on T.A.L.

LITHOLOGIC CONTROL OF ORE DEPOSITS IN THE SAN JUAN MOUNTAINS, COLORADO

37

May 28, 1947

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M.A. June 1947

Frontispiece
Typical View in the San Juan Mountains showing
Volcanic Formations

TABLE OF CONTENTS

TABLE OF CONTENTS (cont.)

ILLUSTRATIONS

ILLUSTRATIONS (cont.)

INTRODUCTION

The selection of ore-depositing horizons by ore-bearing solutions has long been a problem of great interest to geologists and miners. The ability to predict which beds were favorable to ore deposition and which were not can greatly facilitate prospecting and the development of a district. During a summer's field work in the Silverton quadrangle with the U.S. Geological Survey, the writer was made acutely aware of the fact that no acceptable order of favorableness to ore had been worked out for the beds of the Silverton quadrangle. Inspired by the desire to contribute to the solution of this important problem, the writer undertook this paper.

The San Juan Mountain region was selected for study because of the need for such information about the region and because the writer is best acquainted with that area. Only the larger camps of the San Juan region were studied, they include the districts of Ouray, Silverton, Telluride, Lake City, Creede and Bonanza.

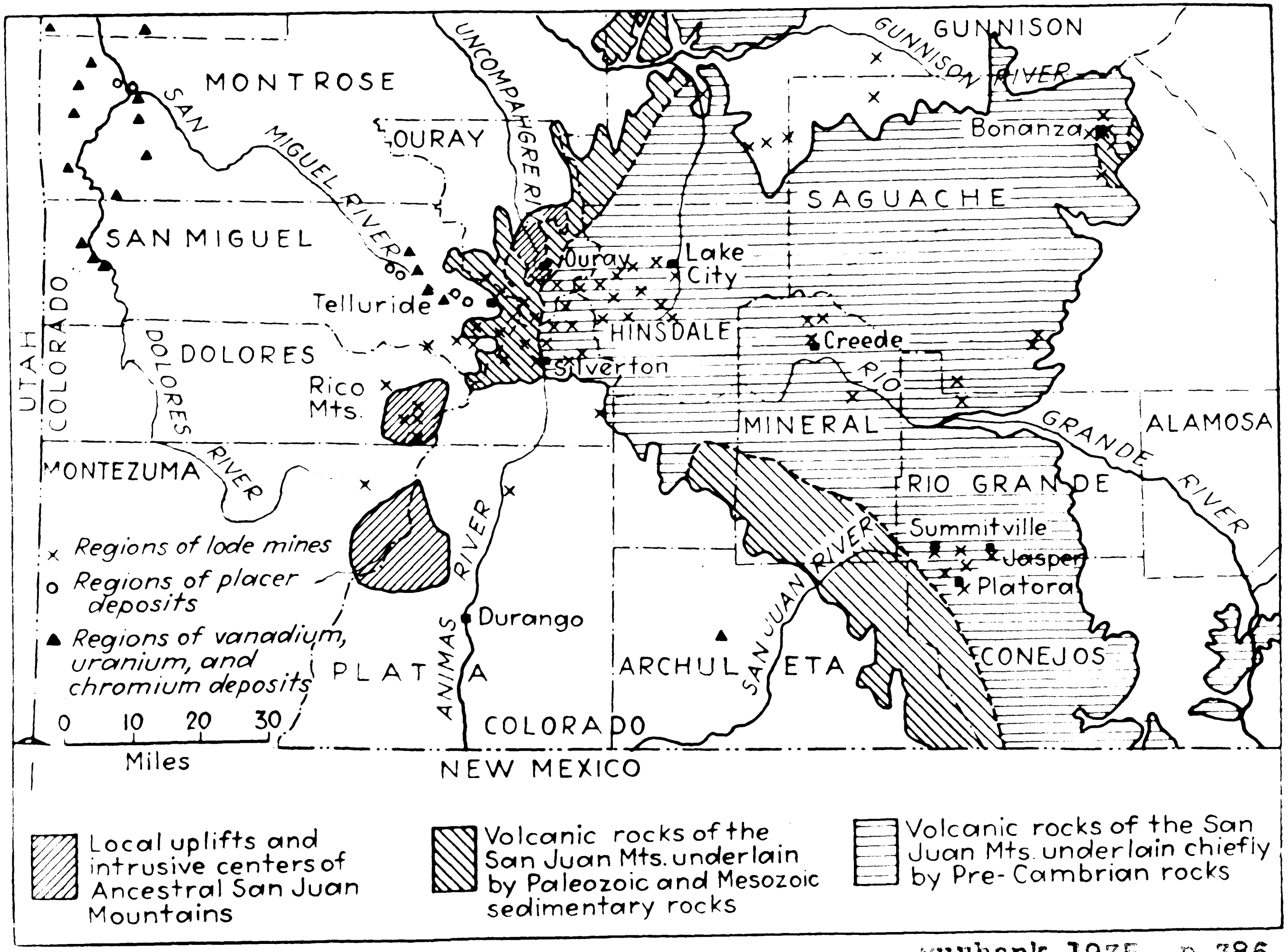
In this search the following techniques for judging favorableness were used: 1. The opinions of the authorities for the districts in which they specialized, 2. Independent conclusions determined from close scrutiny of available published information, 3. The statistical approach representing graphically the total value of ore produced, the number of mining years and the total number of mines in a particular formation.

ACKNOWLEDGMENTS

This report is based primarily on information in the publications listed in the bibliography. From them information has been drawn freely. All the data and ideas set forth concerning the Ouray district come from the reports of W.S. Burbank. The description of the tectonics of the Silverton district comes from the work of W.S. Burbank, but most of the statistics come from F.L. Ransome's report. The descriptionsof tectonics near Telluride are taken from the publications of W.S. Burbank, and the mine descriptions come from C.W. Purington's report. The information on the Lake City district came entirely from the work of J.D. Irving and Howland Bancroft; that on the Creede district comes from reports by W.H. Emmons and E.S. Larsen; for the Bonanza district the data presented was found in the publication by W.S. Burbank and C.W. Henderson.

I desire also to acknowledge the constructive criticism of this manuscript made by Messrs. T.S. Lovering, C.S. Slawson and K.K. Landes. Thanks are due Katharine Bejnar and T.S. Lovering for encouragement and assistance in the preparation of the entire report.

FIG. 1 **SAN JUAN MOUNTAINS in Southwestern Colorado, showing distribution of volcanic formations and the underlying sedimentary rocks and principal areas of mineralization**



Burbank 1935, p.386

Table 1

Tabular Summary of Mineral Deposits of the San Juan Region

Metallogenetic Epoch	Environmental Conditions and Processes of Concentration	Form of Deposits and Metal Concentration	Production[1]
I. Pre-Cambrian	Deep erosion exposing schists and gneisses invaded by batholithic granite and diorite.	Chiefly veins containing gold or copper ores	
II. Jurassic	A. Continental sedimentation on the peneplained borders of Paleozoic and Pre-Cambrian ranges. Sandstone deposits, resting on Pre-Cambrian.	A. Minor placer concentration of gold, probably from the Pre-Cambrian veins.	None
	B. Continental sedimentation and groundwater movements around borders of Paleozoic and Pre-Cambrian uplifts. Sandstone deposits of Triassic and Jurassic age, resting upon Mesozoic or Paleozoic sedimentary rocks.	B. Chiefly concentrations of vanadium, chromium, and uranium. Replacement deposits in sandstones. Minor veins in sandstone.	3,054,374 lb. vanadium 1909–1923[2]
III. Eocene or late Cretaceous	Development of Ancestral San Juan Mountains Stock-like and laccolithic intrusions of diorite, granodiorite, granite, and related rocks, generally porphyritic. 5,000 to 10,000 ft. of sedimentary cover; chiefly Cretaceous marine shales in upper part.	Veins, tubular or tabular replacement bodies, and transitional forms. Lead, zinc, silver, and gold ores.	$35,500,000 (approximate only to 1933). Au:Ag::1:50
IV. Late Eocene or Oligocene	Continental sedimentation on peneplained surface of Ancestral San Juan Mountains. Conglomerate, sandstone, shale.	Minor placer concentration of gold. Probably derived from gold deposits of III.	None
V. Middle to late Tertiary	Development of younger San Juan Mountains A. Several hundred to 5,000 ft. of volcanic rocks, resting chiefly on Pre-Cambrian rocks. Cut near local volcanic centers by igneous stocks and large fault zones.	A. Chiefly vein deposits in the Tertiary volcanic rocks. Minor veins in underlying Pre-Cambrian rocks. Local stockworks or pipes. Silver, gold, and base-metal ores.	$165,000,000 (approximate to 1929). Au:Ag::1:57
	B. (Chiefly in western marginal part of San Juan uplift). Blanket of sedimentary rocks up to 4,000 ft. in thickness, from which Cretaceous shales have been largely removed, covered by several thousand feet of volcanic rock. Sedimentary and volcanic rocks cut by igneous stocks.	B. Chiefly veins in Tertiary volcanic rocks. Smaller veins in underlying sedimentary rocks. Minor small lateral replacement bodies in sedimentary rocks near veins. Silver, gold, and base-metal ores.	$180,000,000 (approximate to 1929. Probably less than $5,000,000 from sedimentary rocks). Au:Ag::1:18
	C. (Western marginal part and outlying stocks and sheets in sedimentary rocks.) 4,000 to 8,000 ft. of sedimentary cover, including Cretaceous shales, in part overlaid by volcanic accumulations up to a few thousand feet in thickness.	C. Veins in both volcanic and sedimentary rocks. Disseminated ore in the sedimentary beds. Chiefly silver and gold ores.	Production not definitely known, but probably less than $10,000,000.
VI. Quaternary to Recent	A. River valleys, flood plains, terraces. Canyon cycle of erosion. Gravels and sands.	A. Placer concentrations of gold.	$250,000

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[1] Production based upon preliminary classification of deposits, and records in Prof. Paper 138, "Mining in Colorado," by C. W. Henderson (1926) and later records of the U. S. Bureau of Mines.

[2] Including deposits of the San Miguel Valley near the San Juan Mountains, only: Hess, F. L.: Uranium, Vanadium, Radium, Gold, Silver, and Molybdenum Sedimentary Deposits. "Ore Deposits of the Western States." Lindgren Volume (A. I. M. E.), p. 461, 1933.

Burbank 1935, p.389

THE SAN JUAN MOUNTAIN REGION

GENERAL FEATURES

The San Juan Mountain region of southwestern Colorado has an area of about 12,000 square miles, approximately the size of the states of Massachusetts and Connecticut combined. The greater part of the region is occupied by a group of high and rugged mountains, many of the peaks exceeding 13,000 feet. These mountains are formed chiefly of Tertiary volcanics or pre-Cambrian rocks but also contain some sedimentary formations.

The "Tabular Summary of Mineral Deposits of the San Juan Region", table 1, is presented to give the reader the environmental conditions of ore deposition and a general idea of the production value of the several epochs.

The geographic location of the several mining districts and an outline of the San Juan Mountains are shown on figure 1. More detailed maps of several districts are included in the body of the report.

The three mining towns of Ouray, Telluride and Silverton are in the extreme western part of the San Juan Mountains and are the most important mining centers in the San Juans. (See Figure 1) This region has a complex geologic history,but only the salient features of the geology need be reviewed here in order to acquaint the reader with the physical environment at the times of mineralization.

GEOLOGIC HISTORY [1]

At the beginning of volcanic activity in late Cretaceous or early Eocene time the western San Juan region was covered by upper Cretaceous formations at least 4,000 feet in thickness. These beds

[1] Burbank, 1930, pp. 208-210

were unconformably covered by late Cretaceous or early Eocene formations which contain volcanic debris and so overlap as to indicate a domal uplift of the region. This uplift was accompanied by the intrusion of monzonite porphyry mainly in the form of stocks and laccoliths. At the close of this igneous activity the first period of ore deposition took place.

During Eocene time erosion carved this great dome into the first generation San Juan mountains. The high altitude gave rise to glaciation for a time, but continued erosion finally culminated in the formation of the Eocene peneplain. In the central part of the eroded dome, except where protected by the resistant monzonite porphyry, the upper Cretaceous formations were entirely removed, and the older formations were extensively eroded. During this long period of erosion in early Eocene time some of the mineral deposits must have been totally destroyed, while others, notably those in the sedimentary rocks at Ouray, were partly exposed to weathering.

In later Eocene time the Telluride conglomerate was deposited upon the peneplain. Minor concentrations of gold occurred in some of the stream deposits.

Following the deposition of the Telluride conglomerate there was another period of erosion which was followed by the great Tertiary volcanic eruptions that formed the San Juan tuff, the Silverton series, and the Potosi series. These eruptions occurred during Oligocene or Miocene time, forming a volcanic plateau and burying the ore deposits of the first epoch to a great depth. After the eruption of the Potosi lavas, the second major group of intrusive rocks penetrated the younger volcanic formations.

Widespread fissuring and some tilting were contemporaneous or slightly later. The second major mineralization of the San Juan region closely followed these disturbances.

With the cessation of volcanic activity, the erosion and dissection of the volcanic plateau went forward rapidly, and another generation of the San Juan mountains was formed. After a considerable period of erosion, warping or doming of the mountain area again occurred, and deep valleys were cut by the rejuvenated streams which were later occupied by early Pleistocene glaciers. Uplift continued through Pleistocene time and streams are now still actively cutting their valleys. Some gold was concentrated in placers during the Pleistocene and Recent.

METALLOGENETIC EPOCHS [1]

The conditions that favored laccolithic intrusions during late Cretaceous and early Eocene time also favored the development of "blanket" replacement deposits. The Ouray stock pierced the Mancos shale forming fissures in and close to it which permitted the escape of gases and vapors to the surface. In the surrounding area fissures penetrated upward into the yielding shales for only short distances, and ore depositing solutions rising along them were forced to spread laterally and seek other channels to places of lower pressure.

Sedimentary beds of comparatively great permeability therefore served as channels of lateral diversion of the ore-bearing solutions. Those permeable beds that were overlain by impermeable shale horizons were especially favorable for diverting the solutions for great distances in nearly horizontal directions.

1. Burbank, 1935, p. 388

Replacement ore deposits of the blanket type were therefore formed in a number of these beds. In the Ouray district there are also early Tertiary fissure veins and some contact-metamorphic deposits near the Ouray stock.

The ores of the first period, early Eocene, contain gold, silver, lead, zinc and minor amounts of copper. See division III, table 1. The most important of these deposits near Ouray have been the lead-zinc veins with associated replacement deposits containing high grade silver ores. Low grade lead and zinc replacement deposits with much barite are particularly characteristic of this period. The gold-bearing ores differ from the gold-bearing deposits of later Tertiary age in that they are generally pyritic and contain tellurides associated with native gold. They are of somewhat less economic importance than silver ores and comprise both veins and "blanket" deposits.

The geologic conditions during the second important metallogenetic epoch are well shown near the Ouray district, where a large part of the upper Cretaceous sedimentary rocks had been removed by erosion before the building of the Tertiary volcanic plateau. The late Tertiary intrusions invaded a cover consisting of the more rigid Paleozoic and pre-Cambrian rocks, and great thicknesses of rigid volcanic formations. Under these conditions the fissures that were formed extended from great depths probably to the surface of the volcanic plateau. The conditions which were responsible for the lateral diversion of the metal-bearing solutions in the first epoch had been largely destroyed by erosion, and as a result the tendency for the formation of blanket type deposits was generally absent during late Tertiary time. Although some ore deposition did take place in the underlying basement of sedimentary and metamorphic rocks, the most important ore deposits of this period have been found within the volcanic formations. The Creede and Bonanza deposits belong to this epoch.

The ores of the late Tertiary period are like those of the first period containing the metals gold, silver, lead, zinc and copper, but the deposits are of somewhat different character mineralogically. The principle gold deposits of this period consist of native gold in quartz veins, as contrasted with the pyritic ores of the first epoch. The silver-bearing veins appear to differ somewhat in the details of their mineralogy, but the relative proportions of the different metals in the deposits of the two periods is as yet unknown.

The final epoch of gold concentration in the San Juan Mountains was associated with the formation of stream deposits during Pleistocene and Recent time. These placers have proved of greater economic importance than those in the Telluride conglomerate.

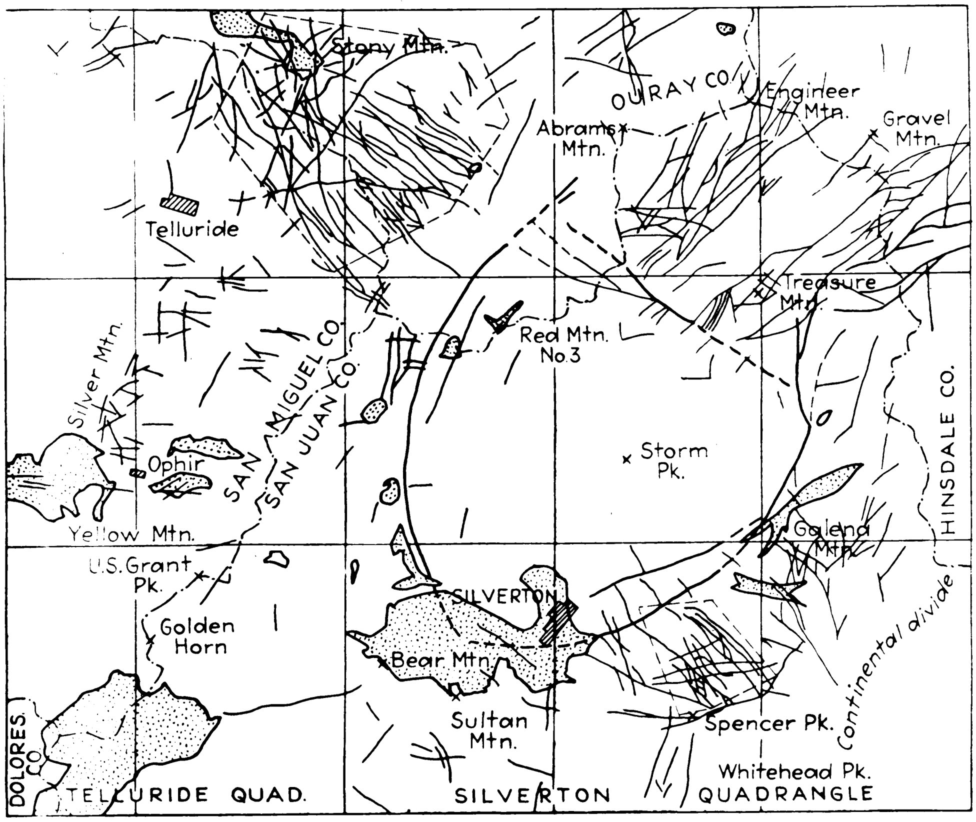
REGIONAL STRUCTURE

W.S. Burbank's work[1] shows that the largest single structural unit controlling ore deposition centers in the Silverton Quadrangle. The area affected is 250 to 300 square miles, and about 75 per cent of the total production of middle and late Tertiary formations has come from deposits structurally related to it.

