THE SUNNYSIDE, ROSS BASIN, AND BONITA FAULT SYSTEMS AND THEIR ASSOCIATED ORE DEPOSITS, SAN JUAN COUNTY, COLORADO

— *by* —

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THE SUNNYSIDE, ROSS BASIN, AND BONITA FAULT SYSTEMS AND THEIR ASSOCIATED ORE DEPOSITS, SAN JUAN COUNTY, COLORADO

by

W. S. BURBANK[1]

ABSTRACT

The Sunnyside, Ross Basin, and Bonita fault systems lie in the northeastern part of the Silverton volcanic area of San Juan County, Colorado. Most of the production of the Eureka mining district has come from veins within or associated with these fault systems. The purpose of this brief review and map of the major structural features controlling ore deposition is to present data that might be of value in mine exploration and development until such time as a detailed geologic map and text can be published.

The exposed rocks of the area are entirely volcanic formations of middle Tertiary age resting on a buried basement of pre-Tertiary sedimentary rocks and pre-Cambrian metamorphic rocks. The intricately faulted and fissured volcanic rocks (The Silverton volcanic series), which exceed 3,000 feet in thickness, may be divided into five major units in this area.

The main fault systems form part of the border faults of a downfaulted caldera-type structure and part of a system of graben faults that extend northeasterly from a central downfaulted block for 6 or 8 miles. Displacements on the major faults range from about 500 feet to possibly as much as 2,000 feet. As a result of the forces generated by intermittent uptilting of the crustal blocks and subsequent downward movements to form the caldera and associated graben, numerous other smaller faults and fissures were formed in the walls of the main faults and in adjoining ground. Dilation of these minor fissures by continued movements on the main faults provided favorable spaces for certain types of ore bodies. The major ore bodies, which yielded about 85 percent of the district's production, were

[1]Publication authorized by the Director, U. S. Geological Survey and by the Chairman, Colorado Geological Survey Board.

associated with the junction of two major faults, the Sunnyside and Ross Basin faults. Other major fault junctions and their associated ore deposits are compared as to their bearing on possible sites for future exploration.

It is concluded that the possibilities of important new discoveries are not exhausted, and that the southwestern part of the graben and nearby structural features lying at the edge of the main downfaulted block constitute the most favorable ground for deep exploration and development. Other general suggestions for prospecting are also given.

Introduction

The Sunnyside, Ross Basin, and Bonita fault systems are major structural features of the northeastern part of the Silverton volcanic center, a caldera-type eruptive center in San Juan County, Colorado.

The location of the area is shown on the index map of figure 1, which covers the western and central parts of the San Juan Mountains, adjacent parts of the Colorado plateau to the west, and the edge of the San Juan basin to the south. The local volcanic features in the Silverton area center around a shield-shaped downfaulted block about 8 miles in diameter near the town of Silverton. This is connected to a somewhat similar center at the northeast near Lake City by a system of northeast-trending faults, to which belong the several faults described herein.

The area is of particular interest because of several mines that had a large production in the past. The Sunnyside and Gold King mines of the Eureka district of San Juan County are among the best known. Most of the production of the Eureka district, amounting to 60 or 65 million dollars in gross metal value, came from vein deposits closely related to the fault systems. The known remaining reserves as well as recent smaller mine developments and active prospecting in the district make the area of continued interest as a source of zinc-lead ores containing gold, silver, and copper.

The field work on these fault systems was part of a cooperative survey extending over several field seasons between 1946 and 1949 in the area between Eureka, Gladstone, and Animas Forks. It was financed jointly by the U. S. Geological Survey and the State of Colorado. A report and map on the entire area and some adjoining country is in preparation by the U. S. Geological Survey. This paper presents briefly, in advance of more complete publication, some of the major structural features of value in the exploration and development of the complex zinc-lead-copper-silver-gold ores of the area.

A complete study of the underground mining operations, past and present, was not possible because many of the older and larger mine workings have not been accessible for some years. It was the purpose of this project, moreover, to provide a general geologic background against which past operations could be studied and future exploration considered. It is therefore emphasized that conclusions drawn must in some instances be evaluated on the basis of past and future underground development and exploration.

Messrs. Dewey Sample and Waldemere Bejnar participated in the field work for parts of two seasons, and their aid is gratefully acknowledged. Likewise the cooperation of the mining companies and of individuals doing mine exploration in the area in recent years is much appreciated.

General Geology

The rock formations exposed in the area are entirely Tertiary volcanic rocks that have accumulated to a thickness of a mile or more on a buried basement composed of Paleozoic and Mesozoic sedimentary rocks and of pre-Cambrian metamorphic rocks. To the west and north Paleozoic and Mesozoic rocks crop out at the base of the volcanic rocks.

The buried line of regional uplift along the contact between the pre-Cambrian rocks and the Paleozoic and Mesozoic sedimentary rocks lies just west of the area discussed in this report (figure 1). Uplift occurred both in Paleozoic and late Mesozoic times and the older rocks were last planated by erosion in early Tertiary time just prior to the eruption of the volcanic rocks. A nonvolcanic formation, known as the Telluride conglomerate, was deposited on parts of this erosion surface prior to the eruptions, but it is probably missing beneath the volcanic capping in many parts of the uplifted areas. A general section of the volcanic rocks as interpreted from exposures in the area is shown in the geologic cross sections of figures 2 and 3.

