). In veins with precious and base metal deposits the base metals dominate at deeper levels. In the Montana-Argentine and Black Bear veins the total base metal contents decreased north, Cu increased to the south and at depth, Zn decreased at depth northward relative to other base metals, and Pb increased updip and to the north but decreases northeast of the west Black Bear vein (Hillebrand, 1968; Fisher, 1990). In general, Ag increases to the southeast and at depth in correlation with increasing galena and copper mineralization.

Fisher (1990) reported that the radial fractures developed around 25 Ma but that mineralization took place at 17 Ma and 10 Ma. These periods of mineralization are correlative with the emplacement of numerous hypabyssal granitic plutons through the western San Juan Mountains from 17 to 9 Ma (Gonzales, 2015). Stratigraphic base metal replacement ore in the Telluride Conglomerate exists adjacent to several of the vein systems in the Idarado where the unit contained calcite and had a higher porosity (Mayor and Fisher, 1971).

The Idarado mine is one of the most famous and noteworthy mines in the region (Fig. 6). Over a period of nearly 100 years the mine developed to depths of nearly 1000 m below the surface and developed about 80 miles (~130 km) of interconnected workings (Hillebrand, 1957). The subsurface workings of the mine span the distance from Red Mountain Pass westward to the town of Telluride (~10 km). Veins are reported to vary from well-delineated tabular structures 2 to 3 m thick to irregular stringers of quartz and sulfides. The dominant ore minerals extracted from the mine were sphalerite, galena, chalcopyrite, pyrite and native gold in a gangue composed of banded and "crustified" quartz (60% to 70%), rhodonite, rhodochrosite, fluorite, barite, calcite, epidote, chlorite, sericite, hematite, and adularia (Hillebrand and Kelley, 1957, 1960; Mayor, 1978; Fisher, 1990). Gold was late in the paragenetic sequence that is documented in these veins (Nash, 1975). An overall Zn:Pb:Cu ratio of 3:2:1 in the veins was noted by Hillebrand (1968). Early production on veins that were later included in the Idarado property was 13,363,866 tons with 0.26 opt Au (3.47 million ounces), 2.69 opt Ag (35.95 million ounces), and 0.85% Pb (227.2 million pounds) (Mayor, 1978). Production by the Idarado Mining Company from 1946 to 1978 was 10,900,000 tons with 0.07 opt Au (0.76 million ounces), 1.91 opt Ag (20.82 million ounces), 2.33% Pb (507.9 million pounds), 0.71% Cu (154.8 million pounds), and 3.63% Zn (791.3 million pounds) (Mayor and Fisher, 1993).

A body of data, as summarized by Fisher (1990), indicates that the northwest-trending veins system that extends from the Red Mountain district (Fig. 6) developed by mixing of metal-laden magmatic fluids with a high volume of meteoric fluids over 10 million years after the collapse of the Silverton caldera. Increased thermal gradients in the region from emplacement of shallow plutons likely contributed to the longevity of these hydrothermal systems.

The Saratoga mine is located near the northern boundary of the Silverton Caldera on the eastern side of Ironton Park (Fig. 3). Replacement ore was found in 1883 (Ransome, 1901) at this location where the Saratoga pipe intersected the Devonian-Mississippian Ouray and Leadville limestones overlain by thin section of Telluride Conglomerate. These units are unconformable on the Proterozoic Uncompahgre Group and are overlain by the volcanic rocks of the Silverton volcanic series. According to Ransome (1901), "The best ore is found resting on the oxidized upper surface of a mass of iron pyrite". This pyrite carries from "3 to 4 ounces of silver and 0.4 to 0.5 of an ounce of gold, being thus too poor to work". Ransome (1901) noted that the "pay ore" was contained in "a carbonate of lead carrying silver, probably as a chloride."

Relationship of breccia pipe and vein systems

A general hypothesis is that formation of the Silverton Caldera is related to the resurgent doming and collapse overlying a deep-seated batholith (Fig. 7). Multiple cupolas formed at the top of the batholith in which hydrothermal solutions, containing metal ions, collected. Areas of weakness along the caldera boundary allowed hydrothermal solutions to be forced upward and outward from the cupolas, forming the carrot-shaped breccia pipes and associated ore chimneys. The vein deposits, using the radial and concentric fracture patterns from the caldera as the plumbing system, provided conduits for hydrothermal solutions to be forced outward and upward from, possibly, adjacent portions of the batholith. Although the most productive breccia pipe deposits formed along the caldera boundary, other radial structures exist outside of the caldera boundary. Burbank (1941, p. 216) argued that the Camp Bird vein developed over an older structural zone that was contemporaneous with "cone or spiral fractures" that developed early in the history of the calderas and controlled the rise of mineralizing solutions from depth (Fisher, 1990). Herness (1966) noted that "Volcanic pipe fractures such as those of the Red Mountains have provided channelization and access for the ore-depositing solutions; and vein ore-shoots in areas not generally considered to be in volcanic pipe environment may be genetically related to subsurface volcanic pipes. The writer sees much evidence that the ring fractures in the Camp Bird area are surface indications of subsurface volcanic pipes which channelized the ore solutions from the cupola source to the Camp Bird vein".

Felsic to mafic intrusions ranging from 26 Ma to 4 Ma were emplaced throughout the western San Juan Mountains (Gonzales, 2015). Those emplaced at ~24 Ma have a strong spatial and temporal relationships with the breccia pipe deposits on Red Mountain. In some other locations 17, 14, and 10 Ma plutons have a spatial relationship between magma emplacement and base + precious metals mineralization (Gonzales, 2015). The influence of Miocene to Pliocene magmatism on mineralization in this area remains an important future research initiative.

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