The core or hub of this structural unit is a down-faulted triangular block that represents a volcanic sink or caldera about eight miles in diameter. Most of the dikes and veins are arranged radially

1. Burbank, 1935, p. 389

FIG. 2 **FRACTURE SYSTEMS** in pattern and principal crosscutting intrusive bodies in the Silverton quadrangle and eastern part of the Telluride quadrangle. Two areas which have been mapped on a scale of 1 in. equals 1,000 ft. are outlined by light dashed lines



Burbank 1935, p.388

about this block like the spokes of a wheel, though a few are concentric and parallel to its margins. Several intrusive igneous bodies are grouped around the margin of the block and in the outlying positions five to eight miles from the margins. Radial fissures connect these outlying centers of intrusion with the central block as shown on the fracture system map, figure 2. The distribution of the different kinds of ores shows that the zoning is outward from the central structure and more or less independent of the exposed igneous bodies.

The ore deposits of these districts are recognized as belonging to three geologic and metalliferous provinces. 1. The early Tertiary Ancestral San Juan Mountains; 2. The late Tertiary San Jaun Mountains; 3. The outlying districts mineralized in pre-Cambrian and Tertiary time. At Ouray, Colorado ores formed in the sedimentary rocks near the quartz monzonite stock are of early Eocene age. The sediments have locally undergone contact metamorphism and hydrothermal mineralization.

These deposits range from low sulfide magnetite and lime silicate ores to massive pyrite bodies with some galena and sphalerite. Locally they are enriched in gold along small late fissures cutting the massive sulfides. From half to three-quarters of a mile north of the stock the principle ores are pyritic replacement deposits in the Dakota (?) quartzite with minor amounts of sphalerite, galena-chalcopyrite and tennantite. The chief value of the deposits is due to the late stage of mineralization confined to the vicinity of the fissures or to the blanket bodies beneath the impervious shales, where tetradymite, gold and silver tellurides, native gold and other minerals of hypogene origin enriched the early primary replacement deposits. The gangue minerals are sericite, quartz and a little barite. The ores from one to three miles north of the stock are chiefly barite lead-zinc veins and associated blanket replacement deposits along the porous Jurassic limestone and other favorable beds. The ore value is dependent to a large extent on the argentiferous tetrahedrite, pearceite and other silver-bearing minerals; the gold content is low. The gangue is quartz, barite, ankerite, and manganiferous calcite. The picture of zoning is somewhat obscured by the late Tertiary volcanic formations that effectively conceal the substratum. These deposits are considered to be mesothermal.[1]

The greater part of production in the San Juan region is from deposits of late Tertiary age, which have been assigned to the epithermal zone. Most of the deposits cluster around the caldera in the Silverton quadrangle. The ores occur chiefly in the simple fissures that radiate from the sunken block. Other veins and dikes are disposed concentrically around the block or diagonally to its faulted margins. The abundance of base-metal ores near the margins of the sunken block and its radial fissures, as well as the position of gold-silver ores of low base metal content in more distant fissure systems, shows that ore zoning was controlled chiefly by the major structural feature. The fact that the veins intersect the exposed intrusive bodies and show little zonal relation to them indicates that the ore depositing solutions were derived chiefly from deep-seated igneous bodies other than those now exposed at the surface. Outlying stocks may be connected with the margins

1. Loughlin, 1936, pp. 442-443.

of the sunken block by zones or swarms of dikes and veins. The massive base metal ores occupy a zone that extends one to four miles from the marginal faults. The ore minerals are pyrite, sphalerite, galena, chalcopyrite, native gold, argentiferous bismuth and lead-bismuth. The gangue minerals are quartz rhodonite, other manganese silicates, alabandite, rhodochrosite, manganiferous calcite and adularia. Beyond this zone the veins are commonly mixed base-metal and silver-gold ores with more barite in the gangue. The distant zone shows greater variations than the nearer zones, and its deposits may be divided into three groups.[1] 1. Ores containing sulpho-bismuthites of lead and silver, tetrahedrite and gold, with a gangue of rhodochrosite and manganiferous calcite; 2. Gold, ores with silver sulpho-salts with a gangue of banded jaspery quartz; 3. Silver ore containing pearceite, tennantite, argentite, stephanite, gold, selenium and tellurium minerals with a gangue of quartz and calcite.

The geologic formations found in this area range from pre-Cambrian rocks through Paleozoic sediments to a thick capping of Tertiary volcanics. The stratigraphic column is shown in figure 3. A more detailed description follows in the discussion of the Ouray mining district.

The eastern San Juan Mountains are mainly a very large volcanic plateau made up of a thick series of lavas which have almost completely covered the underlying rocks and effectively covered the Laramide structures. The ore deposits are in the volcanic formations and closely associated with faults. No general structure is apparent in the San Juan volcanic field west of the Silverton-Lake City area; the various mining districts display structural

[1] Loughlin, 1936, pp. 444-445

features that seem related to local volcanic centers rather than to widespread tectonic features.

The Bonanza district is just west of the boundary between the strongly folded and faulted Paleozoic and Mesozoic rocks of the Sangre de Cristo structural province on the east and the San Juan volcanic field on the west. These great geologic units of southern Colorado are separated by the San Luis Valley which is filled with late Tertiary sediments and recent alluvium. It is probably a large syncline cut by a great fault along the west border of the Sangre de Cristo range.

West of the San Luis Valley in the Kerber Creek region near Bonanza the Paleozoic formations are exposed locally. They are involved with the pre-Cambrian in a series of northwestward striking folds and upon these flexures are superimposed a series of thrust faults striking east to southeast and dipping south to southwest. In most places Tertiary volcanic rocks reach to the edge of the San Luis Valley and obscure the structure of the pre-Tertiary basement. The volcanic rocks are strongly faulted in the Bonanza district, and the fault pattern suggests collapse of a local dome.

In the vicinity of Creede the bedrock exposed is entirely of Tertiary volcanic rocks and forms part of the great volcanic field of the San Juan Mountains. Lava flows form the greater part of the terrain, but there are tuff and breccia deposits as well as small intrusive bodies. The chief deformation of the region has been rather complex block faulting, with some tilting near the faults. The faults are believed to be later than any of the volcanic rocks in the area, and they are earlier than the development of the present topography. The area has been gently tilted toward the south.

LITHOLOGIC CONTROL OF ORE DEPOSITION

SUMMARY OF GENERAL FEATURES

The country rock and the conditions at the time of mineralization differed considerably in the various districts of the San Juan region. Therefore it is not surprising to find differences in the lithologic control of ore deposition in the several districts. Generalizations concerning the lithologic controls have been restricted to one district or part of one district by earlier writers. However, this writer believes it is now possible to recognize some similarities in lithologic controls of deposits in several districts.

It is the writer's opinion that permeability is the most important single characteristic in determining the site of ore deposition in the San Juan region. The kinds of permeability recognized are classified as original permeability, permeability due to leaching, and fracture permeability. Included in fracture permeability are: 1. Small scale fractures formed in rocks when the stress has but slightly exceeded the elastic limit of the rock, 2. Large scale fractures formed when the stress has greatly exceeded the elastic limit of the rock, i. e. strong faults. The structural features that guided the moving ore-bearing solutions probably owed their effectiveness chiefly to the differences in the permeability caused by the structures. Thus open fractures allowed solutions to rise from depth, but cap rocks which effectively closed fractures and impeded the upward movement of solutions forced them to migrate laterally.

The original permeability of the Dakota (?) and Morrison sandstones is the chief characteristic responsible for the bedding ore deposits found in them. Solutions were forced to migrate laterally by an impervious cap of shale, and these solutions moving through the sandstones dissolved cavities in them which were later filled by ore. These sandstones are present in both the Ouray and Telluride districts. As yet ore deposits have been found in these beds only in the Ouray district but exploration has not reached the depth of these beds at Telluride. It may well be that ore bodies will be found in these permeable sandstones in the Telluride district.

Blanket ore deposits similar to those described above occur where the permeability is due to ancient leaching on an old erosion surface. These surfaces mark contacts between formations in the geologic column. Permeability due to leaching is the most important characteristic responsible for the localization of bedding deposits at the contacts above and below the Leadville limestone. The chemical composition of the limestone is such that the rock is capable of being replaced by ore, and this was an important contributing factor. The size of the blanket deposits was largely determined by the amount of permeability created by the attack of hydrothermal solutions on the limestone. Similarly the exceptional permeability of the Pony Express limestone is due to attack by hydrothermal solutions. This limestone was originally a calcareous gypsum bed in which the calcium sulfate has been selectively leached. Both the Pony Express and the Leadville are capped by impervious shale which guided the hydrothermal solutions laterally when they reached these shale horizons. Like the ore-bearing sandstones these limestone formations are present in the Ouray and Telluride districts, but production comes only from Ouray, for exploration has not reached them at Telluride. Outside of the San Juan region the Leadville limestone is very productive in the Gilman and Leadville mining districts.

Many of the ore shoots in the San Juans are localized by no other recognizable characteristic than the fracture habit of the different wall rocks traversed by fissures. Some of the mineralized fissures at Ouray in the sedimentary rocks make ore where the fissure is between walls of limestone or quartzite; however, where the walls are of shale, no ore is found. This localization is attributed to the clean open breaks of the harder rocks permitting free circulation of ore solutions, as contrasted to the tight, gougy fractures in shale which inhibit the circulation of solutions. A comparable relationship exists between the tuffs and rhyolites in the volcanic series.

The San Juan tuff, a very favorable horizon for ore deposits, owes this favorableness to the way it fractures when the stresses causing the fracturing only slightly exceed the elastic limit of the rock, (Burbank, 1941). This formation is found in the three mining districts of Ouray, Silverton and Telluride and is productive in each of the districts. The amount of movement along the fractures in these three districts has been small and the stresses developed have been only slightly in excess of the elastic limit of the rocks. The San Juan formation is composed of tough rocks which will resist considerable stress before they rupture, but when they do break, the fracture is a large and open one although the movement may be small. The Picayune formation in the Lake City district contains beds very similar to the San Juan tuff, and they are equally favorable to ore deposition where traversed by faults of small displacement. It is interesting to observe that andesitic and latitic rocks, which more closely approach the composition and texture of the tuff than do rhyolites, contain more and better ore deposits than are found in the rhyolites. This holds true only under conditions of stress as described above. This relationship was first observed and correctly postulated for the rocks in the Silverton district where W.S. Burbank[1] explained the more favorable character of Burns latite as compared with the Eureka rhyolite as a host rock for lodes on the basis of their fracture habits.

Rhyolite rocks tend to shatter in tight breaks when the movement is small and presumably the stress that produced the break was not greatly in excess of the elastic limit of the rock. The Potosi rhyolite at Telluride, Ouray, and Lake City, and the Eureka rhyolite of Silverton substantiate this relationship by the lack of ore deposits found in them. However, when the stress that caused the rhyolite to rupture was enough in excess of the elastic limit of the rock to cause faults of substantial movement, the fractures were no longer tight and unfavorable to ore deposition. Under these conditions the fractures in the rhyolite were as permeable as the fractures in other volcanic rocks. In the Bonanza district the Bonanza formation, which includes some rhyolite beds, is about as productive as the Rawley andesite, the other large producing horizon. Therefore, it is not surprising to find the largest production in this camp coming from the fault contact between these two formations. Also in the Creede district where the displacement along the faults was large, the Willow Creek rhyolite and the Campbell Mountain rhyolite are the most productive formations. The rhyolites at Creede differ from those of other districts in being partly replaced by ore.

Although in general the volcanic rocks of the San Juan region

[1] Burbank, 1933, pp. 191-212

are not chemical precipitants of ore, one of the tuff beds in the Creede formation is believed to have precipitated hypogene native silver. Chemical precipitation occurred in the tuff bed at Creede due to the presence of organic matter in a permeable bed. The organic inclusions reduced the ore-bearing solutions causing the precipitation of native silver. A similar occurrence is observed at Ouray where the bituminous shale which underlies the Pony Express limestone contains native silver. Chemical reaction with the calcareous rock is also partly responsible for the ore deposits in the limestone above this shale.

The statistical analysis of ore occurrence in the various districts (as summarized in plates 2 to 5 and 8) lead to the conclusion that the major part of the ore localization due to lithologic control can be ascribed to the fracture habit of the rocks. Original permeability is somewhat less important, but is a major factor in the Ouray district. The various other lithologic controls such as carbonaceous and calcareous beds which react with ore-bearing solutions are principally of local importance.

LIST OF MINES AND PROSPECTS OF THE EARLY TERTIARY EPOCH (UNCOMPAHGRE)

NORTHERN DIVISION

1. Wanakah (Bright Diamond, Iron Clad, and others.
2. American Nettie group.
3. { Great Western.
   Mayflower tunnel.
4. Memphis.
5. Pony Express.
6. Bachelor, Wedge, Neodesha.
7. El Mahdi.
8. Calliope (Dexter, Iowa Chief).
9. Little Eva (?) and others.
10. Black Silver, Champion.
10a. Ely tunnel.
11. Newsboy, Slide, and others.
12. Black Girl.
13. Senorita.
14. Plezy.

WESTERN DIVISION

15. Grey Eagle, Speedwell.
16. { Rock of Ages.
   Grand View.
17. { Plutus.
   Sampler.
18. Morning Star.
19. Stenographer.
20. Teller.
21. Red Rose, Gem, Float, Queen of Ouray, and others.

SOUTHERN DIVISION.

22. Mineral Farm, Miser's Dream.
23. (?) Forest Belle, Grey Squirrel.
24. Trout and Fisherman.
25. Columbine.
26. Legal Tender.

EASTERN DIVISION

27. Skyrocket.
28. Samoa
29. Valley View and Cascade group (Cascade Creek)
30. Lone Widow.

LIST OF MINES AND PROSPECTS OF THE LATE TERTIARY PERIOD (SILVERTON AND COW CREEK)

AMPHITHEATER AREA

31. Portland, Denver, and others.
32. Oak Street.
33. Aspen, Leadville, Boulder.
34. Rose.
35. Dyke, Germania, and others.

BEAR CREEK AREA

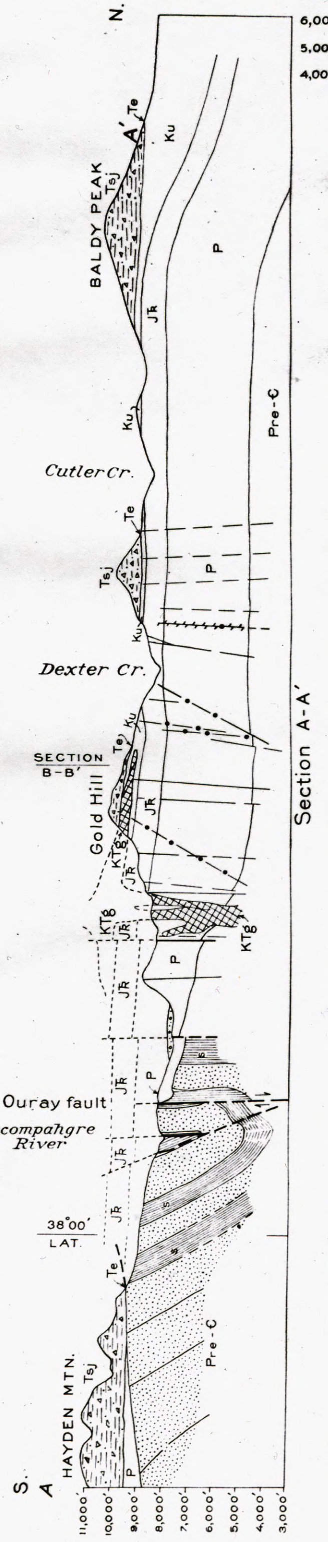
36. { Silver Queen, and others.
   Grizzly Bear.

HAYDEN MOUNTAIN SECTOR

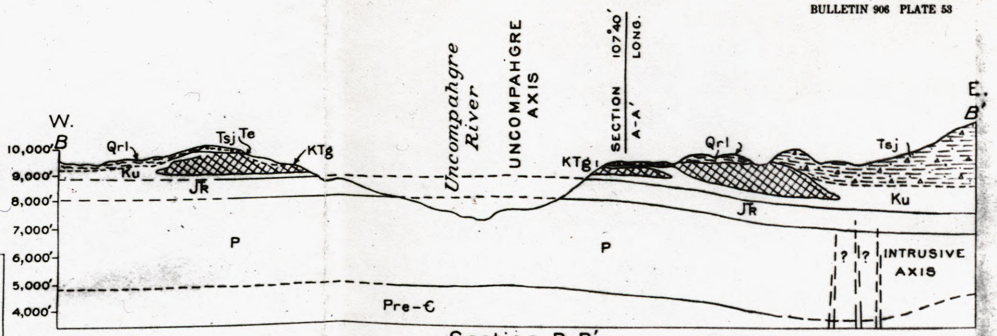
37. Combright group.
38. Sutton group.
39. Dunmore group.
40. Ores and metals, manganese.
41. New Mineral Farm.
42. Thistledown.
43. Lloyd group
44. Japan-Moslem.