The principal stratiform volcanic formations consist of the San Juan tuff, the Silverton volcanic series, and the Potosi volcanic series. The San Juan tuff and the Silverton volcanic series are restricted to an area of the western San Juan Mountains around Silverton in San Juan, Ouray, and San Miguel Counties and around Lake City in Hinsdale County. The Potosi volcanic series consists chiefly of rhyolitic eruptives and occurs throughout the San Juan region.

The San Juan tuff locally forms the base of the volcanic succession and consists of tuff and breccia accumulated in part by eruptive processes and in part by erosional processes. It is not exposed anywhere in the area of faulting under discussion, but some thickness of it may lie beneath the exposed lavas of the Silverton volcanic series and below the bottoms of the deepest mines.

The Silverton volcanic series comprises the principal rocks cropping out in the area. It is a complex of flows, sandy and shaly tuffs, welded tuffs, breccias, and instrusive bodies. The rocks have a total thickness in excess of 3,000 feet. The average composition of the series is probably near quartz latite, but flows of rhyolite and andesite are also represented as well as the more common latites. Five major units of the Silverton series are recognized from the base upwards: the Picayune volcanic group, the Eureka rhyolite, the Burns quartz latite, the pyroxene quartz latite, and the Henson tuff. All except the Henson tuff are definitely identifiable in the Eureka-Gladstone-Animas Forks area, and it is possible that some of the sandy tuff beds in the upper part of the pyroxene quartz latite on Bonita Peak and adjoining ridges may be equivalent to tuffs correlated with the Henson tuff 5 miles or more north of Bonita Peak.

The flows and welded tuffs of the rhyolites and the Potosi volcanic series are not exposed in the local area of faulting described, but remnants of them cap many of the highest ridges surrounding this area.

In the Cement Creek area near Gladstone the rocks forming the lower slopes are probably chiefly the Burns quartz latite, but the higher ridges of Bonita Peak and Emery Peak between the Cement Creek and Eureka Gulch drainages are composed of the overlying pyroxene-bearing lavas with beds of sandy tuff and breccia. In some of the mine explorations below the ridges and high basins flows belonging to the Eureka rhyolite have been penetrated by mine workings. This is true in the Placer Gulch area north of the Sunnyside mine and in American tunnel of the Gold King mine in the Cement Creek area.

In the California Gulch, Animas Forks, and Animas valley areas the principal rocks exposed on the lower slopes and valley bottoms belong to the Eureka rhyolite. The various lava flows are distinguishable chiefly by textural differences, but in many places adjoining Cement Creek the recognition of different volcanic units is much hampered by strong and pervasive alteration. The least altered and least disturbed of the flow rocks are those of the pyroxene quartz latite on the higher ridges.

Further discussion of the local details of the various units of the volcanic formations is left for the more complete report on the area. Many of the local features of the various units are described in the Silverton folio by Cross, Howe, and Ransome.[2] More general descriptions may also be found in a brief review of the geology of the San Juan region by Cross and Larsen.[3]

THE MAIN FAULT SYSTEMS

The main fault systems to be described are part of the northeastern border zone of a large volcanic caldera, only

[2]Cross, W., Howe, E., and Ransome, F. L., U. S. Geol. Survey Geol. Atlas, Silverton folio (No. 120) 1905.

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

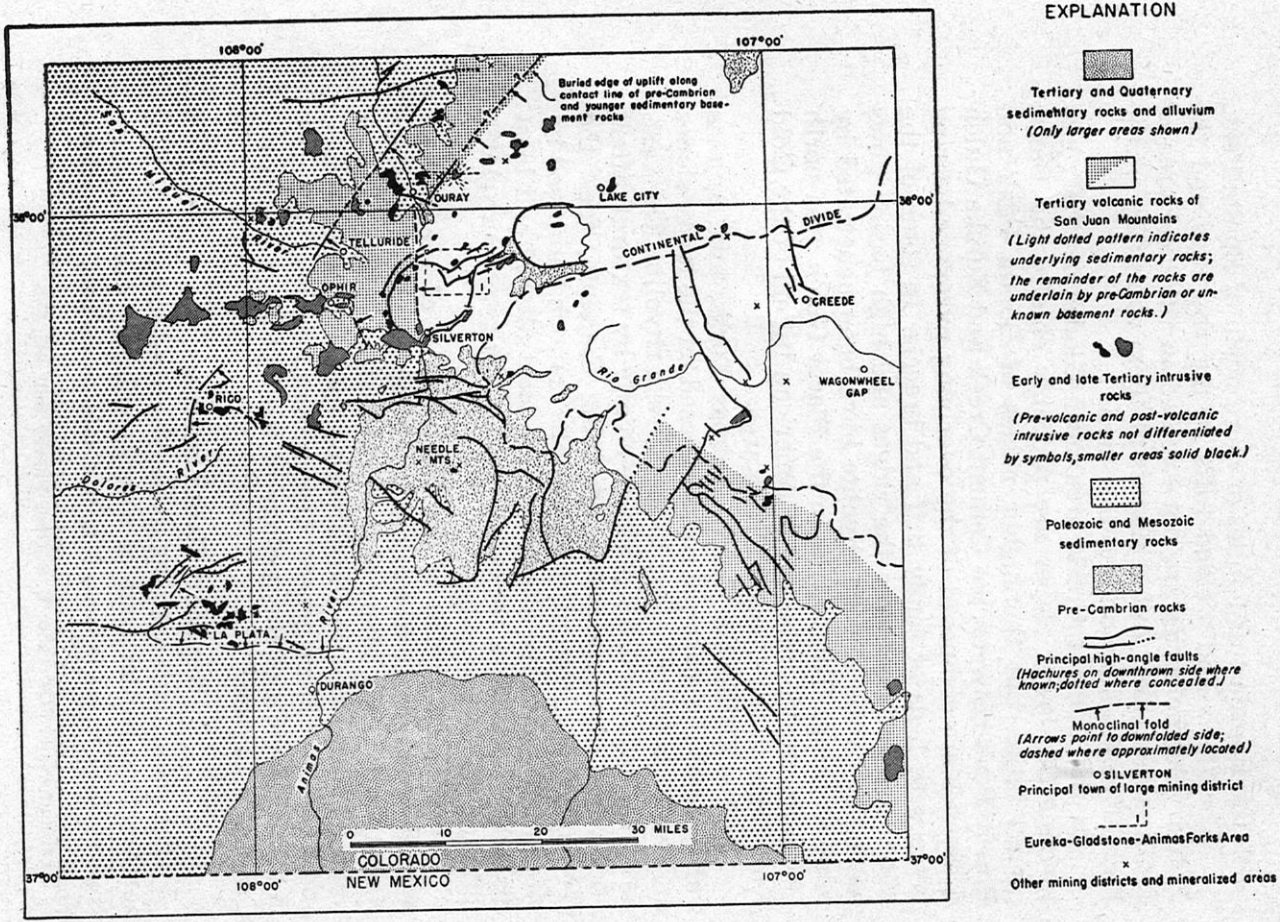

FIGURE 1. - INDEX MAP OF SOUTHWESTERN COLORADO SHOWING LOCATION AND STRUCTURAL SETTING OF THE EUREKA-GLADSTONE-ANIMAS FORKS AREA, COLORADO

part of which is detailed in figures 1 and 2. The structural features of this area as a whole have been reviewed and illustrated elsewhere.[4]

The Ross Basin fault at the head of Cement Creek above Gladstone was first mapped in the Silverton folio. It trends east to east-southeast and dips steeply to the south. The Eureka rhyolite and Burns quartz latite exposed at the head of the north branch of Ross Basin and in Poughkeepsie Gulch north of the fault zone are downthrown 800 to 1,000 feet at the head of Cement Creek on the south side of the fault zone. The fault extends east through a narrow pass at the head of the east branch of Ross Basin to Sunnyside Basin, where it joins the northeast-striking Sunnyside fault near Lake Emma. As shown in figure 2, the Ross Basin fault is unrecognizable east of its nearly right-angle junction with the Sunnyside fault. However, from a point near this junction east-southeastward to Eureka on the Animas River, the volcanic flows and tuffs forming the steep north slopes of Eureka Gulch are tilted southward. This monoclinal tilting and bending of the flows amounts to a displacement of more than 500 feet, and in a sense the whole section of volcanic rocks south of a line between Ross Basin and Eureka is downthrown or downtilted to the south toward the central downfaulted block of the Silverton caldera floor. The overall displacement caused by combined tilting and faulting amounts locally to as much as 2,000 feet.

The Sunnyside fault begins essentially at its junction with Ross Basin fault and extends northeastward across Treasure Mountain to the Animas valley, where one branch of it forms the strong Cinnamon fault, which extends into Hinsdale County. The displacement on the Sunnyside fault near its junction with the Ross Basin fault is probably about 1,500 feet, but this estimate is complicated by some tilting of beds in both walls of the fault. The fault dips steeply southeastward. To the northeast the throw on the fault diminishes somewhat, having been estimated at about 800

[4] Burbank, W. S., Late Tertiary ore deposits; Districts of the Silverton volcanic center: Mineral Resources of Colorado, pp. 419-421 and pl. 28, State of Colorado Mineral Resources Board, Denver, 1947.

to 1,000 feet in the vicinity of Treasure Mountain. The main Sunnyside fault cannot be traced south beyond its junction with the Ross Basin fault, although some fissuring and minor faulting occur more or less in line with it on the Bonita Peak ridge to the south.

The Sunnyside and Ross Basin faults thus have a common footwall at their junction in Sunnyside Basin. Most of the ore bodies of the Sunnyside mine occur along the legs of the two faults and in the fractured common footwall within a few thousand feet of the junction. This is an unusual type of ore occurrence in the San Juan area, but owing to the great width of the fractured zones and the strong disruption of the rocks the ore bodies are exceptionally wide and extend in strength through a vertical range of at least 2,000 feet. It is likely that they continue even deeper.

Complementary to the Sunnyside-Cinnamon fault extending northeasterly across parts of Treasure and Eureka Mountains is a large fault traceable from a point near Emery Peak at the south to and beyond the Animas River at the north. For most of its length it is known as the Toltec fault. The fault dips to the west and the rocks are downthrown on the northwest side, so that the long narrow block between it and the Sunnyside fault forms a downfaulted trough or graben and is dropped like a keystone wedge between the tilted flows of the major faults on either side. In general the flows both east and west of the graben are tilted away from it. This tilting is believed to be in part caused by small initial tilts that have been progressively accentuated as the keystone wedge between the main faults sank intermittently downward, thus forcing apart the rocks on either side. A generalized geologic section across these faults is shown in section B-B', figure 2.