DEXTER CREEK AREA

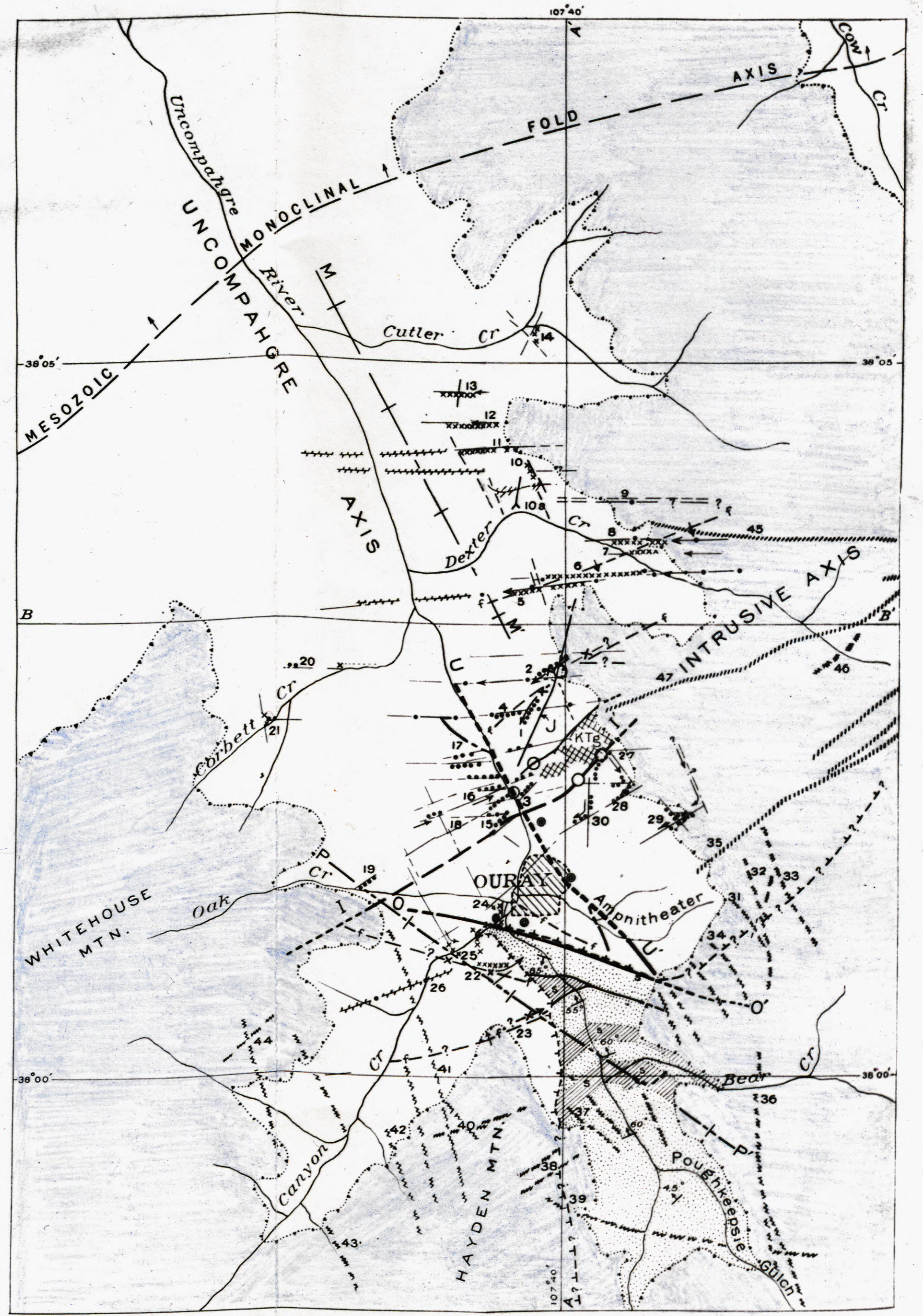
45. Calliope dike.
46. Sunday.
47. Dike of Bridalveil Creek



Section A-A'



Section B-B'



STRUCTURE MAP OF THE UNCOMPAHGRE DISTRICT, OURAY COUNTY, COLO.

By W. S. Burbank

1939

0 1 2 3 4 5 Miles

0 5,000 10,000 15,000 20,000 25,000 Feet

EXPLANATION OF STRUCTURE MAP

GENERAL FEATURES

Boundary of Tertiary formations.

Boundary of Paleozoic formations. (Inferred extension beneath Tertiary formations shown by question marks)

Outcrops of pre-Cambrian quartzite.

Outcrops of pre-Cambrian slate.

●
Position of recent hot springs

STRUCTURAL FEATURES OF LATE TERTIARY AGE

Late Tertiary veins.

Late Tertiary dikes of the Cow Creek center.

STRUCTURAL FEATURES OF PRE-CAMBRIAN TO EARLY TERTIARY AGE (IN PRE-TERTIARY FORMATIONS)

Fissures and clastic dikes (with dots) with moderately inclined mineralized channels or veins (Inferred direction of movement of solutions shown by arrows)

Fissure, dike, or fault zone, with steeply inclined mineralized channels.

Bedding channels of mineralization showing inferred direction of movement of solutions.

—f—?—f—
Flexures or fault-folds.

Igneous dikes and plugs of the silver-lead zones of mineralization.

J
Jonathan dike.

Dikes of the intrusive axis and of gold zones of mineralization (except Jonathan dike) not differentiated from fissures.

KTg
Cross-cutting intrusive igneous rocks of the Uncompahgre center. (Laccolithic bodies and sills not shown)

I——I'
Southeast boundary of intrusive zone.

U---U'
Uncompahgre "break."

M—+—M'
Radial axis of late Mesozoic uplift.

O——--O'
Ouray fault.

P—+P'
Radial axis of late Paleozoic uplift.

60°
Strike and dip of beds of Uncompahgre formation

EXPLANATION OF GEOLOGIC SECTIONS

Qrl
Recent landslide debris.

Tsj
San Juan tuff, with Telluride conglomerate locally present beneath it (Tertiary)

Te
Telluride erosion surface (early Tertiary).

KTg
Quartz monzonite and granodiorite porphyry, quartz diorite, and related igneous rocks (late Cretaceous or early Tertiary).

Ku
Upper Cretaceous formations.

JŦ
Jurassic and Upper Triassic formations.

P
Paleozoic formations.

Pre-Cambrian quartzite.

S
Pre-Cambrian slate.

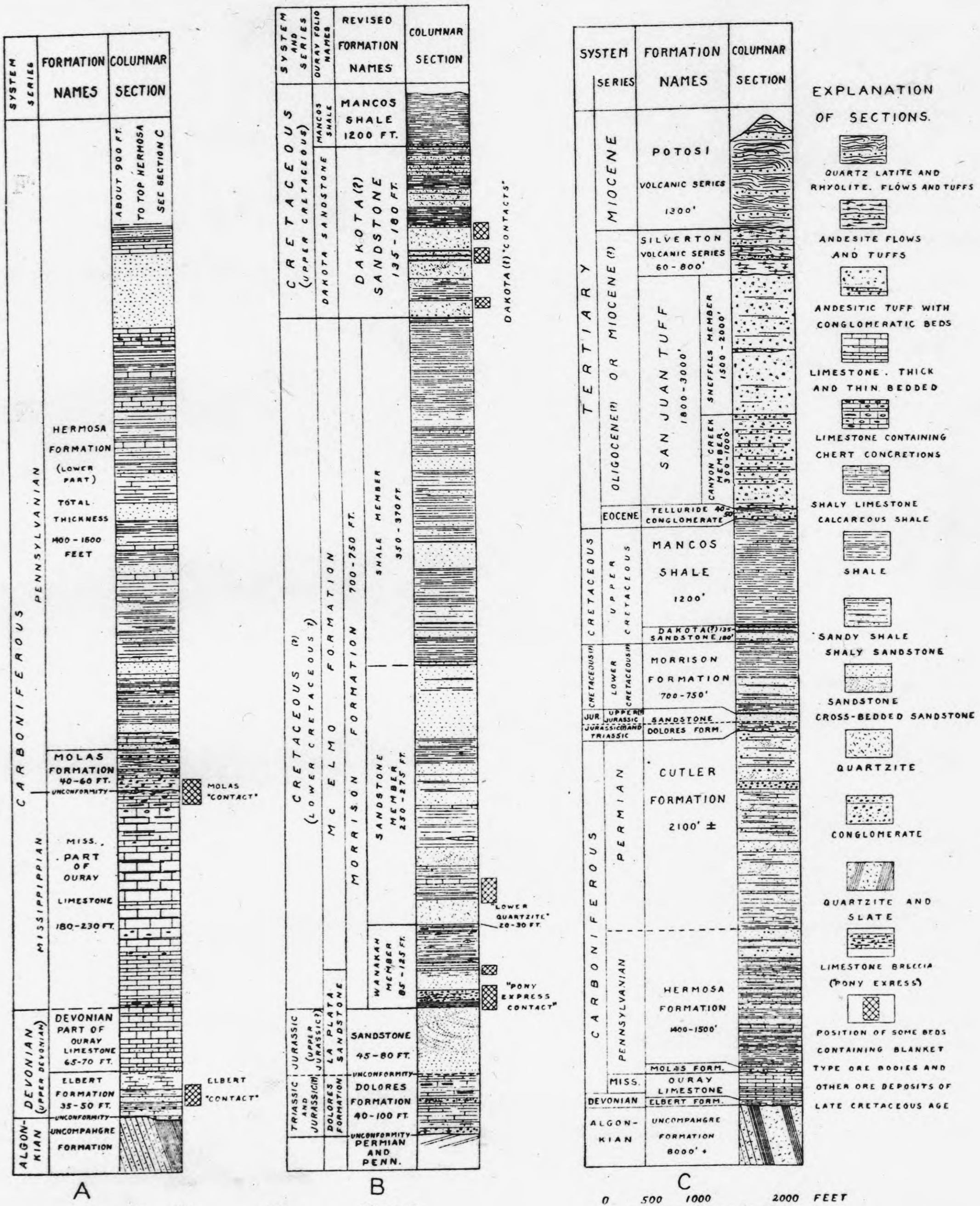
EXPLANATION OF MINERAL DEPOSITS

•••••••
Gold ore.

×××××××
Silver-lead ore.

Burbank 1940, p.200

Figure 3



Stratigraphic sections of the rocks of the Ouray mining district. A. Section of part of Paleozoic sedimentary formations, based upon sections measured south of Ouray, and upon the section of the Molas and Hermosa formations near Oak Creek. B. Section of the Mesozoic sedimentary formations. Morrison formation measured on cliffs north of The Amphitheatre. Dakota sandstone measured near Schofield Tunnel, American Nettie mine. C. Generalized section of complete stratigraphic column of the Ouray district.

Burbank 1950, p.155

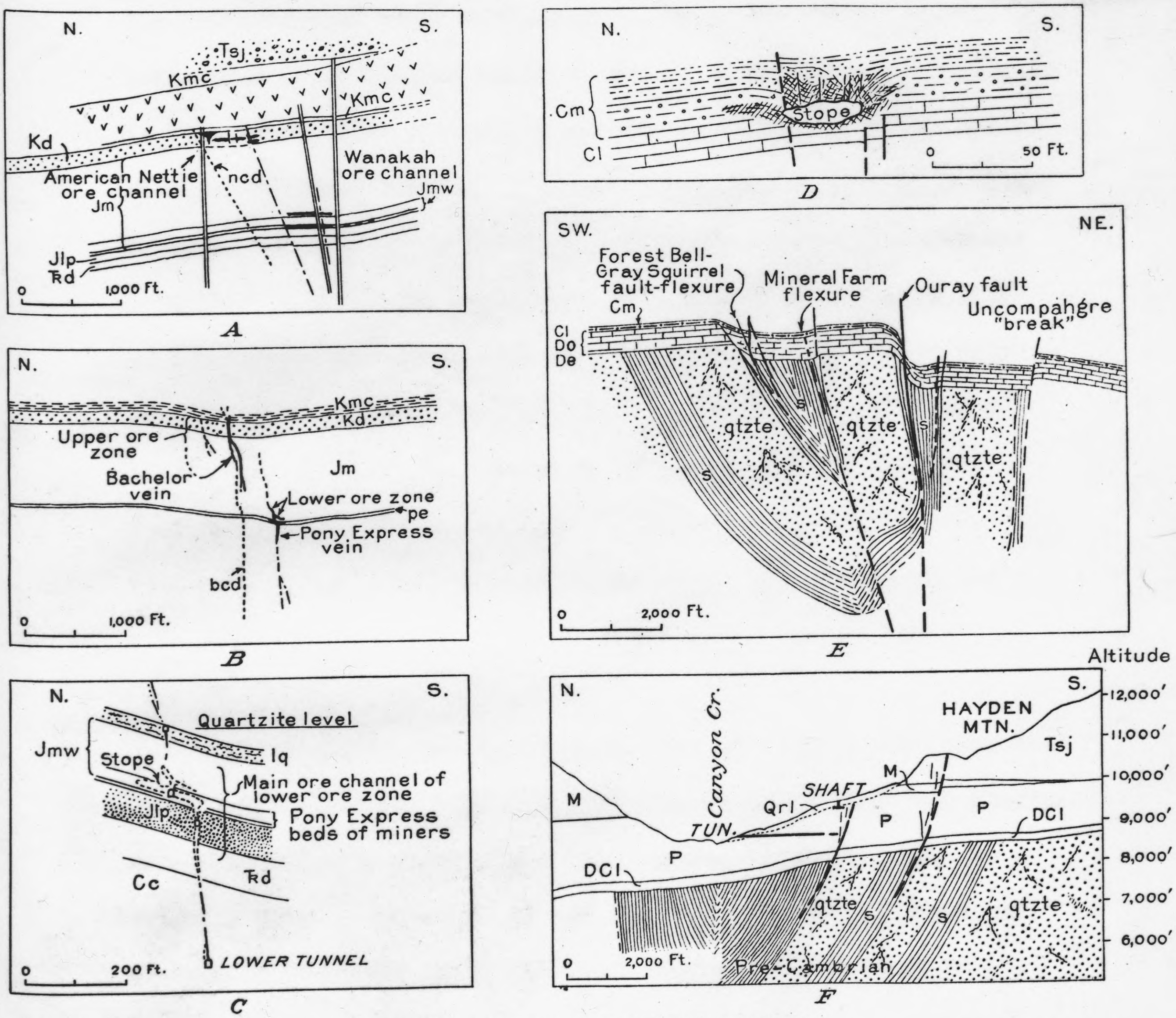


Figure 4

TYPES OF STRUCTURAL CONTROL OF ORE DEPOSITION.

A, Generalized section through the American Nettie-Wanakah flexure and ore channels. *B*, Generalized section through the Pony Express and Bachelor veins and flexure. *C*, Section through the Pony Express vein and bedding channel. *D*, Section through the Mineral Farm ore channel, at contact of Molas formation and Leadville limestone. *E*, Idealized section in southern part of district, with restoration of eroded parts of the lower Paleozoic limestone; shows relations of the main faults and folds in the pre-Cambrian basement to faults and flexures in the immediately overlying Paleozoic limestones. *F*, Section approximately through the New Mineral Farm mine on the north slope of Hayden Mountain; approximate position of concealed syncline in slate beds of Uncompahgre formation is indicated; tunnel on north-south vein is nearly parallel to plane of section.

Qrl, Quaternary and Recent landslide and morainal debris; Tsj, San Juan tuff; Kmc, Mancos shale; Kd, Dakota (?) sandstone locally altered to quartzite; Jm, Morrison formation, which includes the Pony Express limestone breccia of miners (pe) and the lower quartzite of miners (lq); Jmw, Wanakah member of Morrison formation; Jlp, lower La Plata sandstone of miners; Ꞧd, Dolores formation; M, Mesozoic formations undifferentiated; Cc, Cutler formation; Cm, Molas formation; Cl, Leadville limestone; DCl, Devonian and early Carboniferous limestones; Do, Ouray limestone; De, Elbert formation; P, Paleozoic formations, Molas, Hermosa, and Cutler, undifferentiated; s, slate, and qtzte, quartzite of Uncompahgre formation; ncd, Nettie No. 2 clastic dike of miners; bcd, Bachelor clastic dike.

Burbank 1940, p.200

OURAY MINING DISTRICT

Most of the mines near Ouray, Colorado are in the sedimentary formations (see figure 3). The grade of ore is much better in the veins between walls of quartzite, limestone and other hard rocks than it is between walls of shale. A partial explanation is that circulation of the ore solutions through the tight shale fissures was much impeded. At some places shale acted as a "roof" or upper barrier and forced the ore-bearing solutions to migrate laterally up dip along more permeable beds. (See cross section of American Nettie Mine, Section A, figure 4). The better vein ore shoots in the harder rocks are attributed to the ability of these rocks to break cleanly so as to leave open spaces for filling by mineralizing solutions. Permeability is sometimes considerable at contacts between two formations; for example, at the base and at the top of the Leadville limestone (see figure 4, Section D).

South of Ouray most of the mines are in the San Juan formation of andesite tuffs and breccias. The favorable physical and chemical characteristics of these rocks are obscure, although they have a slightly greater permeability and are possibly a better chemical precipitant than rhyolite, the other common volcanic rock in the area. The most probable reason for the favorableness of the San Juan formation over the Potosi rhyolite is its more open fracture pattern. The andesite tuffs and breccia are tough rocks, and when deformed sufficiently to fracture, they yield to make only one fissure. Rhyolite is a more brittle rock, and when it is subjected to stress, it fails along a shattered zone in which ore solutions are dispersed.[1]

[1] Moehlman, 1936, p. 392

Many of the most valuable ore deposits have been found along veins at a change in strike or dip. Differential movement along a plane of varying strike or dip will leave open spaces that ore-bearing solutions can fill, as in the Sunny Side and Camp Bird mines (see figure 5). Structural control of this type appears to be the most strongly recognized influence in ore deposition in the western San Juan Mountains. A detailed description of the productive formations and those which influence ore deposition follows:

Formations At Ouray[1]

The oldest formation that is favorable to ore deposition is the Devonian Elbert. This formation contains conglomerate, quartzite, shale and limestone, but only the argillaceous and calcareous beds contain replacement deposits which are small however. The dolomitic Ouray limestone overlies the Elbert and is locally mineralized and recrystallized. At its contact with the overlying Leadville limestone small bedding deposits occur near fissures. Small unfilled and partly filled solution cavities are also present along this contact. The chemical characteristics of these rocks account for the deposit formation.

The Leadville limestone is thicker than the Ouray limestone. The upper part is a coarse-textured, elastic limestone and is overlain unconformably by five to ten feet of red shales of the Molas formation. The large amount of Mississippian chert nodules included in the basal Molas beds indicate that considerable erosion took place before the deposition of the Molas formation. Apparently, the beds at the contact were porous, for they localized ore deposition. Mineralization along this contact is followed in small

[1] Burbank, 1930, pp. 157-185.

synclinal flexures where the Molas collapsed into caves formed by hydrothermal solutions moving along fractures in the top of the limestone (see Section D, figure 4). The primary factor determining deposition was chemical. The rest of the Molas formation is mainly inhospitable red conglomerates and red shales.

The Hermosa formation lies conformably upon the Molas and consists of alternating beds of sandstone, shale and thin limestones, massive beds of grits and some conglomerate. No blanket ore deposits have been found in this formation although some pyritic replacement deposits exist which are related to the Ouray stock. The Cutler formation overlies the Hermosa, but contains no ore deposits. The Dolores formation which has an unconformable contact with the Cutler is also barren.