It is not certain that the Toltec fault terminates at Emery Peak, the farthest point southwest to which it has been traced. However, it is joined here by a strong northwest-trending fault zone that skirts the west flanks of Emery and Bonita Peaks. This fault zone, which may be called the Bonita fault, is another element of the major

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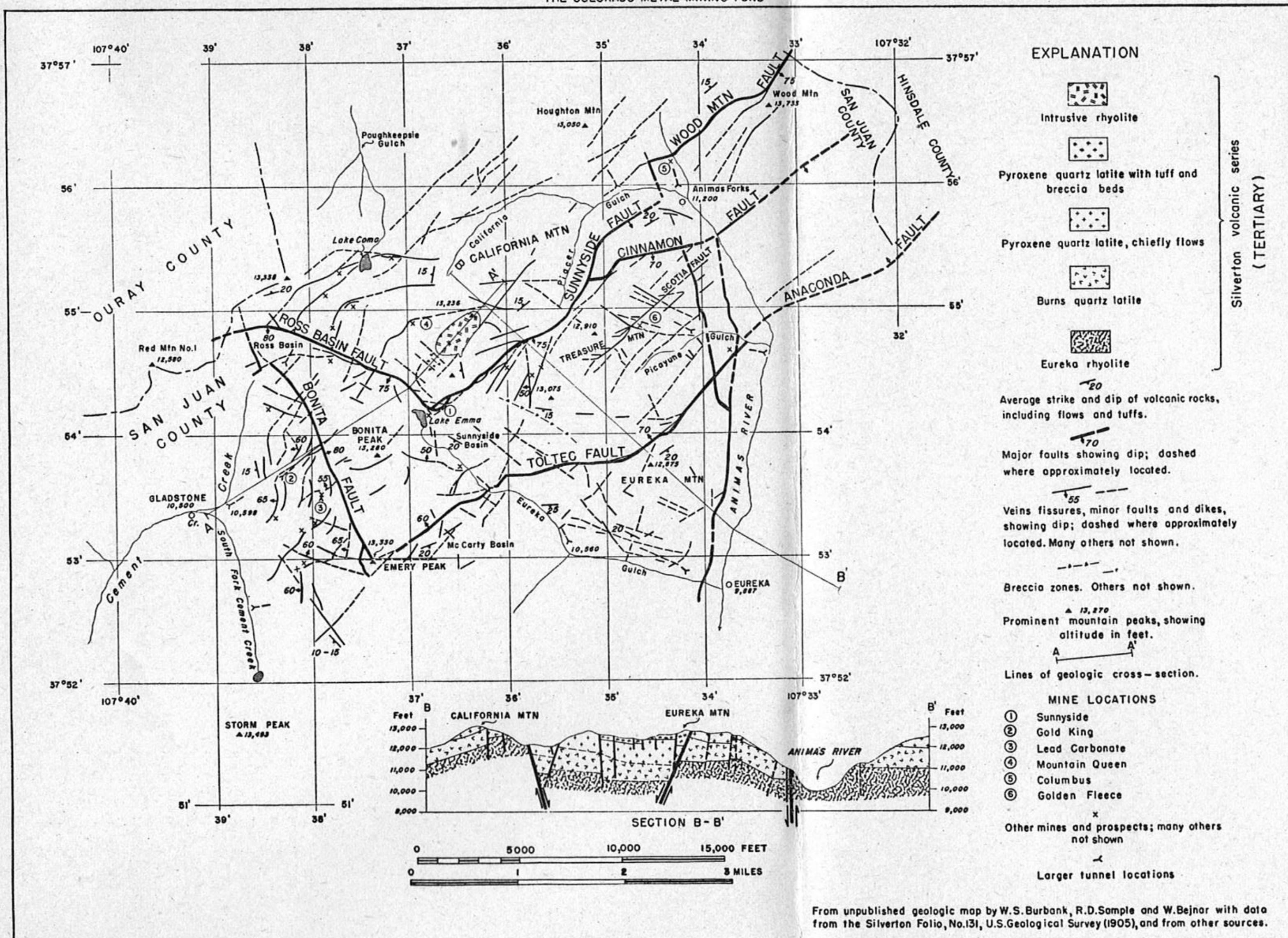

FIGURE 2. – OUTLINE STRUCTURE MAP OF THE EUREKA, ANIMAS FORKS, AND GLADSTONE AREAS, SAN JUAN COUNTY, COLORADO

fault network described in this paper. The Bonita fault zone is a relatively wide broken zone extending from a point just south of Emery Peak for about 3 miles northwestward to a junction with the Ross Basin fault near the head of Cement Creek. The fractured and fissured zone forming the Bonita fault is locally 400 to 500 feet wide, and individual fault fissures dip nearly vertically to slightly northeastward. Tuff beds in the pyroxene quartz latite on the higher slopes, forming the east wall of the fault zone, are tilted eastward. The displacement, where measurable, is locally at least 300 feet and in places may amount to appreciably more than this.

A geologic section across the Bonita Peak fault block is shown in figure 3. This section extends from a point near Gladstone at the southwest across the Ross Basin fault, just west of its junction with the Sunnyside fault, to the ridge of California Mountain. It illustrates the general downward displacement of the rock formations from north to south, owing in part to the Ross Basin fault and in part to the southward tilting of the beds. The formations lie about 2,000 feet lower near Gladstone than on the slopes of California Mountain. The total displacement involved is not very accurately known, since the Eureka rhyolite lies below valley level at Gladstone and the effects of local thickening and thinning of the units cannot be estimated.