The Morrison formation has two ore-bearing horizons. The lower is the Pony Express limestone which forms an important ore-bearing horizon in the sedimentary rocks. These beds commonly range in thickness from ten to twenty-five feet and are bituminous limy shale and limestone breccia. The limestone breccia is a very permeable bed that owes its peculiar texture and structure to the selective solution of gypsum from a deposit of limestone-bearing gypsum. The small interstitial lenses of limestone in the original deposit had slumped so as to form a bed of breccia as much as twenty feet thick, although the original unit was at least fifty feet thick. The resulting bed is a permeable carbonate, so its chemical and physical characteristics account for its ready reaction with the ore-bearing solutions in forming vein and bedding deposits. At places the highly bituminous shales at the base of the breccia have precipitated small, high-grade copper-silver ore shoots by reducing the ore bearing solutions.

Above the Pony Express limestone is the sandstone member of the Morrison formation. Its base is marked by a light-colored bed of sandstone or quartzite from twenty to thirty feet thick. Because this formation commonly contains bedding deposits and is altered to quartzite in the central part of the district, it is known as the "lower quartzite". Originally it may have been much more porous than the majority of the other sandstones in the Morrison, which do not show as much alteration.

Several important ore bodies occur within the Dakota formation which overlies the Morrison, the most important of these being the upper "contact" of the American Nettie mine (see Section A, figure 4). The blanket ore bodies of this "contact" lie in the massive quartzite below a fairly thick shale bed close to the middle of the formation. The lower "contact" of the mine lies in the basal sandstone beneath a shale bed. Between these two "contacts" other smaller deposits are present. The description of the American Nettie mine below includes details of this kind of deposit.

Mancos shale which lies upon the Dakota had been removed by erosion from most of the Ouray district area before the deposition of the Telluride conglomerate. Where the shale is present it had considerable influence on the nature of intrusive masses, many of which spread into laccolithic bodies at horizons near the base of this formation.

The Telluride conglomerate transgresses all of the older sedimentary rocks and is composed of detritus of schist, granite, granite porphyry, quartzite, slate and small amounts of other sedimentary rocks. In some places this formation includes sandstone, shale and limestone beds. Some "fossil" gold placers have

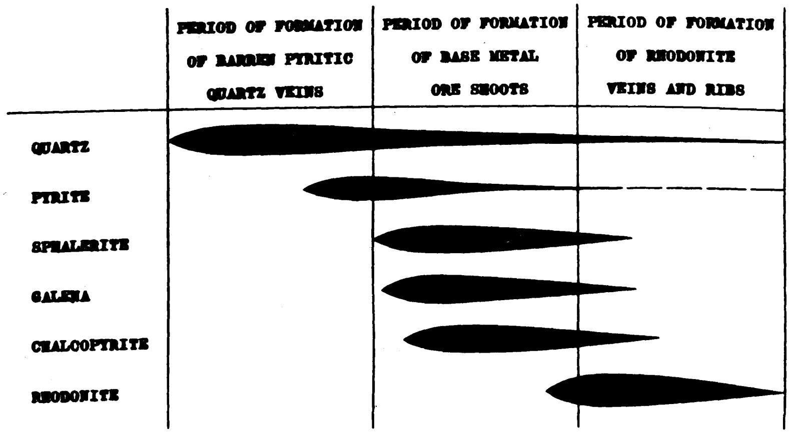


FIG. 5A Sequence of Mineralization—Sunnyside Mine.

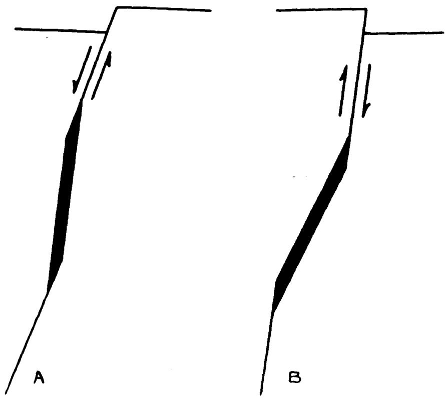


FIG. 5 Mechanics of control of location of ore shoot by variation in dip of the vein fissure. *A*, In a normal fault the steeper portions of the vein are the more favorable. *B*, In a reverse fault the flatter portions of the vein are the more favorable.

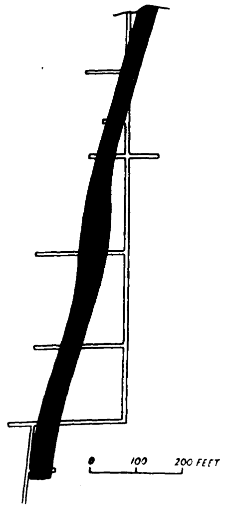


FIG. 5 Modification of ore shoot by variation in dip. The steeper portions of the vein are wider and richer. The vein fissure is known to be a normal fault. Washington Vein, Sunnyside Mine, Colorado.

Hulin 1929, p.40

been mined in this bed, but few deposits of commercial importance occur.

The earliest surface deposits of volcanic origin preserved in the Ouray district consist of the San Juan tuff, a very thick accumulation of water-laid tuff, breccia and agglomerate. The maximum thickness is 3000 feet, and except for the lower few hundred feet it is composed of andesite and latite. The basal part contains boulders and pebbles of granite and pre-Tertiary rocks.

The upper part of the tuff is the Sneffels member and is characterized by uniform lava fragments, mostly of fine porphyritic lava containing small feldspar phenocrysts. The bulk of the production from the Tertiary veins between Ouray and Telluride has come from the Sneffels member.

Above the San Juan tuff lies the Silverton series of dark-colored porphyritic lavas of dense texture, commonly amygdaloidal or vesicular near the top and interbedded with thin tuffs, agglomerates and flow-breccias. Apparently, no commercial deposits occur in this formation in the Ouray district, but in early mine reports it may not have been distinguished from the San Juan tuff.

The uppermost division of the volcanic complex developed in the western San Juan mountains is the Potosi volcanic series. These rocks are massive flows with a few thin agglomerate and tuff beds; most of the rocks are latites or quartz latites; however, rhyolite constitutes a subordinate part of the series. In Potosi Peak, the type locality, the formation is 1250 feet thick. This series of lavas is now found only on the higher peaks and ridges; elsewhere erosion has removed the rocks and exposed the older underlying formations. Fissures appear to tighten when they break into the Potosi, and the amount and value of the ore diminishes.

The following qualitative diagram of producing formations was compiled primarily on the basis of the description by W.S. Burbank.[1] Because of the scarcity of published production figures a more inclusive diagram could not be prepared.

Ore Controls in Typical Mines

American Nettie Mine.- The American Nettie Mine is located near the lower portion of the cliff which forms the east side of the Uncompahgre Canyon. The value of its ore between 1889 and 1904 was $1,500.000.

The sequence of events at the American Nettie Mine was as follows:

1. Intrusion of the quartz porphyry as dikes and sills.
2. Cooling of the porphyry shattered the rocks producing fissures.
3. Hot alkaline waters charged with metallic sulfides ascended the fissures until their progress was barred by the impervious shales. Then they found porous layers where they could migrate in a lateral direction.
4. The alkaline waters dissolved the quartzite and deposited metallic sulphides, much quartz was redeposited as a matrix with the sulphides. Hydrous solutions penetrated beyond the sulphide deposits and produced large cavities in the quartzite. Later quartz druses were deposited on the cavity walls.
5. Erosion carved the Uncompahgre Valley leaving the quartzite in an elevated position. Meteoric waters percolated

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[1] Burbank, 1940, pp. 208-213

through the outer portions of the rocks and oxidized the pyrite to ferric sulphate and sulphuric acid which dissolved gold and silver and redeposited them in the lower sulfide zone where the ferric sulfate was largely reduced to ferrous state which has no solvent effect on gold and silver. The sequence of mineralization is essentially the same as that presented in figure 5A.

Some values came from the silver present in the ore, but most of the values were from the gold which averaged six ounces per ton of sorted rock. The ore is found in the upper Dakota (?) quartzite which is capped by forty feet of black carbonaceous Mancos shale (see figure 4, Section A). Above the shale is a quartz monzonite porphyry sill about 500 feet thick. Post-porphyry vertical fissures cut the formations and made ore in pear-shaped and irregular bodies at several horizons in the quartzite. The largest deposits are just below the Mancos shale. The ore does not continue far from the shoots, although cavities lined with quartz exist as far as thirty feet away. The oxidized ores are stained with limonite and contain native gold which is concentrated at the bottom of the weathered mass. The primary ores contain pyrite, chalcopyrite, galena, sphalerite, gold and silver tellurides, molybdenite and gray copper. The contact of the ore with the quartzite is usually very sharp and shows an irregular undulating surface. At a much lower horizon in the Morrison formation some production comes from the Wanakah or Pony Express member.

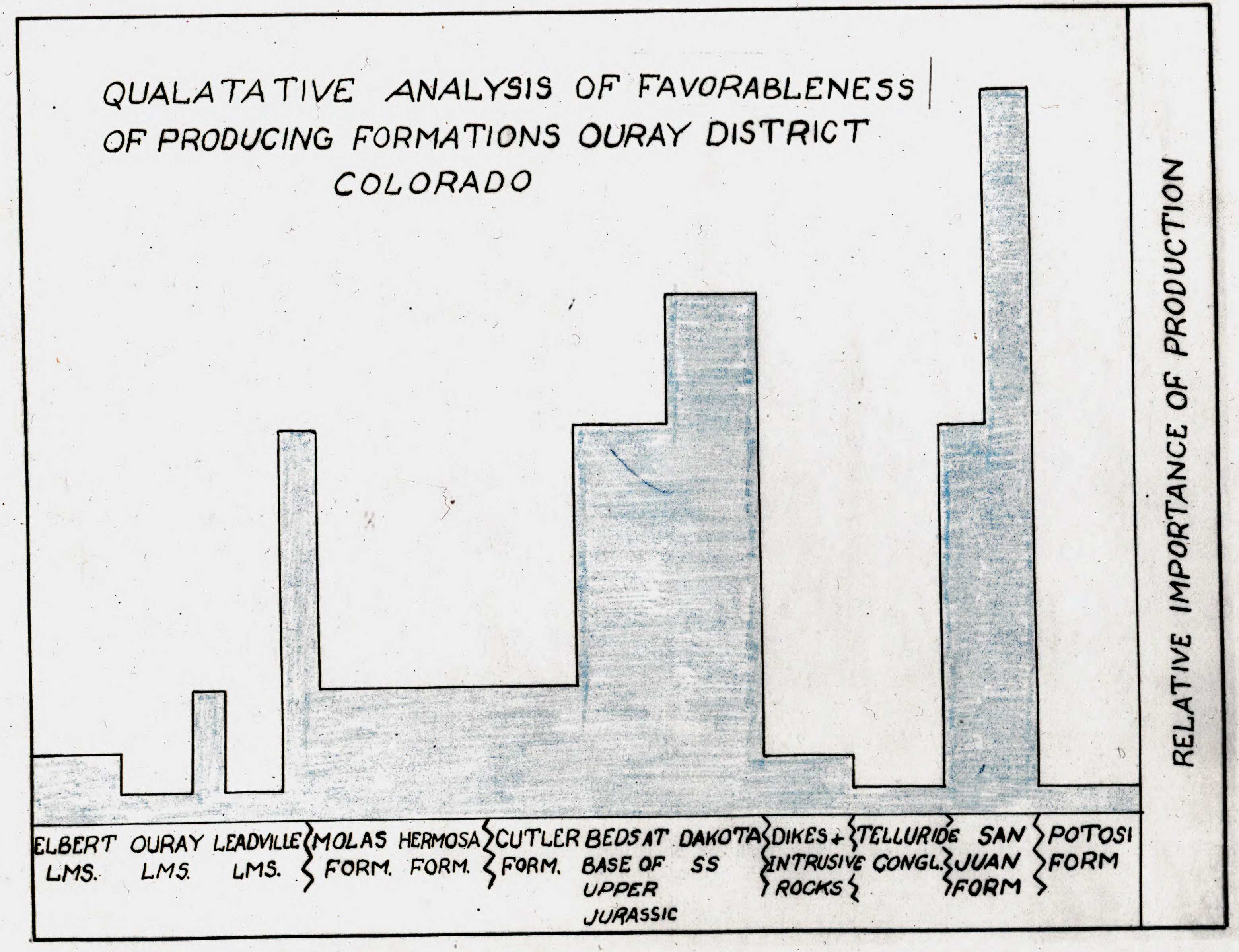
<u>The Camp Bird Mine 1879-1947</u>.- The Camp Bird Mine is about five miles south of Ouray at the head of Imogene Basin. Its total

production had reached the value of \$27,000,000 by 1936 making it one of the richest mines in the San Juans. The average strike of the vein is N80°W and its average dip is 70° south. The country rock is the San Juan tuff.

The localization of the lodes is attributed by J.E. Spurr[1] to openings formed along the vein by horizontal movement due to a variation in strike. These openings were formed where the strike changes from an east-west direction to a west-northwest direction when the southern block moved toward the west. The movement was about fifteen feet, and it left open spaces of about five feet at the greatest variation in strike. In the ore solutions that rose in these channels gold and silver migrated farther than quartz or calcite and moved both upward in the fissure and to some extent laterally into the wall rock. The more permeable the wall rock, the more favorable it was for the precipitation of gold and silver within the vein, and if the wall rock was porous enough, the ore solutions penetrated it also. Vein material crossed the first andesite flow of the San Juan tuff, but the gold stayed below it in the porous breccia. The impervious flow caused a constriction so that the gaseous constituents were forced to penetrate the wall rocks below and precipitate the ore. The vein continues to great depth, but the gold is not found more than 700 feet below the andesite flow. A change of dip toward the vertical occurs where the fissure cuts the more dense flows, and this may be an influencing factor in making the fissure less permeable at this place. The value of the ore is almost entirely from free gold. Associated minerals are pyrite, galena, sphalerite, chalcopyrite,

1. Spurr, 1925, pp. 133-134

QUALATATIVE ANALYSIS OF FAVORABLENESS OF PRODUCING FORMATIONS OURAY DISTRICT COLORADO



quartz, fluorite, calcite, and rhodochrosite.

Evaluation of Lithologic Control

The relative importance of production from the various lithologic units at Ouray was qualitatively evaluated by the writer after a careful scrutiny of the literature and is presented in Plate 2. A statistical comparison of the formations was impossible because of the lack of detailed mine production data. Plate 2 not only shows the relative importance of production but also the approximate location of the ore within the formation. For example, the greater amount of production from the San Juan tuff came from the upper Sneffels member of that formation, also the chief production from the Leadville limestone came from near its contacts with other beds rather than from the middle of the formation.

SILVERTON MINING DISTRICT

Silverton is in the center of the Silverton quadrangle and is about 20 miles south of Ouray (see figure 2). Most of the rocks of the Silverton mining district are also present in the Ouray district and need only be mentioned here. All the formations from the pre-Cambrian through the Permian Cutler are found in the Silverton quadrangle. Some of the Paleozoic sediments were preserved in down-faulted blocks, but even they were exposed to erosion during the intervals before and after the deposition of the Telluride conglomerate.

Formations at Silverton

The Telluride conglomerate rests upon an erosion surface of low relief, which separates the rocks of pre-volcanic time from those of the volcanic epoch. The conglomerate, which is of Oligocene (?) age, is of non-volcanic character and is composed chiefly of pre-Tertiary and early Tertiary rocks eroded from the dome-like uplift of the ancestral San Juan Mountains in late Cretaceous and early Eocene time. The conglomerate is overlain in most places by the San Juan tuff.

The San Juan tuff comprises tuffs, breccias, and conglomeratic beds that were the first accumulations of volcanic debris upon the denuded surface of the early Tertiary San Juan Mountains. The tuffs rest in some places upon the Telluride conglomerate, and in others directly upon surfaces of older rocks that formed the ancestral mountains. Locally the San Juan tuff was removed by erosion before the deposition of the Silverton volcanic series.

The Silverton volcanic series, which is a thin unit near Ouray, attains a thickness of several thousand feet and is here the most common surface formation. It is subdivided into four units, the Picayune volcanic group, the Eureka rhyolite, the Burns latite and the Pyroxene andesite.

The Picayune formation is not common in the Silverton district. It consists of augite andesite occurring as tuff, breccia or agglomerate and massive flows. The Eureka rhyolite in this area is separated from the San Juan tuff by an epoch of erosion that produced deep valleys and removed much of the San Juan formation. The lower Eureka rhyolite consists of a series of thick flows of rhyolite or quartz latite. The lava is high in silica, alkalies and lime, and low in magnesia and iron, a composition that favors the alteration of thoroughly fractured rock near the veins to soft masses composed largely of sericitic minerals. Such alteration produces gouge that tends to seal fault fissures. The position of the rhyolite near the base of the volcanic succession may in part account for the smaller production from this series of flows, for the greater cover would tend to decrease the size of open spaces. This decrease may offset the tendency of certain ores to contain increasing amounts of gold and copper, and decreasing amounts of lead and silver at greater depths.

The middle tuff-breccia member of the Eureka rhyolite represents the beginning of an epoch characterized by erosion and transportation of land waste accompanied by eruptions of rhyolite flows and breccias. The abundance of pre-Cambrian and andesitic fragments, and the imperfect sorting and rounding of materials make this bed look very much like the San Juan tuff.

The upper flow breccia member consists of a heterogeneous assemblage of thin lava flows, breccias of andesitic and rhyolitic lavas and fine-grained tuff beds.

The third volcanic formation in the Silverton series is the Burns latite, and it is separated from the Eureka by a well-defined erosion surface that locally truncates the underlying flows of rhyolite. The lower tuff-breccia member comprises about 450 feet of tuffaceous beds and breccias composed of conspicuously porphyritic latite or quartz latite. Some beds are composed of immense blocks six to eight feet in diameter intermingled with smaller angular fragments and a matrix of fine tuff or sand, showing that their accumulation must have been brought about in part by several volcanic agencies.

The middle latite flows rest on a more irregular surface than the basal contact of the Burns latite. There is no evidence of an erosion period between the two members. Breccias are also interbedded with these flows that are mainly indistinguishable from the lower breccias. Typical flows of the latite overlap each other in a most irregular manner and are notable for their two strikingly different facies of crystallization. These flows for purposes of description will be distinguished by the terms "massive facies" and "fluidal facies", but actually all gradations between the two types exist. The massive facies is a dark gray porphyritic lava with hornblende and biotite in clearly defined crystals with locally some magnetite and pyroxene. The ground mass has a subcrystalline or vitreous appearance in the most massive lavas, which gives to the rock brittleness, a splintery fracture and resistance to weathering and erosion. The fluidal facies is distinguished by its lighter gray or greenish color and by its flow structure, which suggests a lava that has been sheared by its own motion. Biotite flakes are seen when the rock is broken along its flow lines, but the hornblende, magnetite and other dark minerals of the massive lava appear to be represented largely by chloritic products and disseminated iron oxides.