In summary, the Ross Basin, Sunnyside, and Bonita faults form the west and southern bounding faults of an elongated structural trough, or graben, projecting northeastward from the downfaulted central block of the caldera floor. The eastern border of this graben is formed chiefly by the Toltec fault. The faults all dip steeply inward toward the center of the graben. The graben is 1½ to 2 miles wide and 8 to 10 miles long, continuing northeast into Hinsdale County beyond the limits of the area under discussion. At the south this main leg of the graben ends in a triangular or boot-shaped termination, which lies within the edge of the downfaulted central block. It is a wedgelike body that tapers downward. The most productive ore deposits of the area

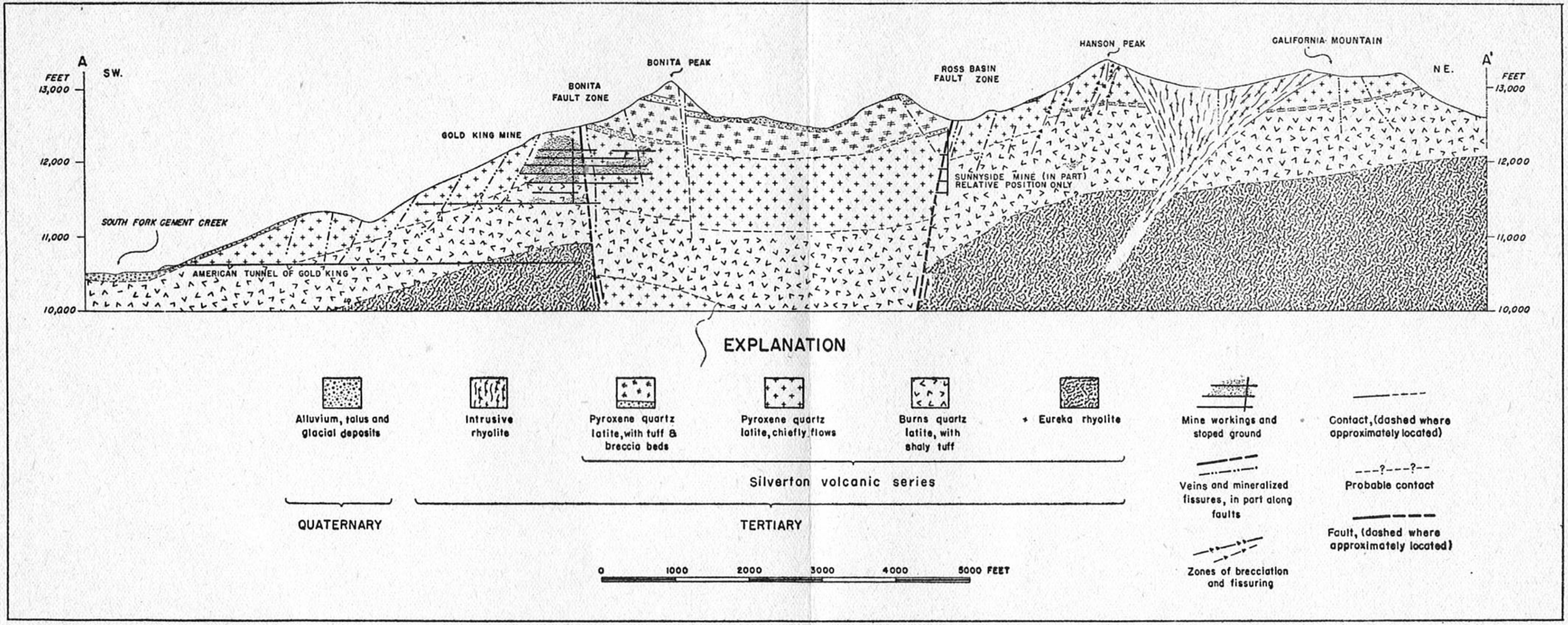

FIGURE 3.- GEOLOGIC CROSS SECTION FROM THE SOUTH FORK OF CEMENT CREEK NORTHEAST TO CALIFORNIA MOUNTAIN

lie near some of the junctions of the main faults bounding this boot-shaped termination or in transverse fissures contiguous to the walls of the bounding faults.

Structural Localization of Principal Ore Shoots

The Ross Basin, Sunnyside, and Toltec faults all contain ore shoots in places along their walls or parallel to them. Some of the larger ore shoots of the Sunnyside mine are alined along either the Ross Basin fault or the Sunnyside fault. No large ore shoots have been developed within the Bonita fault zone itself, although some stretches of it appear moderately mineralized at the surface.

Several mines bordering the boot-shaped termination of the graben have yielded most of the production of the Eureka district. The Sunnyside mine, by far the largest single producer, lies at the junction of the Sunnyside and Ross Basin faults, forming the upper side and instep of the boot. The Gold King, Lead Carbonate, and other mines, yielding about 15 to 20 percent of the production, are along northeast trending veins close to the footwall of the Bonita Peak fault, which form the bottom or sole of the boot.

Many other veins and smaller mines lie throughout the length of and outside the limits of these main fault systems, but their total metal output is relatively small. Mineralization throughout the area is later than practically all of the faulting and fissuring and is clearly controlled by deep fractures and open fissures related to the downsinking and faulting of the rocks.

Many linear miles of fissures containing low-grade veins of quartz, rhodonite, and carbonate gangues are exposed in the area, but the better-grade base-metal and precious-metal ore shoots are of more limited distribution. The largest ore shoots of the Sunnyside mine were about 1,000 to 1,400 feet long and have been mined through a vertical range of about 1,400 feet. Some are known to extend at least 600 feet deeper. In places the ore bodies were 40 to 50 feet from wall to wall. The ore bodies of this mine all occur near or within the strong fault junction formed by the Ross Basin and Sunnyside faults, where the total displacement is 1,000 feet or more (figure 3).