In the upper tuff member of the Burns latite are the fossiliferous beds of limestone and shale which furnish the evidence of the age of the Silverton series. There is about one hundred feet of this tuff that is overlain by Pyroxene andesite.

The Pyroxene andesite covers much of the surface in the central part of the Silverton quadrangle north of the Animas River. The massive basal flows differ from the massive facies of the Burns latite in that they contain greater abundance of pyroxene, less conspicuous feldspar crystals and a more granular texture of the dark-colored base.

Before attempting to generalize the reasons for preferential ore deposition, the classic work of W.S. Burbank[1] will be presented in order to give the reader an insight into the complexity of trying to determine the favorableness of the formations for ore deposition. Silver Lake Basin and Dives Basin were two of the areas covered by his study that shed much light on this difficult problem.

Silver Lake Basin

There is considerable variation in the physical properties of the different volcanic rocks of the San Juan region, and it has been a common experience to find that certain rhyolite flows contain comparatively tight and essentially barren fracture zones, whereas andesitic or latitic rocks along the same line of fracturing contain wide and productive ore bodies. An explanation is that

[1] Burbank, 1933, pp. 191-212.

bodies of rhyolite flows underwent sufficient elastic and plastic deformation under the impact of earthquake shocks and crustal stresses to yield and change their shape by small deformations distributed through large masses of rock, whereas more rigid and brittle rocks failed to distribute the strain and, therefore, broke along different and coarser systems of fracture. The amount of open space afforded by each single fracture would of course be much greater in the andesitic, which had but few fractures, as compared with the many small ones formed during the distributive yielding of the rhyolitic rocks (see figure 6).

The upper portions of the Eureka rhyolite flows appear to be unfavorable here, under the particular conditions of fissure formation described above. Not enough information about the flows in the lower Eureka formation is available to determine whether or not they are similarly unfavorable.

Dives Basin

The greatest range in physical properties of the different rocks is that between the massive facies of the Burns flows and the breccia beds of the fluidal facies. Ransome[1] stated that the hard massive sheets of andesite were found to be less favorable for the deposition of ore than the softer breccias. Ransome used the term "andesite" for all the massive flows and breccias of the Arrastre Basin, which since have been classified as latites by Cross. The nature of the fissuring observed at the surface in these massive beds suggests that they tended to become fractured more intimately by diagonal sets of fracture planes, and the open spaces were consequently distributed through a great width of lode.

1. Ransome, 1901, p. 164.

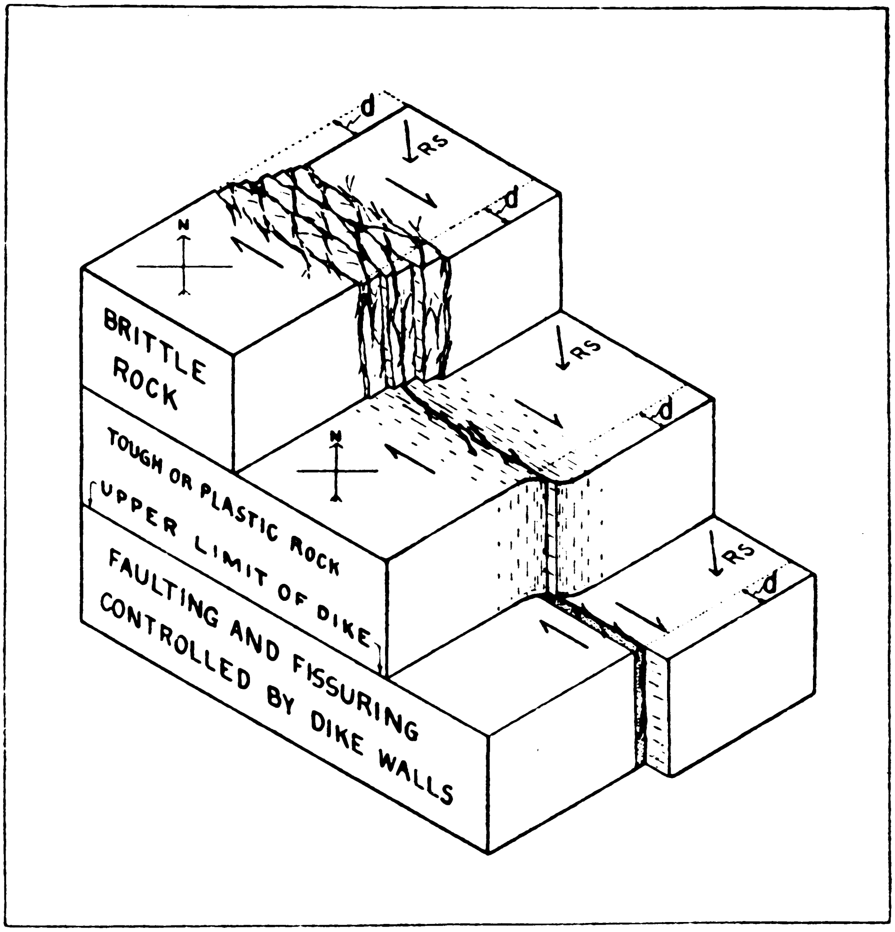


Figure 6 Diagrammatic illustration of change of character of fissuring under different geologic settings. RS, regional stress; d, relative displacement of walls in horizontal direction.

Burbank 1933, p.204

Why diagonal fissuring under certain conditions produces favorable lodes and under other conditions less favorable lodes is apparently dependent on physical laws governing the spacing of fissures. Becker[1] developed on a purely mathematical and physical basis a partial theory of the spacing of fissures, in which he showed that under ideal conditions the division of bodies by sets of fissures resulted in blocks whose faces are parallelograms.

In the description of Silver Lake fissuring it was shown, however, that the so-called tension fractures are in reality the result of combined shearing and tensional stresses; therefore, they might be expected to follow certain rough rules of spacing. It is also apparent from inspection of these fissures in the field that some law of spacing was operative. Where the principle planes of movement were closely spaced the diagonal fissuring is likewise closely spaced, and where the planes of movement are widely spaced, as near Silver Lake, the diagonal fissures are widely spaced and correspondingly increased in size.

In applying this generalization to the conditions in Dives Basin it is necessary also to consider the physical characteristics of the different rocks, because from observation it is apparent that some of them have less tendency to become divided by sets of diagonal fissures. Becker's[2] theory also accords with such facts, as he stated: "If a tough mass is acted upon by a shearing tool, it will undergo a single cut. But if one attempts to cut a brittle substance like glass with a shearing tool, it shatters instead of simply dividing."

In the Dives Basin the tough rocks, represented by the fluidal

1. Becker, 1893, pp. 57-68. 2. Ibid., p. 60.

facies of the Burns flows, and the more plastic rocks, represented by certain of the breccia beds interbedded with these flows, were those most capable of distributed deformation or strain under shearing stress. The brittle or massive rocks, represented by the massive facies of the Burns flows and by the Pyroxene andesites, were, on the other hand, incapable of deforming in this manner and consequently, were shattered, much as glass is shattered by a shearing engine. The basal tuff-breccia of the Burns was not exposed here.

Applying the empiric and theoretic principles to the fracturing of these rocks gives the conditions diagramatically represented by figure 6, which shows the change in character of a rupture passing from one kind of rock to another. The change would not,of course, be as abrupt as indicated, but in constructing the section the movement is assumed to have been solely horizontal and only slightly more than sufficient to develop primary types of rupturing in all the rocks. The actual displacement of the walls may have involved vertical as well as horizontal components during initial rupturing, and furthermore, the initial rupturing would not occur simultaneously in all the different beds. According to theory, the more brittle rocks would rupture first, while the other rocks were still undergoing elastic and plastic deformation.

It is known that movement along the shear zone from the North Star Mine to and beyond the Dives Mine was greatly in excess of the amount that could have been caused by initial rupturing at all horizons. These excess or supplementary displacements involved both horizontal shifting and down-faulting of the hanging wall, and resulted at the North Star Mine in further fracturing and rotation of the shattered blocks of brittle latite. Where the walls of the principle planes of movement were close together, this action would finally reduce the blocks between the walls to a rubble. Also at places along the Shenandoah-Dives Dike similar rubble was produced where the shearing planes were confined within or near the dike walls. This supplementary movement along such shear planes, even where no dike is present, is similar in its action to movements along dike walls, and the action is controlled in part by pre-existing surfaces of rupture. Its effect upon openings, where the primary rupturing was of a simple character, would be like that already described and would be controlled by changes in strike and dip of the initial fracture plane. Where the primary rupturing was complex, its effects would be unpredictable, but would probably result in further rotation and confused fracturing of the blocks.

The most complex vein structure accords with such interpretation. Similar complex fissuring might be found at greater depths, where there are considerable thicknesses of the more brittle rocks. Fissures of simple pattern, however, are found in the lower levels of the Dives Mine, and it appears from the mine maps that along these lower levels the ore-bearing veins largely occupy fissures parallel to the main shear zone, though at places these fissures tail out and are overlapped en echelon by other fissures that likewise turn and parallel the main shear. This simplification of the fissures may indicate either that the rocks at this depth are not brittle, that the dike is present along the vein fissure or that the dike is not far beneath these workings. These dominant ruptures are, however, connected by subordinate fissures that have resulted from minor movements supplementary to the movements that caused the primary rupturing.

Since this excess supplementary movement along the main fault evidently became less intense, because of gradual dissapation of the fissuring energy along diverging fractures, the ore bodies along the shear zone should become more dependent on the nature of primary rupturing, and owing to the feathering of the fissure systems, they would very likely become individually smaller. Only a few of the diverging fissure systems away from the main shear appear to have been opened sufficiently to enclose bodies of ore. However, as the fissuring energy along the shear zone became weaker and its divergence more pronounced, it is expected that diverging fracture planes, like those of the Silver Lake footwall system, would be opened to greater width than those paralleling the main shear.

Beneath the Dives Basin at depths corresponding to the Eureka rhyolite the nature of the fissuring is evidently dependent on the presence or absence of the dike beneath the basin, and, if the dike is present, on the depth at which it occurs. If the dike fails to extend beneath the basin or extends at so great a depth that it fails to cut the Eureka rhyolite, the fissuring in the rhyolite is probably tighter and less favorable than that already found in the deep workings at Arrastre Gulch. The physical properties of the rhyolites and of the breccias interbedded with them suggest that the zone of shearing would be comparatively simple rather than complex. Supplementary movements would be more likely than initial rupturing to produce large openings, and therefore, openings along the main shear zone might be expected to become gradually smaller towards the southeast.

If, however, the dike extends beneath the basin and cuts the

Eureka rhyolite, the greater part of the shearing movement would be concentrated along the dike walls, with the result that less of the fissuring energy would be expended in producing distributive deformation in the rhyolites and breccias. Under these conditions openings of favorable size might be expected to continue much farther southeast than under the conditions mentioned above.

Ore Localization

The most productive shoots of the veins in the Silverton mining district lie between walls of andesite breccias or the massive and fluidal facies of the Burns formation flows. The reasons for this have already been discussed.

Another controlling factor in ore deposition in the Silverton area is the presence of gougy slip planes impermeable to mineralizing solutions, and another the open spaces formed by differential movement at places of change in strike or dip of a fissure. These factors are treated in more detail in the description of the Shenandoah-Dives Mine.

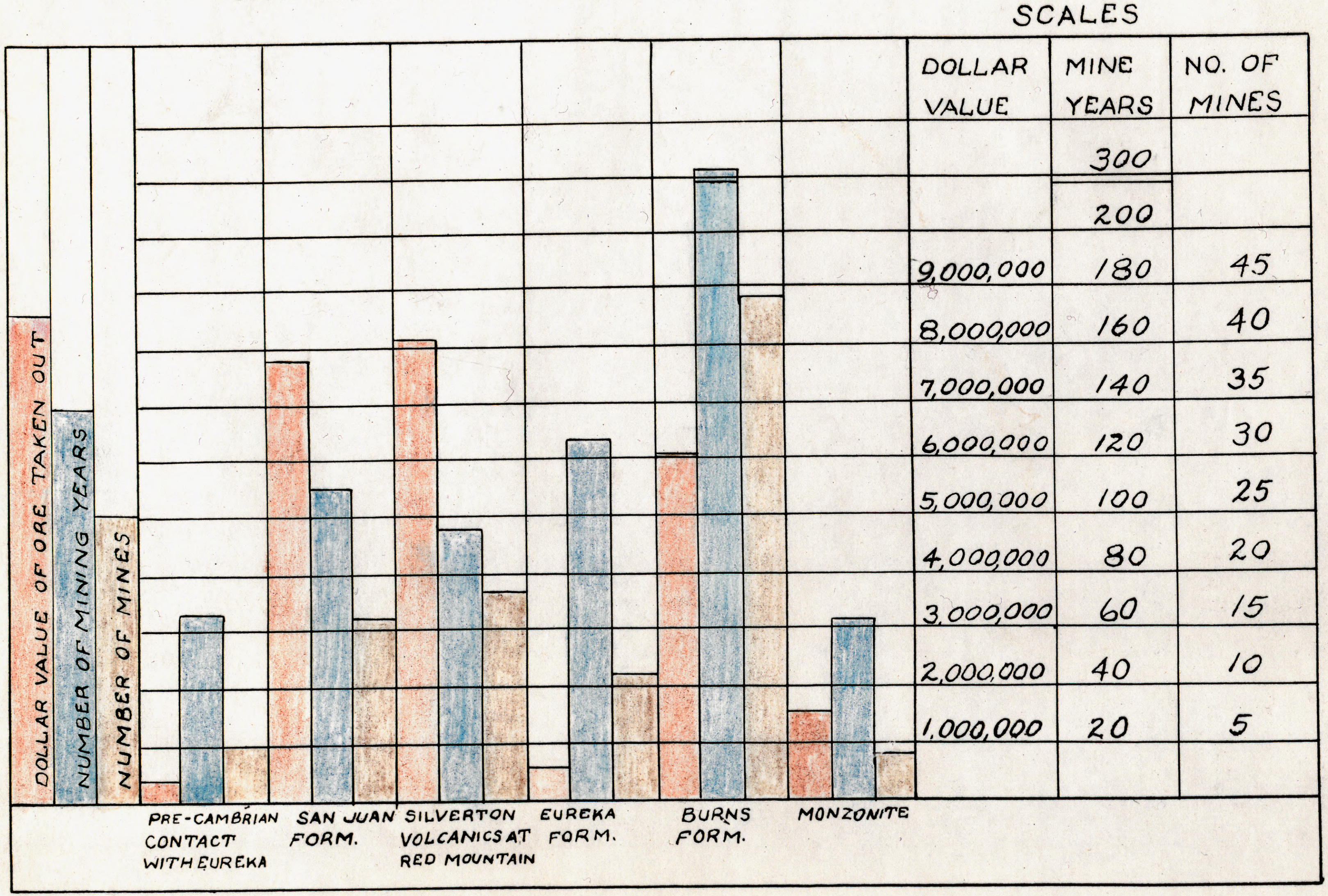
The San Juan formation is the most productive single formation in the Silverton quadrangle, and the Burns formation is a close second. The favorableness of these two rocks is attributed chiefly to their open fracture habit. The mines in the San Juan formation are mainly outside the Silverton mining district, but within the limits of the Silverton quadrangle, whereas mines in the Burns are chiefly within the Silverton mining district. A small production comes from the Eureka formation and an intruded monzonite (see plate 3).

Statistical Method of Evaluating Lithologic Control

The data for the statistical diagram, plate 3, were taken from

Plate 3

SILVERTON QUADRANGLE
COMPARISON OF PRODUCING FORMATIONS



F.L. Ransome's publication, "The Economic Geology of the Silverton Quadrangle, Colorado." Though this paper was published in 1901, it is the best source available for production figures. The diagram, therefore, represents the area of the Silverton quadrangle, whose boundaries are shown by the eastern two thirds of figure 2.

In arriving at a figure for the length of mining activity "mine years", it was necessary to divide the mines into three groups: 1. Mines with a record of mining years, 2. Mines without a record for either mining years or production. For each such mine described two years were added to the total, 3. Mines without a record of mining years but with a record of production. For each mine thus described two years were added to the total plus one year for each $5000 worth of ore produced. For the total number of mines, the number of mines described was taken.

In his work south of Ouray R.S. Moehlman[1] determined an order of favorableness of wall rocks that differs somewhat from the one determined from Ransome's report.

Moehlman's classification in descending order of favorableness is: 1. San Juan tuff, 2. Picayune formation, 3. Burns breccia, 4. Burns latite, 5. Potosi tuff, 6. Potosi flows.

The Picayune formation or the Potosi series does not appear in this diagram because no mines were described in these formations; however, it is possible that some of the production credited to the San Juan tuff and the Burns formation actually belong to the Picayune formation. The Red Mountain district which is found in the Silverton volcanic series cannot be credited to any one formation within the series because the rocks are altered beyond recognition.

[1] Moehlman, 1936, pp. 390-391.

Ore Control in Typical Mine

The Shenandoah-Dives Mine.- The Shenandoah-Dives is the most important mine near Silverton and is located four miles southwest of the town. It is on a system of veins striking NW-SE, the main vein following an andesite dike which forms at least one wall of the fissure where the best ore is found. The country rock includes both Eureka rhyolite and the Burns latite group. Vertical displacement of 135 feet has occurred, accompanied by about an equal amount of horizontal movement. In general there has been an alternation of horizontal shifts and gravity adjustments of the fault blocks. The cycle seems to have started with a strong shift to the northeastward, tilting the hanging wall of the Shenandoah-Dives dike toward the southeast. This shift was both accompanied and followed by down-faulting of the blocks, during which the hanging walls slid downward and somewhat eastward relative to the footwalls. The fact that east-west zones of fissuring were not appreciably opened by these movements suggests that the crust was under radial compression. With movements of this nature changes of strike or dip of the fault surfaces have an important influence on localization of highly fissured or open ground which is favorable to the localization of ore shoots.

Structural features controlling the limits of the ore shoots are of at least two kinds; gougy slip planes generally parallel to the strike of the lode, that were relatively impermeable to the mineralizing solutions, and certain changes in strike or dip whereby the amount of open space was reduced below the minimum width allowable by current methods of mining. Changes in strike of the dike and fracture system combined with the relative horizontal of the walls appear to have been a factor in producing zones of open and of tight fissuring. Broken ground of considerable vertical extent was produced chiefly by the early horizontal component of shifting, and by downward slipping of the hanging wall before and during mineralization forming gouge planes which acted like baffles. These gouge seams tended to divide the open zones into a series of channelways of comparatively low dip, which had a greater horizontal than vertical extent. At places where the vertical zones were not tightly sealed by the limiting gouge planes or baffles, the channels extended upwards with more nearly vertical elongation and afforded openings through which portions of the ore-depositing solution rose more directly toward the surface.

Under the conditions existing along dike walls or other surfaces of discontinuity that were refissured, the nature and physical properties of the wall rocks have a minimum effect on the fracture systems formed and on the nature of open spaces.

TELLURIDE MINING DISTRICT

General Features

The Sneffels and Telluride districts combined will be called the Telluride district in this report. It includes the most productive vein deposits of the San Juan region and comprises a swarm of northwest-trending dikes, fissures and veins at the northwest border of the caldera. Fissuring and tensional rupturing of the competent formations took place concurrently with the formation of the northwest axis of downwarping exterior to the main caldera. The early dike-filled fissures were curved in strike and represent a simultaneous development of radial tension fissures about the main caldera and an outlying intrusive center situated about seven 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.

Under conditions of incipient deformation the massive uniform body of the San Juan formation was probably the main storage reservoir of fissuring energy, produced by down-bending of the shallower rock formations. By comparison neither the Potosi volcanics above nor the sedimentary rocks beneath would be resilient enough to store equal energy in the form of strain. The conditions are comparable to those of a slab of resilient material embedded between layers of stiff mud, and the whole system being subjected to bending under its own weight. Very little energy would be stored in the mud, for minute cracks would form in it. The energy stored in the slab would be partly released when the stress exceeded the elastic limit and ruptured, and the cracks produced would be larger and more open than those in the mud.[1] Fissuring is continuous from the San Juan through the andesites and rhyolites above. However the fissuring in the rhyolite is tight for it was protected from severe strain by the alternation of rocks between it and the basement.

The geologic formations found in the Telluride district are similar to those of Ouray and Silverton and do not warrant a separate description. The sedimentary rocks are summarized in table 2, and the volcanics in table 3.

The most productive formation is the San Juan tuff, and nearly all the large mines produce from it; that is, the Virginius, Tomboy, and Smuggler-Union. The latter two mines are briefly described below. The sedimentary rocks have a much smaller production than the San Juan tuff; the producing beds are the Telluride conglomerate and the Triassic sandstone. The lower Paleozoics, like the Leadville limestone, may be ore-bearing horizons in the Telluride district but in most places they are not exposed at the surface and no mines have been worked down to their depth. The least productive beds are the volcanics above the San Juan tuff. This is partly due to the fact that some of the rhyolitic beds fracture with a tight pattern and also to a large extent to the position of these formations above the very favorable San Juan tuff. Ores occurring for some distance above the upper San Juan contact tend to verify this latter point.

1. Burbank, 1941, pp. 232-234.

TABLE 4. SEDIMENTARY FORMATIONS OF THE RED MOUNTAIN, TELLURIDE, AND SNEFFELS DISTRICTS

	AGE	NAMES USED LOCALLY	NAMES AND SYMBOLS USED IN THIS REPORT AND ON GEOLOGIC MAP			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.
			Wanakah marl member		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.
		†La Plata sandstone	Bilk Creek* sandstone member				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.
			Pony Express* limestone mem.				10 - 25	Dark bituminous shaly limestone, limestone breccia, and bedded or nodular limestone.
			Entrada sandstone		Je	45 - 80		Massive white sandstone, distinctly cross-bedded in upper part; commonly more even bedded in lower part.
	Jurassic (?) and Upper Triassic	Dolores formation	Dolores formation		TRd	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.
Palezoic	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.
	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.
		Molas formation	Molas formation			40 - 60		Red calcareous shale, sandstone with pebbles of quartzite and chert, and interbedded conglomerates with many chert pebbles.
	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.
	Upper Devonian		Ouray limestone			65 - 75		Mainly gray, buff, white, fine-textured, dolomite or dolomitic limestone; layers of pinkish clastic limestone with fossils locally.
		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.

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

Burbank 1941, p.150

TABLE 3 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.

Burbank 1941, p.152

Degrees of favorableness can not be assigned to rock formations without careful consideration of their structural environment. This was discussed earlier for the sedimentary rocks at Ouray and for the volcanics at Silverton. It may be restated here that the type of open fissuring of the San Juan tuff made it a very favorable host rock for ore deposition, tight fissuring in the rhyolites made them less favorable (see figure 6).

Published data was not sufficient to construct a production graph of the various formations for the Telluride district, but the largest production by far came from mines in the San Juan tuff. The top three are the Tomboy 1880-1926 with a production valued at $23 million, the Smuggler-Union 1875-1936 with a production valued at $20 million and the Virginius 1879-1936 with a production valued at $12 million.[1]

Ore Control in Typical Mines

The Smuggler-Union Mine.—The Smuggler-Union Mine, within sight of Telluride, is on one of the largest productive veins in the world. It is in the San Juan tuff and extends horizontally over four miles and vertically down to 1300 feet. This vein is characteristic of the fissure-filling type, figure 7, but some local variations occur. From a typically banded structure it changes to a linked structure (stockworks), and from "horse"-filled fissures gradations exist to solid vein material with a minimum of country rock fragments. The normal faulting has an almost vertical dip. However, the poor ore zones are related to the flatter dips, thus suggesting filling of open spaces in the steeper parts of the fissures. The average vein thickness

[1] Moehlman, 1936, pp. 380-382.

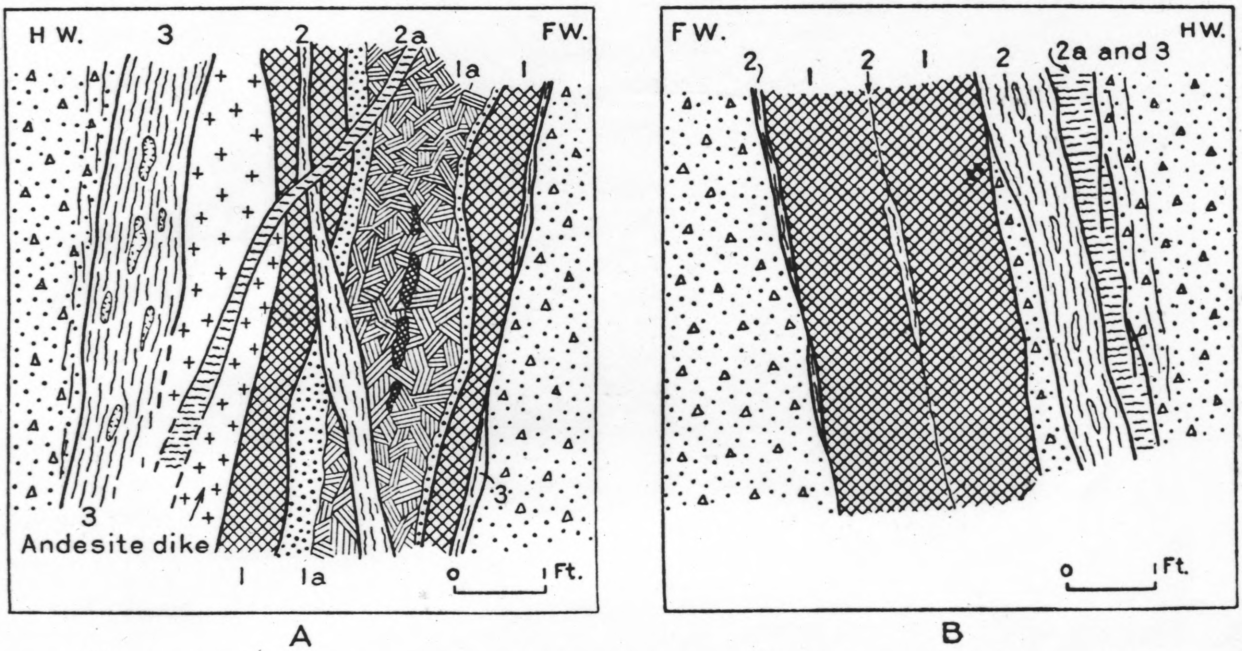


FIGURE 7 —Typical structure of late Tertiary compound veins in the intermediate zone of the Sneffels district. Both hanging wall (HW.) and footwall (FW.) of veins are San Juan tuff.

A. Sketch of back of stope, Highland Chief vein. 1, Base-metal vein with border of quartz containing pyrite, sphalerite, and galena, grading inward to massive mixed sulphide; 1a, quartz with pyrite and sphalerite forming narrow border, with inner part of vein chiefly barite and massive galena; 2, quartz with rhodochrosite and narrow crinkly bands of sulphides, mainly pyrite and sphalerite; 2a, gray and white ribbony or banded quartz with pyrite; 3, white chalcedonic quartz with pyrite, and crystal-lined vugs.

B. Sketch of a breast, Cumberland vein, Revenue tunnel workings. 1, Base metal ore, mainly the massive sulphides, pyrite, sphalerite, and galena (silver-bearing), with minor gangue of quartz, ankerite, barite, sericite, and calcite; 2, quartz and rhodochrosite vein with narrow crinkly bands of sulphides of pyrite and sphalerite, with some chalcopyrite, and galena (rhodochrosite and galena mainly in center of vein); 2a and 3, granular quartz and sericite (containing small specks of pearceite), argentite (?), and some pyrite (also gray banded quartz with narrow streaks of fine pyrite, some of which is gold-bearing, and late barren quartz with vugs belonging to stage 3).

Burbank 1940, p.250

is five feet, and the ore is uniform in value over long horizontal distances except in the rhyolite where it diminishes in quantity and richness. The ratio of values in the ore for gold and silver is about 1:1. The primary minerals are white quartz, dark resinous sphalerite, galena, pyrite, chalcopyrite, proustite, pearceite, and free gold. The mines production up to 1936 was $20 million worth of ore.

The Tomboy Mine.- The Tomboy Mine is located three and one half miles east of Telluride on a vein that shifts so constantly from one set of fissures to another that its average strike must be determined from its survey plotted on a map. The country rock of the vein is the San Juan tuff. The limits of the narrowly cleaved zones which have been filled with ore are fairly well defined, and it is only occasionally that stringers accompany the main lode. The average width of the vein is four to seven feet, and it is characteristically a solid filling between two walls. The linked type of vein is very well shown in places, but it is subordinate to the solid filling type. Unreplaced angular fragments of country rock are frequently found within the vein. This is the evidence that the ore is the filling of open spaces unaccompanied by chemical replacement of country rock. The value of the ore comes almost entirely from gold, three quarters of which is in the native state. The gold is often associated with galena, and sphalerite in narrow streaks which cross from one wall to the other in the vein, and is fairly continuous throughout the workings.

LAKE CITY MINING DISTRICT

The Lake City district is about twenty miles east of Ouray. Lake City is in the northern part of Hinsdale County where Henson Creek flows eastward into Lake Fork, a southern tributary of the Gunnison River. The ore deposits covered by this report are along Henson Creek to the west of Lake City for ten miles and to the south along Lake Fork for three miles. Of the total production of the Lake City district, the greatest value was in silver and gold.

General Features

In general the veins are formed at moderate depths and are on the edge of the highly mineralized Telluride-Silverton region. The fissuring has occurred since the last intrusion of magma in the Miocene or Pliocene, and it cuts all the intrusives except the Potosi rhyolite and later rocks.

The surface formations are all of Tertiary age and of igneous origin. In order from oldest to youngest they are: San Juan tuff, Picayune volcanic group, Eureka rhyolite, Burns latite, Pyroxene andesite, Henson tuff, Potosi volcanic series, and Hinsdale volcanic series. The many intrusives found in the area range in composition from quartz monzonite to andesite.

The veins of the Lake City district formed partly through the replacement of shattered sheeted zones in the country rock but chiefly through the filling of open spaces. The main alteration of the wall rock has been silicification, seritization, and pyritization. Adjoining the vein where the most intense alteration has taken place, the wall rock has been altered to a black jasperoid material extending four to five feet beyond the vein. Pyritization extends farther into the country rock than other types of alteration.

Ore Localization

The greatest number and the most valuable of the lodes in the Lake City district are found in the Picayune volcanic group, which consists of lavas and fragmental rocks. These volcanics range in composition from dark andesites to dacites, quartz latites, and light gray rhyolites. Eighty per cent of the value of Hinsdale county's total production has come from this formation.

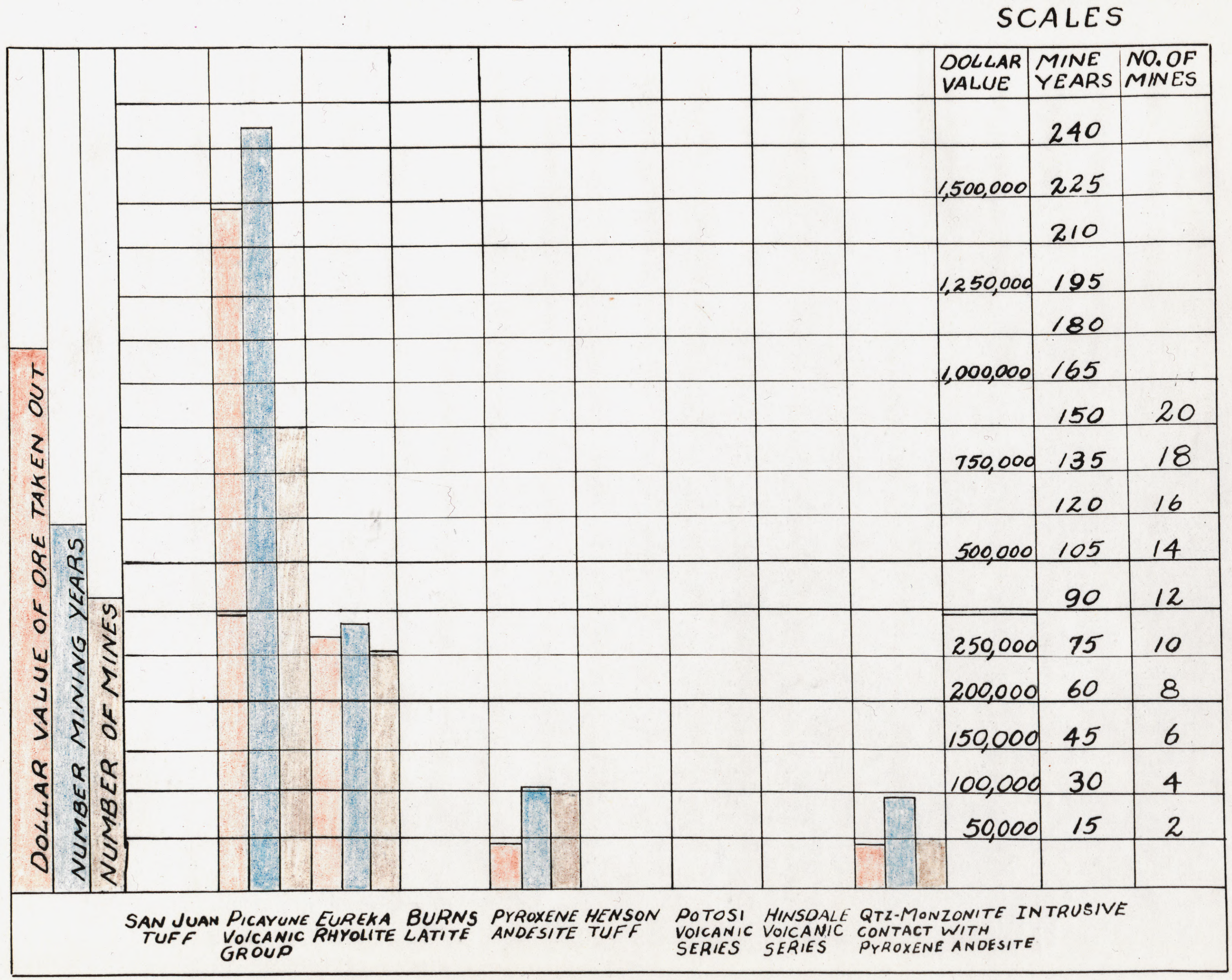
The effect of country rock as a chemical precipitant of ore minerals has apparently not been important in the Lake City district. The ore minerals of many of the veins vary at places where no change occurs in the wall rock; on the other hand veins have the same mineralization throughout several different formations.[1] The ore minerals are argentiferous galena, tetrahedrite, sphalerite, pyrite and ruby silver. The gangue minerals are mainly quartz with some barite. Apparently very little chemical difference or difference in permeability exists between the numerous rhyolites, andesites, and latites found in the various formations.

Many of the producing veins such as the Ute, Ulay, and Hidden Treasure veins contain "horses" or fragments of wall rock included in the ore, and they clearly follow pre-mineral fissures. Most of the veins in the Lake City district exhibit variation in strike and dip. The ores are often banded, and "horses" are not replaced by ore minerals. This indicates that most of the ore was deposited in open spaces as vein filling. The open spaces were formed by faulting along a fissure of varying strike or dip (see figure 4). The Ute, Ulay, and Hidden Treasure lodes are characterized by pinch and swell in the direction of strike and dip.

1. Irving and Bancroft, 1911, p. 46.

LAKE CITY DISTRICT
COMPARISON OF PRODUCING FORMATIONS

Plate 4



Evaluation of Lithologic Control

Data for the enclosed graph, plate 4, were obtained from Irving and Bancroft, 1911. The period covered is from 1874 to 1908. The figures for the total value of the district's production came from two sources; 1. Listed production values for various mines, 2. Approximated production values based on tonnage figures for several mines. Where sufficient information was not available no approximations were made.

In arriving at a figure for the length of mining activity or "mine years", it was necessary to divide the mines into three groups: 1. Mines with a record of mining years, 2. Mines without a record for either mining years or production. For each mine described two years were added to the total, 3. Mines without a record of mining years but with a record of production. For each mine described two years were added to the total plus one year for each $5000 worth of ore produced. For the total number of mines, the number of mines described was taken.

Ore Control in Typical Mines

<u>The Ute, Ulay and Hidden Treasure Mines</u>.[1]- From 1871, when the Ute Mine was discovered, until 1908 the Ute, Ulay and Hidden Treasure Mines have had a total production valued at $12,000.000. This is eighty-six per cent of the total value of ore produced in Hinsdale County. All the veins are found in the Picayune volcanic group, and the value of the ore is in its silver content.