As shown by geologic cross sections across both the foot and leg of the graben, the volcanic formations are tilted away from the graben on all sides. This tilt indicates probably that while the graben was being formed there were periods of alternate tensional and compressional stresses that operated like the opening and closing of the jaws of a crusher. As the jaws opened, the central block wedged downward and when the jaws closed, it tended to force outward and to tilt the bounding volcanic beds and flows. The causes of this action may be related to the repeated welling up of molten rock at depth, followed by loss of pressure and by subsidence of the earth's crust. The final result of these repeated actions was the formation of a crude arch of the volcanic formations with a downfaulted keystone block in the center.

The downward sinking of the keystone blocks produced a wedging action on the surrounding rocks. In some areas bounding the triangular-shaped boot a repetition of uplift and wedging action tended to dilate the fissures close to the footwalls of the main faults. This action is believed to be mainly responsible for localizing the better ore bodies in transverse fissures within a belt 1,000 to 1,500 feet wide along the southwest border of the Bonita fault. A late-stage dilation of these veins also concentrated gold in the earlier-formed base-metal ores. The veins inside the keystone block of Bonita Peak were generally under all-sided compression and hence not as well mineralized.

A somewhat similar dilation of veins is noticeable in the footwall of the Ross Basin fault. But here in addition a number of ore shoots were formed farther from the main fault at "dog-leg" angles formed by intersections of the northeast-trending fissures with east-trending fissures and minor faults. These trend and dip sympathetically to the main Ross Basin fault.

Veins in The West or Footwall of The Bonita Fault

The surface mapping of a belt about 2 miles long and half a mile wide along the west or footwall side of the Bonita fault brings out the pronounced concentration of veins in this belt as compared with the east side of the fault. A number of veins have an east-northeast to east-southeast strike abutting the footwall, and others crosswise to them have a north to northeast strike. Many of the more north or northeast-trending veins dip at relatively low angles to the west. Some of these "flat veins" were local sources of high-grade ore close to the walls of the steeper east-northeast-trending veins of the Gold King mine. Most of these flat veins lie west of or within the footwall belt of the Bonita fault. They are possibly confined chiefly to the shallower flows of pyroxene quartz latite, having resulted from the southwest tilting and stressing of the shallower more brittle rocks in the footwall belt of the fault zone (figure 3). It is thought likely that mineralizing solutions were fed into the flat veins through the steeper east-striking fissures, which in turn were fed at greater depths by solutions rising along the fractured footwall of the Bonita fault zone.

The relations of the known productive ore bodies of this footwall belt to the Bonita fault are especially instructive with regard to the possibilities of future exploration and development in this area. Two noteworthy groups of ore bodies are those developed by the Gold King and Lead Carbonate mines (Nos. 2 and 3, figure 2). The Gold King mine was primarily a gold and silver producer, but lead and copper constituted a little more than 15 percent of the monetary value of its ores in the period of operation between 1898 and 1925. Zinc was not recovered and contributed only penalties so far as the value of the ore was concerned. In the Lead Carbonate ore shoot the base-metal values have amounted to 45 percent or more of the gross value of the ore,[5] although only about 37 percent of the gross value of these base metals was realized in smelter returns.

[5]Ehrlinger, H. P., The relation of heads values, metal payments and net returns to the various metals in a typical San Juan ore, Mining Year Book, Colorado Mn. Assoc., p. 39, 1949.

More modern methods of milling have of course benefited the recovery of metals from the Lead Carbonate ore mined in recent years. As estimated on a gross basis these two veins, with minor production from other veins in the footwall belt of the Bonita fault, have yielded roughly 15 percent of the total output of the area contiguous to the main fault systems shown in figure 2.

The main workings of the Gold King mine are no longer accessible, but records and mine maps indicate that the main ore shoots lay in veins of northeast strike and steep dip. About four-fifths or more of the mine workings lay in the west or footwall side of the Bonita fault and extended about 600 feet west of the center line of the fault zone. Some additional ore bodies were found, however, about 500 feet east of the center line, in the hanging wall of the fault (figure 3). It is to be noted also that the main ore shoots of the Gold King have a tendency to lengthen downward to a depth of at least 700 feet. This lengthening is conceivable due in part to the structural influence of the numerous flat west-dipping veins in the football of the Bonita fault. These may have acted as baffles or channels tending to deflect the ore solutions eastward and back against the footwall of the fault as they ascended. There is within the edge of the fault zone itself a vein known as the Red vein, which was described by Ransome.[6]

This vein displaced the northeast-trending veins in the upper levels 30 feet or more to the left. The Red vein dipped about 75° eastward and is probably a strand of the Bonita fault. It contained chiefly rhodonite and 50 years ago was considered low in metal values. A similar bending and displacement of the veins was noticeable at deeper levels. Other cross-faulting is recorded locally on old mine maps across a belt 600 feet or more in width. As noted above, the intersections of the steep veins with the flat west-dipping veins yielded local shoots of ore, but the details of these ore bodies are not recorded.

[6]Ransome, F. L., Economic geology of the Silverton quadrangle, Colorado: U. S. Geological Survey Bull. 182, pp. 254-256, 1901.