The veins are characterized by considerable brecciated country rock which is included in the vein filling, but the brecciation is on a relatively small scale. The ore minerals are argentiferous galena, tetrahedrite, sphalerite, pyrite and ruby silver. The

[1] Irving and Bancroft, 1911, pp. 80-93.

gangue minerals are mainly quartz and barite with a few manganese-bearing minerals. The country rock has been silicified, but the metalliferous minerals have been confined to the vein. There is only a minor degree of replacement of the wall rock. The strikes and dips of the fissures are irregular. In one place the strike changes from N 46°E to N 37°E to N 19°E in 2700 feet, and it is here that a large ore body is located. At another place the vein diverges 45° ,continues for forty-five feet, and returns to its original direction. Variations in width of vein where pinches and swells follow one another in the direction of dip and strike indicate that there has been movement and suggests structural control. The ore bodies of the Ute, Ulay and Hidden Treasure Mines are fissure veins and distinctly the result of the filling of open fissures.

The Golden Fleece Mine.[1]-From the time of its discovery in 1874 to 1908 the Golden Fleece Mine has had a total production valued at $1,400,000. This is 8.0 per cent of the Hinsdale County production and makes the Golden Fleece the second largest producer in the county. The values of the ore are in gold and silver in a ratio of 1:1. The ore minerals are petzite (gold telluride), argentiferous tetrahedrite, pyrite, galena, and pyrargyrite. The gangue minerals are fine-grained clay, white quartz and rhodochrosite. Unlike other large producers in the Lake City district, the Golden Fleece Mine is in the Eureka rhyolite.

The country rock is a stratified flow breccia interbedded with volcanic tuffs and agglomerates that dip 27°W. The fine-bedded tuffs and flow breccias give way to a conformable series of extremely coarse agglomerates containing sub-angular boulders which make up most of the rock. The vein terminates upwards

[1] Irving and Bancroft, 1911, pp. 107-110

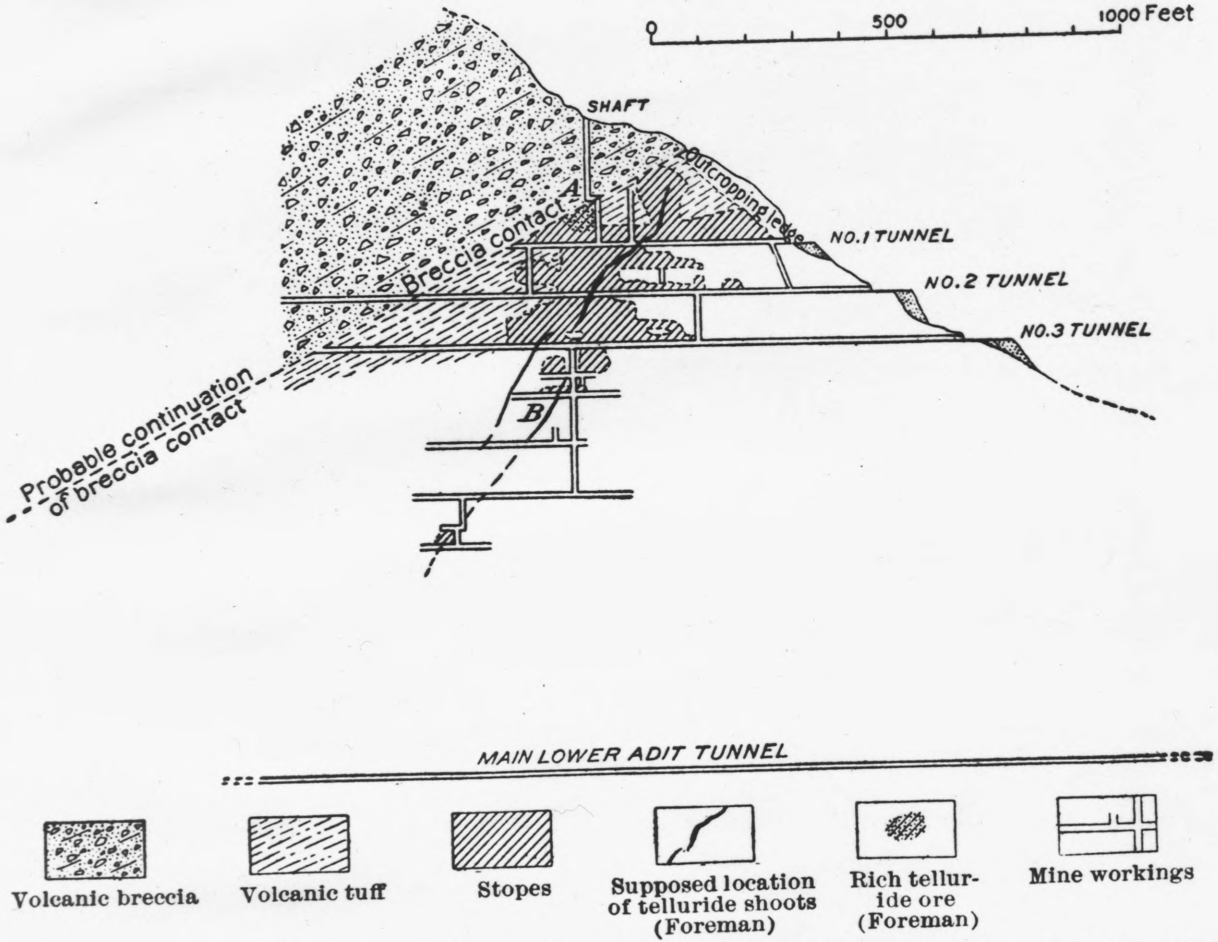


Figure 8 Longitudinal section of the Golden Fleece vein, showing position of agglomerate contact and ore shoots.

Irving and Bancroft 1911, p.108

against this contact as a roof and nowhere enters the coarse breccia (see figure 8).

T.A. Rickard[1] believed that the different physical character of the coarse breccia from the underlying tuff caused pre-mineral fissure to remain tight in the breccia while it broke clean and open in the tuff. Later mineralizing solutions filled the open spaces of the tuff with a vein, but before the vein reached the breccia it broke into minute stringers. However, later investigators, I.D. Irving and Howland Bancroft, dispute Rickard's conclusion and believe that the breccia contact is a bedding plane fault and that the vein has been displaced.

1. Rickard, 1903, p. 346.

CREEDE MINING DISTRICT

The Creede mining district is in Mineral County, southwestern Colorado, near the geographical center of the San Juan Mountains. The town of Creede is on Willow Creek, a few miles above its junction with the Rio Grande. The district measures about four and a half miles from east to west and five and three-quarters miles from north to south, as shown on the accompanying map.

General Features

The bedrock exposed in the vicinity of Creede is entirely Tertiary volcanic rock and is part of the great volcanic field of the San Juan Mountains. The relation of the formations in the Creede district to those of neighboring areas is shown in insert 1. In ore localization, however, the rhyolites of this district are of more economic importance than those of any other district in the San Juans (see plate 5). The oldest rocks exposed comprise a succession of rhyolites and quartz latites, chiefly in flows but contain some clastic material, and collectively are known as the Alboroto group of the Potosi volcanic series.

The lowest formation of the Alboroto group, the Outlet Tunnel quartz latite, is exposed only in two small areas in the bed of East Willow Creek. It is made up chiefly of biotite-hornblende-quartz latite but contains some pumiceous rhyolite. The rhyolite comprises both flows and fragmental material and is overlain irregularly by the Willow Creek rhyolite, one of the most economically important beds in the Creede district.

The Willow Creek rhyolite is composed of several flows of purple-drab to gray fluidal banded rhyolite. The main part of the rock is dense and has the luster of freshly broken porcelain, but streaks or lenses of a decidedly porous nature and a few centi-

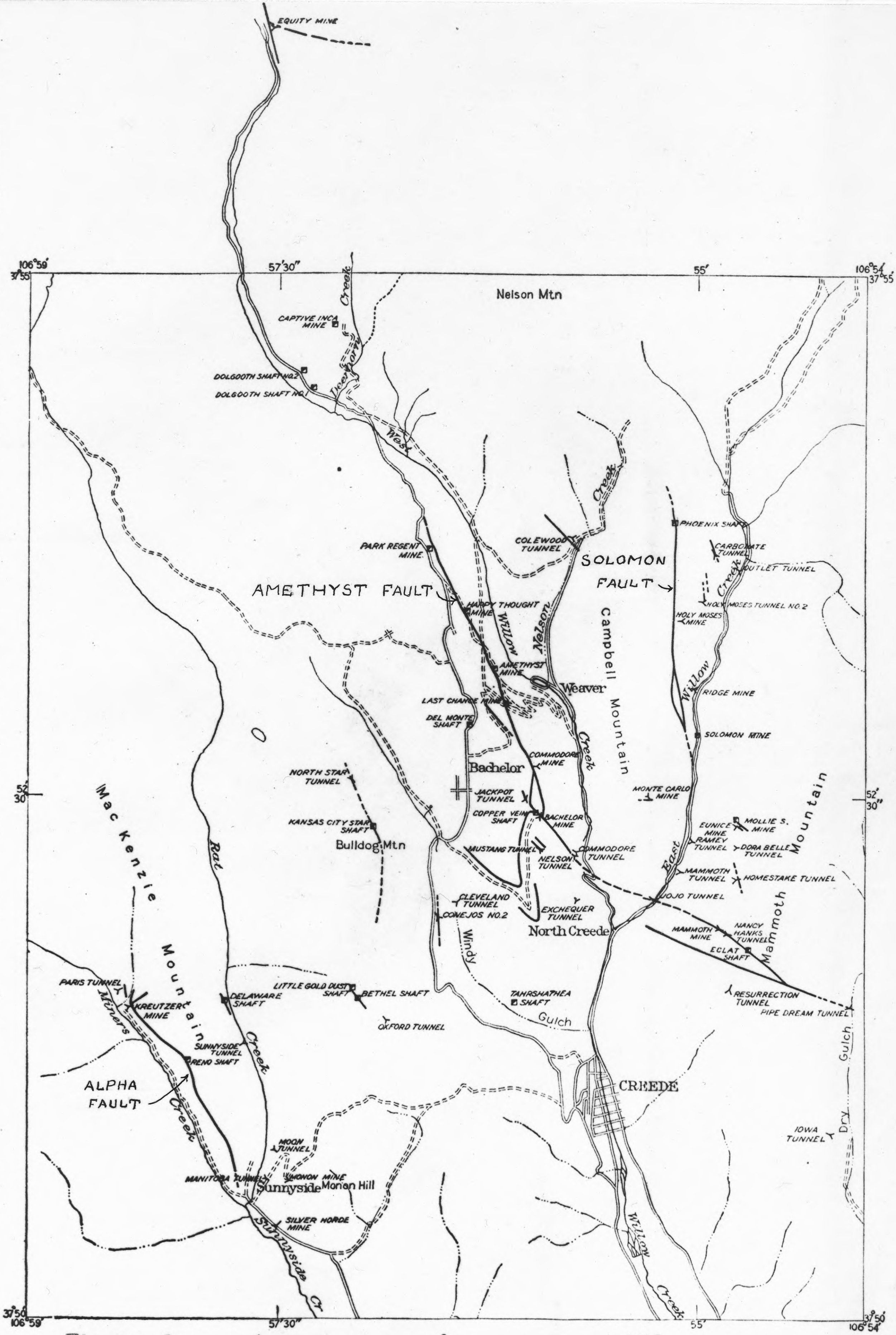


Figure 9

MAP OF CREEDE DISTRICT, COLORADO, SHOWING PRINCIPAL MINES AND PROSPECTS AND MINERALIZED FAULTS AND VEINS

Larsen 1929, p.102

Geologic formations in a part of southwestern Colorado.

[The waved lines indicate erosion intervals.]

Insert I

	H. B. Patton (quoting unpublished names of Whitman Cross and E. S. Larsen), 1917 (Colorado Geol. Survey Bull. 13, with map)--Platoro-Summitville district, southwestern Colorado.			W. H. Emmons and E. S. Larsen, 1922 (this report)--Creede district, southwestern Colorado.		Whitman Cross (folios and other published reports)—San Juan Mountain region, southwestern Colorado.
	Hinsdale volcanic series.			Absent.		Hinsdale volcanic series. 0-1,200± feet. Probably Miocene or Pliocene. Lava flows of rhyolite, andesite, and basalt. Named by Whitman Cross in 1911 (U. S. Geol. Survey Bull. 478, p. 22) for important development in Hinsdale County.
				Quartz latite porphyry dikes. Miocene (?).		
	Fisher quartz latite. [Thickness 0-3,000+ feet. Named for exposures in vicinity of Fisher Mountain, Creede quadrangle.]			Fisher quartz latite. Miocene (?). 0-100± feet.		Intrusive rhyolite, andesite, latite, and quartz monzonite porphyry.
	[Absent.]			Creede formation. 0-2,000± feet. Lake beds of tuff, with some flows of quartz latite in upper part. Miocene.		
Potosi volcanic series.	Piedra formation. [A series of volcanic flows, with subordinate tuff, predominantly of rhyolite and quartz latite. Thickness 0-2,000+ feet. Separated from underlying Huerto formation by an erosion interval. Named for exposures in Piedra Peak, San Cristobal quadrangle, Colo.]	Potosi volcanic series (Miocene).	Piedra group.	Nelson Mountain quartz latite. 0-350 feet.		
				Rat Creek quartz latite. 0-500 feet.		
				Quartz latite tuff. 0-500 feet.		
				Andesite. 0-500 feet.		
				Intrusive andesite.		
				Tridymite latite. 0-400 feet.		
				Windy Gulch rhyolite breccia. 100-200+ feet.	Rhyolite tuff (to east). 0-200 feet.	
				Hornblende quartz latite. 200 feet.	Mammoth Mountain rhyolite. 0-1,000 feet.	
	Huerto formation. [A series of andesitic flows and tuff breccias, 0-2,000+ feet thick, which commonly overlies the Alboroto formation rather regularly. Named for occurrence on Huerto Peak, in the southern part of the San Cristobal quadrangle, Colo., west of Huerto Creek.]			Absent.		Potosi volcanic series. 0-2,000± feet. Miocene. Lava flows of rhyolite, quartz latite, andesite, and tuff. Locally divisible into several formations. Named by Whitman Cross in 1899 (U. S. Geol. Survey Geol. Atlas, Telluride folio, No. 57) for development on Potosi Peak, Silverton quadrangle.
	Alboroto formation. [A series of quartz latite and rhyolite flows with some tuff. Thickness 0-3,000+ feet. Separated from Summitville andesite by an erosion interval. Named for occurrence in Alboroto Mountain, in the southeast corner of the San Cristobal quadrangle, Colo.]		Alboroto group.	Equity quartz latite. 0-1,000 feet.		
				Phoenix Park quartz latite. 0-500 feet.		
				Intrusive rhyolite.		
				Campbell Mountain rhyolite. 0-1,000 feet.		
				Willow Creek rhyolite. 0-1,000+ feet.		
				Outlet Tunnel quartz latite. 250-350+ feet.		
	Summitville andesite. [Named for exposures near Summitville, Colo. Thickness 0-3,000+ feet.]					
	Treasure Mountain latite. [Named for exposures on Treasure Mountain, in northwestern part of Summitville quadrangle. Thickness 0-1,000+ feet.]			Absent.		
	Palisade andesite (Conejos formation). [Palisade is long preoccupied by Palisade diabase of New Jersey. The name adopted by U. S. Geological Survey for these rocks is Conejos formation, derived from their exposures along Conejos River. Thickness 0-3,000+ feet.]					
						Silverton volcanic series. 0-4,000± feet. Probably Oligocene or early Miocene. Succession of flows of andesite, latite, rhyolite, tuff, and breccia. Locally divisible into several formations. Named by Whitman Cross in 1901 (U. S. Geol. Survey Bull. 182, p. 32) for extensive development in Silverton quadrangle.
						San Juan tuff. 0-3,000± feet. Probably Eocene. Series of stratified and water-laid andesitic tuffs, breccias, and agglomerates. Named by Whitman Cross in 1896 (Colorado Sci. Soc. Proc., vol. 5, pp. 225-241) for important development in San Juan Mountains.
						Lake Fork breccia. 0-1,000± feet. Probably Eocene. Chiefly chaotic andesitic flows and breccias locally developed in the Uncompahgre and adjoining quadrangles, Colorado. Here named by Whitman Cross and E. S. Larsen for exposures in the Lake Fork of Gunnison River in Uncompahgre quadrangle.
						Telluride conglomerate. 0-1,000± feet. Probably Eocene. Coarse conglomerate, containing pebbles and boulders or schist, granite, quartzite, limestone, and other Paleozoic rocks, with, locally, fine sandy limestones. Originally named "San Miguel formation" by Whitman Cross in 1896 (Colorado Sci. Soc. Proc., vol. 5, pp. 225-241) for exposures on north side of San Miguel River in the vicinity of Telluride. San Miguel being preoccupied by a Cretaceous formation of Texas, this conglomerate was in 1905 (U. S. Geol. Survey Geol. Atlas, Silverton folio, No. 120) renamed by Mr. Cross Telluride conglomerate.

Emmons and Larsen 1923, p.12

meters thick make up about ten per cent of the rock. Some exposures of the Willow Creek rhyolite are over 1000 feet thick, and its somewhat irregular surface is overlain by the Campbell Mountain rhyolite, another economically important formation.

The Campbell Mountain rhyolite is a flow breccia commonly reddish-brown or drab and has a dull luster, indistinct fluidal texture and a characteristic mottled appearance. It is generally porous, with pores less than one millimeter across; the larger ones are lined with drusy crystals of quartz and feldspar. Angular and rounded inclusions of older rocks are present. Fragments of the underlying Willow Creek rhyolite are abundant only near the contact with that formation. The Campbell Mountain rhyolite attains a thickness of 1000 feet near Creede but becomes thinner to the northeast and east. The Phoenix Park quartz latite is chiefly above the Campbell Mountain rhyolite but is in part interbedded with that formation.

The other volcanic formations of minor importance as host rocks to ore deposits are: the Equity quartz latite, the hornblende quartz latite, and the tridymite latite. The Equity quartz latite is closely related to the Phoenix Park quartz latite, but in the northeastern part of this district it usually overlies the Campbell Mountain rhyolite where it has a thickness of about 1000 feet. The hornblende quartz latite was extruded after the Equity quartz latite on a rugged erosion surface. The tridymite latite which is mostly in one flow over 400 feet thick overlies the hornblende quartz latite irregularly.