The Lead Carbonate ore shoot also lies close to the footwall of the Bonita fault. Unlike the Gold King vein, it dips 50° to 70° northward, but it is likewise of nearly east strike. The ore shoot developed lies entirely in the footwall of the Bonita fault, and attempts to follow the vein eastward and across the fault zone were unsuccessful. The ground for 500 feet or more is highly fractured and altered, and fissuring along the trend line of the vein is discontinuous. Westward from the fault the vein is cut by cross-fissures of westward dip belonging to the more northerly striking systems of fractures. Near the surface the known ore bodies do not extend more than 600 feet west of the center of the Bonita fault zone, and the longest base-metal and precious-metal shoot was about 300 feet. Development has not been sufficient to determine if the shoot lengthens appreciably in depth, although cross-veining and fracturing indicate a similarity to the structural controls of the Gold King ground.

As in other parts of the region, gold was concentrated relatively late in the sequence of vein formation, and its relative concentration in the ores of the Gold King and Lead Carbonate veins appears indicative of a late-stage dilation of veins in the immediate footwall zone of the Bonita fault. Westward toward the valley of Cement Creek and its South Fork the ores in all the vein systems appear to become increasingly pyritic and generally lower in precious-metal content. Also along the east side of Cement Creek north of Gladstone local bodies of mineralized breccia are characterized by very heavy concentrations of pyrite, which may be related genetically to the pyritic alteration so widespread in the Red Mountain area west of Cement Creek. The oxidation and leaching of these bodies has formed conspicuous accumulations of iron oxide in the glacial and alluvial beds along the bottom of the valley.

The Bonita-Toltec Fault Junction

The Bonita and Toltec faults form a junction or intersection at the heel of the boot near the crest of Emery Peak at an altitude above 13,000 feet. Although geologic study of this area is not complete, some apparent features of the intersection may be brought to attention. As seen on figure 2, this junction might be thought to be similar to that of the Ross Basin and Sunnyside faults. It is actually quite different in some important structural features. The Bonita and Toltec faults possess a common hanging wall in the enclosed angle between them whereas the Ross Basin and Sunnyside faults have a common footwall in the enclosed angle. Another feature of possible significance is the occurrence of an intrusive rhyolitic plug within the common footwall block of the Ross Basin-Sunnyside faults. The upward thrust of this intrusive body may have played a part in raising or supporting the common footwall block of the Sunnyside and Ross Basin faults. No such intrusive body has yet been recognized in the Emery Peak area. These differences could be of some influence in controlling the occurrence of ore shoots. It may be mentioned that one of the strong east-southeast-striking veins of the area joins the junction just west of Emery Peak. Whether or not these junctions are strongly mineralized at depth remains to be determined. The area appears worthy of serious consideration in future exploration. The higher slopes of the Emery Peak stand above 13,000 feet, and the ground beneath the Peak is relatively remote from present mine developments.

THE BONITA-ROSS BASIN FAULT JUNCTION

The Bonita fault and the Ross Basin fault join near the head of Cement Creek in a network of faults and fissures, many of which are partly concealed beneath the glacial and alluvial deposits of the valley. The branches and offsets of the faults in a relatively narrow wedge between the main faults form a broken block of highly mineralized but not very productive ground.

The operations of the Great Mogul mine lying near the head of Cement Creek are the most extensive in the area. The main workings were evidently chiefly in the vicinity of the Ross Basin fault and its hanging-wall fractures. The ores were relatively high in iron and zinc and presented insurmountable metallurgical difficulties during the period of operation. The structural relations of the ore shoots are not known in detail by the writer.

In some veins just south and west of the fault junction the ore minerals have replaced flat-lying partings of shaly tuff and sheared rock between the lava flows. Mineralogically they are somewhat like the pyritic veins along Cement Creek and its South Fork west of the Bonita fault zone farther south.

Veins in The Footwall of The Ross Basin Fault

The footwall belt of the Ross Basin fault contains a number of productive veins that join the fault nearly at right angles. As shown on figure 2, many of these veins take sharp eastward turns or bends at a distance of a few thousand feet north of the fault. These bends are due to intersections with a strong system of nearly east-trending fissures and minor faults that are generally of steep south dip and have been downthrown toward the south in the same manner as the Ross Basin fault. The influence of this system may also be noted still further east on California and Treasure Mountains.

The more conspicuous shoots of ore in the belt north of the Ross Basin fault are commonly to be found near the bends or "dog-leg" angles between the northeast and east-trending fissure systems. The Mountain Queen, Mountain King, Queen Anne, Cashier, Bonanza, and Belcher veins are examples of such shoots. Some of these are identified on the map, and other veins of this group are indicated by crosses. This belt of similar structural controls and mineralization in the footwall of the Ross Basin fault is about a mile wide and extends into the headwaters of Poughkeepsie Gulch at least to the vicinity of Lake Como.

The Ross Basin fault itself has localized a number of ore shoots within branches of the fault or in its immediate walls. The George Washington ore shoot of the Sunnyside mine in the Ross Basin fault zone near its junction with the Sunnyside fault has been one of the most important ore shoots of the district. It is about 1,000 feet long and has been mined to a depth of about 1,400 feet when operations of the mine ceased. The ore shoot lies between walls of pyroxene quartz latite and Burns quartz latite.

Base-metal and gold-silver production from the smaller veins along the Ross Basin fault zone and from the veins in the footwall belt has been relatively minor and chiefly from shallow workings. Although production records are incomplete, the total production is somewhat less than 5 percent of the total for the area.

Veins Along The Northeast Fault and Fissure Systems

The most productive veins of the northeast fault and fissure systems are those tributary to the Sunnyside fault near its junction with the Ross Basin fault. These include the Sunnyside, Sunnyside Extension, and No Name veins and others extending about 2,000 feet northeast from the junction. The longest single ore shoot of this group was about 1,500 feet in length along the strike. Still other veins occur in an area extending about a mile northeast of the junction and over a width of half a mile or so in the hanging wall of the Sunnyside fault. A few veins extend also into the footwall of the fault, splitting off as a result of the influence of the east-trending fissure system noted in the wide north of the Ross Basin fault.

General Conclusions

Both from the statistics of past production and from the surface expression of faulting and mineralization, the most favorable areas for major development lie near the several major faults and their junctions at the boot end of the graben. Most of the past production has come from between walls of pyroxene quartz latite or between walls of this rock and Burns quarty latite. Ores at the Sunnyside-Ross Basin fault junction probably extend to a depth of 10,000 feet or more. The effects of deeper-lying rocks, such as the Eureka rhyolite, on the productivity of veins may be governed in part by the local strength of fissuring. Many years ago Purington[7] postulated that the ores of these areas were confined to the younger and shallower formations, chiefly the "pyroxene andesite" of Cross, Howe, and Spencer, as defined in the Silverton folio. He believed that the veins diminished in value as they entered the older or underlying more siliceous formations. These would include the Burns quartz latite and the Eureka rhyolite. However, from the structural conditions outlined above, it seems more clearly true that the major faults and their junctions, with attendant subsidiary fracturing, have a dominant effect on ore-shoot control, and that this effect locally outbalances the adverse effects of relatively less favorable wall rocks. Each ore shoot and area thus involves special problems that must be considered in relation to the regional and local structural controls, to the fracturing characteristics and other effects of enclosing rocks, and to the strength of mineralizing processes.

The general relations of the more productive ore bodies to the several fault systems and the lack of systematic exploration in some parts of the fault systems and contiguous belts of mineralized ground indicate that the productive potentialities are not exhausted. The more favorable ground includes the footwall belt of the Bonita fault, parts of the wide mineralized belt in the footwall of the Ross Basin fault, and probably some ground contiguous to the junction of the Sunnyside-Ross Basin faults at greater depths or in the hanging walls and footwalls of the major faults that have not already been thoroughly prospected. Some suggestions for prospecting bearing on these particular blocks of ground may be summarized briefly.

If the Gold King and Lead Carbonate ore shoots can be considered representative of structural localization of shoots close to the footwall of the Bonita fault zone, they afford clues to the most effective exploration of the Bonita fault belt as a whole. As the Bonita fault lies high on the upper slopes of the 13,000-foot ridge between Bonita and Emery

[7]Purington, C. W., Treasure Mountain, Colorado: Min. and Sci. Press, vol. 97, pp. 23-25, 1908.

Peaks, the footwall of the fault zone has been approached at depth in only one place, and that is near the heading of the American tunnel of the Gold King mine, as shown in figure 3. The heading of the tunnel doubtless closely approaches the fault zone or possibly penetrates it, but neither lateral nor vertical development work has been done to any extent, and the tunnel was never connected with the mine workings which are more than 800 feet above. Therefore, little information is available as to possible vertical changes in the character of fissuring and mineralization with depths approaching the practicable limit of deeper tunnels. Several other transverse veins along the length of the fault belt bear relations to the fault similar to those of the Gold King and Lead Carbonate vein systems. Further studies of the potentialities of these veins as well as the west-dipping cross veins of this belt appear worthy of particular consideration in any long-range development of the area. The possibility that some shoots may tend to shorten at higher altitudes may be an important consideraton. The effect of this shortening, coupled with the concentration of higher-grade ores in a relatively narrow block of ground closely abutting the fault, is illustrated in figure 3, which is a typical profile across the Bonita fault. It is evident that the potential importance of some shoots of ore cropping out at high altitudes may be difficult to evaluate.

While these features are all relatively favorable to the existence of undeveloped potentialities, there is a possibility of relatively unfavorable rock characteristics and other changes at depth that are not entirely evaluated from surface studies. But such possibilities can generally be evaluated correctly as judicious exploration is carried forward.

The further exploration and development of known and potentially productive ground near the Ross Basin-Sunnyside junction are justified by past production. The exploration of ground outward at depth from this most productive center is of course a logical way to expand the area of development along and near both the Sunnyside and the Ross Basin fault systems and their contiguous veins. The footwall area of the Ross Basin fault and both the footwall and the hanging wall of the Sunnyside fault include examples of shallow ore shoots that may have counterparts at greater depth.

The ores of these several belts surrounding the boot of the structure are much alike in mineralogical characteristics, containing zinc and lead in the ratio of about 2 to 1. The ores are all relatively high in iron and contain quartz and rhodonite as the dominant gangue minerals. Gold is introduced chiefly late in the mineral sequence. It appears likely therefore that the ore-forming solutions have a common source beneath the downfaulted keystone blocks and rose along active belts of fissuring chiefly in the main faults and their footwalls. Nearer the surface the solutions also became dispersed into subsidiary fissures formed and kept open by the wedging and dilating action of the keystone blocks. Concentrations of gold that may locally enhance the value of base-metal ore appear likely to be found in much more restricted parts of the vein systems that have been dilated by late-stage settling of the fault blocks. Vein intersections and transverse fissures in the immediate footwalls of major faults are among the more favorable places. In other situations transverse hanging-wall fissures may have provided channels through which the gold-bearing solutions could have leaked more readily than through the highly compressed walls of major fault systems. Many of these details must of course be worked out independently for each block of ground under study.

Although this review is by no means the complete story of all fissuring and mineralization in the area under consideration, it covers the key structural features with which the most productive ore bodies are associated.