The Creede formation was deposited in a lake that occupied a valley carved out of rocks of the Potosi volcanic series. The lower part is made up of fine-textured, thin-bedded rhyolite tuffs, with some coarser material near the borders of the old lake. It contains numerous bodies of travertine which indicates the presence of abundant hot springs during this period. The upper part of the Creede formation is somewhat coarser textured and consists of well-bedded breccia and conglomerate with some fine tuff and intercalated thin flows of soda rhyolite. None of the other rocks listed in the stratigraphic column contain discovered ore bodies, so they do not warrant a description here.

After volcanic activity had ceased, erosion again became the dominant geologic agent, and the present mountains and canyons were carved from the great volcanic pile in two erosion stages. The first stage which continued to moderate maturity reached a base level about 1000 feet higher than the present Rio Grande River and developed broad valleys and rolling hills in the southern part of the district. The second stage began with a considerable increase in stream gradient, and the larger streams cut their beds headward to develop the rugged canyons above Creede. After the streams had cut down their beds nearly to their present level, the upper portions of the main streams were occupied by glaciers that widened the valleys but did not cut them much deeper.

The chief deformation of the region has been rather complex block faulting with some tilting near the faults. Nearly all the ore deposits lie along these faults. The faults are believed to be later than any of the volcanic rocks of the area, and earlier than the development of the present topography. The area has also probably been gently tilted to the south.

Most of the major faults are normal faults with steep dips and strike a little west of north. An exception is the Equity fault which strikes nearly east, dips steeply north and is the only reverse fault in the area. One of the most striking characteristics of the faults is the manner in which they die out along their strike. The great Amethyst fault, southeast of the Commodore Mine, breaks up into a number of faults some of which have throws of over 1000 feet. North of the Park Regent Mine the throw of the Amethyst fault is believed to decrease rapidly and is probably small just south of the Equity Mine; but here the Equity fault joins it, and beyond this junction it again has a large throw for some miles. The Alpha and Ridge faults pass into considerable fractured folds at their northern extremities and are lost. Some faults end abruptly against other faults, and sharp changes in strike are not uncommon.

Nearly all the faulting is believed to have occurred during a rather brief geologic epoch and preceeding the mineralization. However, the minor crushing and slickensiding of vein material in nearly all the veins shows that some movements have taken place since the mineralization.

The Amethyst fault system is the most prominent structural feature of the region, and it gains additional importance from the fact that the productive Amethyst vein lies along it. Ninety-eight per cent of the district's production comes from this one vein. Its chief production comes from between the south line of the Bachelor claim and the north line of the Park Regent claim (see map figure 9). North of the Commodore Mine the fault is clean cut with a strike of about N 23° W and a dip of 50°-70°W. At the surface the western or hanging wall is the upper Creede formation in the southern part, and the Windy Gulch rhyolite breccia in the northern part. However, a few hundred feet below the surface the Campbell Mountain rhyolite forms the hanging wall for the full length. The eastern or footwall is Willow Creek rhyolite both at the surface and to the present mining depth. The throw here is at least 1400 feet. The Amethyst fault branches south of the Commodore Mine and comes together again near the Bachelor Mine. South and east of West Willow Creek there is a network of related faults, but no one of them can be considered the continuation of the Amethyst fault.

Ore Localization

The lithologic ore controls in the Creede district are very obscure. However, it is interesting to observe that most of the district's production comes from faults between the Willow Creek rhyolite and the Campbell Mountain rhyolite (see plate 5). In the western San Juans the rhyolites were very barren rocks, because the faulting was mild and the fractures that resulted were tight. At Creede, however, the faulting was strong,and as a result the fractures in the rhyolites were not tight but apparently more open than in the other volcanic beds. Openings due to changes in strike and dip were important structural controls in places, whereas replacements of shattered zones of rhyolite are of less economic importance. The replacement of wall rock in general is of less importance in this district than the filling of open fissures.

The ore deposits of the Creede district are chiefly silver-lead fissure veins in rhyolite. A very small production comes from silver ore in fracture zones in shattered rhyolite. The veins occupy strong fault fissures and generally are extensive both vertically and along the strike. All these veins strike in a northwesterly direction and the majority dip west or southwest.

The principle veins fill fissures along normal faults, and at some places there are subordinate fissures, particularly in the hanging wall, which join the principle faults in depth. Such relations suggest that the hanging wall of a fault was shattered as it was drawn downward by gravity along the footwall.

In the Amethyst vein the ore minerals include zinc blende, argentiferous galena, gold, pyrite, chalcopyrite and their alteration products. The gangue minerals include quartz, much of it amethystine, with chlorite, barite and fluorite. Hydrothermal metamorphism is not pronounced over very wide areas, but along the most productive portions of veins considerable alteration has occurred in the form of silicification and sericitization. Locally the gangue contains thuringite $(H_{18}\,Fe_8(Al.\,Fe)_8\,Si_6O_{41})$ and near the Amethyst vein adularia has been found in veinlets cutting rhyolite. Ribbon quartz and symmetrically banded crusts are common indicating deposition locally in open spaces. The mineralization is of Miocene or later age.

In some of the deposits enrichment is pronounced. The rich secondary ores extend downward to a depth of several hundred feet because of the relief of the area and the open character of the veins. Deep and rapid circulation was possible. Ground water containing sulphuric acid and ferric sulfate dissolved silver in the oxidizing zone and precipitated native silver when an increase in alkalinity or a decrease in the proportion of ferric to ferrous sulfate occurred.

The fractured zones of silver ore in shattered rhyolite occur in thin veinlets of green chrysoprase and other green copper minerals and locally carry very high percentages of silver. Argentite, cerargyrite and native silver are plastered on the walls of the thin, narrow cracks. Iron sulphides are not abundant. The rhyolite along the veinlets is apparently fresh and not greatly affected by hydrothermal metamorphism.

Some of the ores have been deposited in open spaces and some by replacement of wall rock. It is not everywhere possible to distinguish ore that has been formed by one process from that formed by the other, and where replacement has been almost complete, there is little evidence remaining of the older material. It is believed that the major part of the deposits were formed in open spaces since some of the ore occurs in crustified bands and many wall rock fragments in the vein show no replacement.

In the Commodore Mine, a typical mine on the Amethyst vein and one with a large production, ore was produced from beds in the Creede formation. On the west slope of Monon Hill silver ore was found along the unconformable sedimentary contact between the Creede beds and the underlying Willow Creek rhyolite. Southwest of the Commodore Mine mineralized beds of tuff produced considerable silver ore. Especially rich in silver were replacements of vegetal matter in the tuff. It seems probable that solutions rising along fault fractures permeated the tuff beds and mineralized beds with a high organic matter content. Total production from these bedded deposits was valued at $800,000.

After all the volcanic formations of the Creede area had been laid down, great faults several miles long were formed, and the district was broken into a number of great block mountains. After the movement along the faults was nearly completed, mineralizing solutions from below, moving through the openings along the faults, deposited the primary ore. The surface at that time was much higher and many hundreds of feet of rock then present have since been removed. During this erosion interval ground water solutions leached the primary ore from the oxidized zone and deposits of secondarily enriched ore were created below (Emmons and Larsen, 1923).

In the main Amethyst vein most of the large bodies of rich ore in the upper workings were formed by downward moving solutions at the time the upland valleys were being sculptured, and were near or above the ground water level of that time. The ore of the lower workings was probably formed by the enrichment of primary vein filling by descending surface waters while the present canyons were being eroded. This ore is mostly of lower grade than that of the upper workings. However, if since the lowering of the water table, a length of time had elapsed equal to the time during which the upper ores had been concentrated, then all the ore would occur as one deposit near the present water table if the views of Emmons and Larson on the supergene origin of the rich ore is correct.

In general, next to the producing veins, the wall rock is somewhat fractured but not much altered, ore is lacking where the wall rock is much altered.

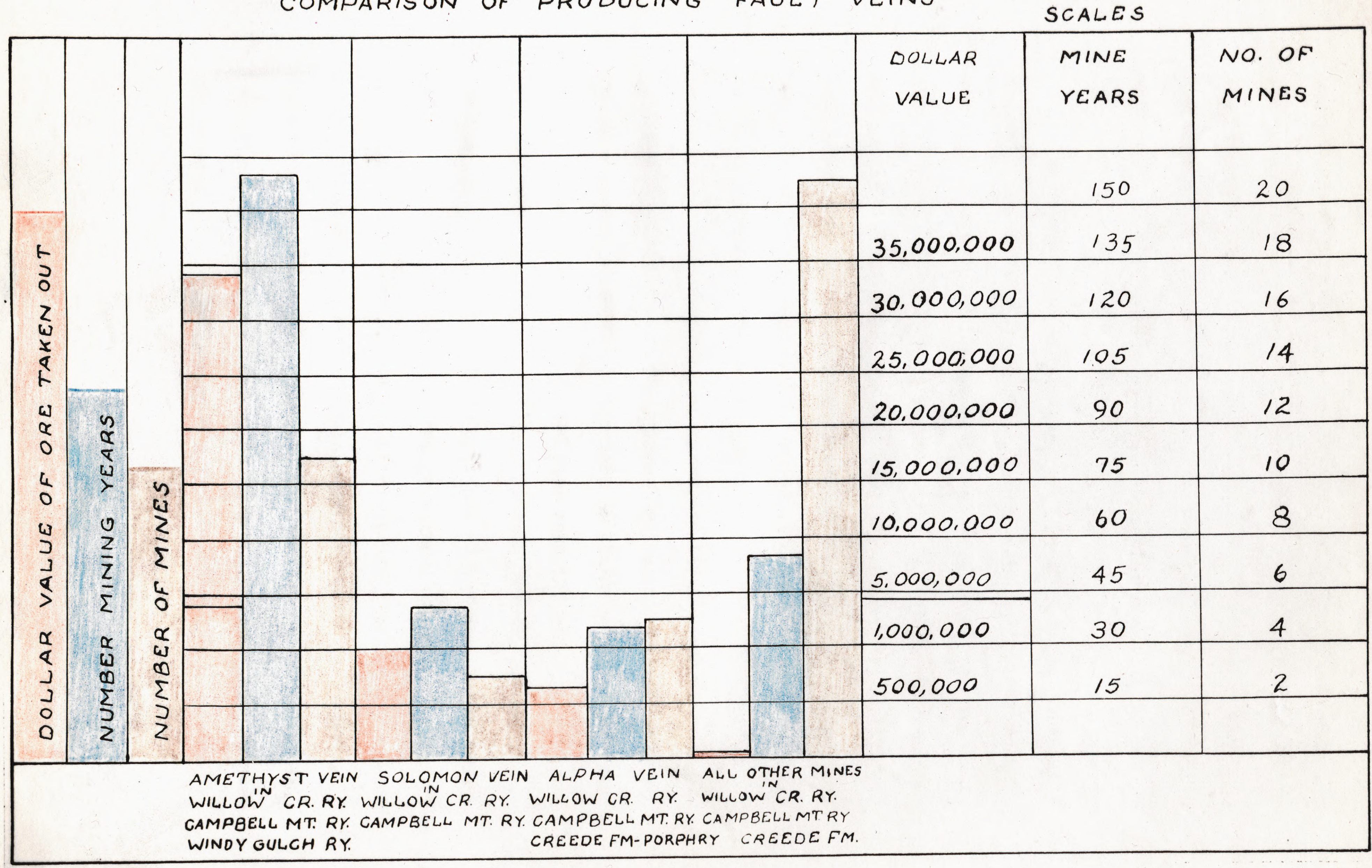
Evaluation of Lithologic Control

Data for the enclosed graph, plate 5, were obtained from Emmons and Larson, 1923. The period covered is from 1884 to 1912. The figures for total value of the district's production came directly from the reference.

In arriving at a figure for the length of mining activity or "mine years", it was necessary to divide the mines into three groups: 1. Mines with a record of mining years, 2. Mines without a record of either mining years or production. For each such mine

Plate 5

CREEDE DISTRICT
COMPARISON OF PRODUCING FAULT VEINS



described two years were added to the total, 3. Mines without a record of mining years but with a record of production. For each mine described two years were added to the total plus one year for each $5000 worth of ore produced. For the total number of mines, the number of mines described was taken.

Ore Control in Typical Mine

The Commodore Mine 1891-1912.–The Commodore Mine is about two miles north of Creede on the Amethyst vein. The outcrop of the vein on the Commodore claim is not conspicuous for it is covered nearly everywhere by talus. The Amethyst vein is along the Amethyst fault plane in this mine, and most of the ore has been taken from the fault fissure rather than from fractures in the foot or hanging wall. The footwall is everywhere in the Willow Creek rhyolite. The hanging wall in the lower levels is the Campbell Mountain rhyolite, above the third level it is a tuff member of the Creede formation. In the hanging wall four fissures nearly parallel to the fault in strike but dipping into the fault plane at depth supplied some shipping ore.

The best grade ore comes from between 200 and 500 feet below the surface on the fault vein. Most of the ore is oxidized, and the principle minerals are native silver, caragyrite, pyromorphite, anglesite, cerusite, smithsonite, limonite and wad. At depth galena, sphalerite, pyrite and chalcopyrite become increasingly abundant. The gangue minerals are white and amethyst quartz and barite. Post-mineral faulting is pronounced on all levels and the ore as deep as 1450 feet below the surface is partly oxidized.

THE BONANZA MINING DISTRICT

The Bonanza district covers about 35 square miles in the extreme northeastern part of the San Juan Mountains of southwestern Colorado. The town of Bonanza is on Kerber Creek at a latitude of N $38^{o}17'30''$ and a longitude of $106^{o}08'30''$. The Bonanza district extends from a mile west to about two miles east of town, and approximately four miles both north and south. The range in altitude is from about 8500 to a little over 12,000 feet above sea level (see key map figure 10).

General Features

The rocks of the district are principally lavas of Tertiary age, probably Oligocene, which rest on a basement composed of pre-Cambrian metamorphics and Paleozoic sedimentary rocks (see figure 11 for stratigraphic column). In Laramide time the Bonanza region underwent strong folding and thrust faulting, and the folds and faults are older than the volcanic formations. The folds in the Paleozoic rocks trend north-northwest, roughly parallel to the north end of the Sangre de Cristo Range which lies to the east. Along Kerber Creek about 5000 feet of the Paleozoic formations have been overridden obliquely to the trend of their folds by thrust blocks of pre-Cambrian granite. The thrust blocks moved in a north-northeasterly direction relative to the younger underlying sedimentary formations. Because of the apparent difference in the direction of application of the forces causing the earlier folding and later thrust faulting, it is inferred that they represent two epochs of deformation, although perhaps different parts of a single major cycle.

After the folding and thrust faulting there occurred a

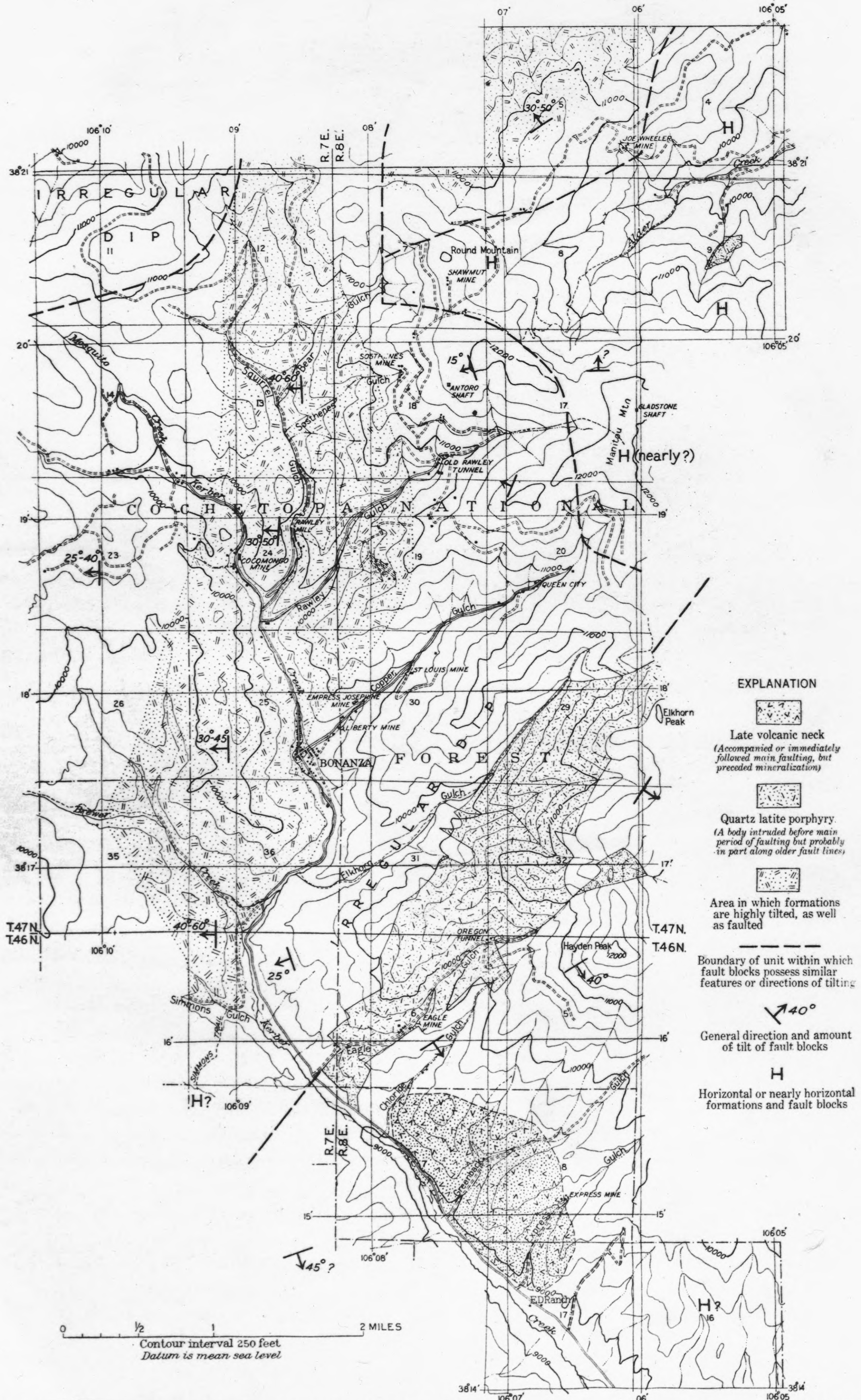


FIGURE 10 Key map of the main structural features of the Bonanza district, showing the general tilting of fault blocks in different parts of the district

Burbank 1932, p.52

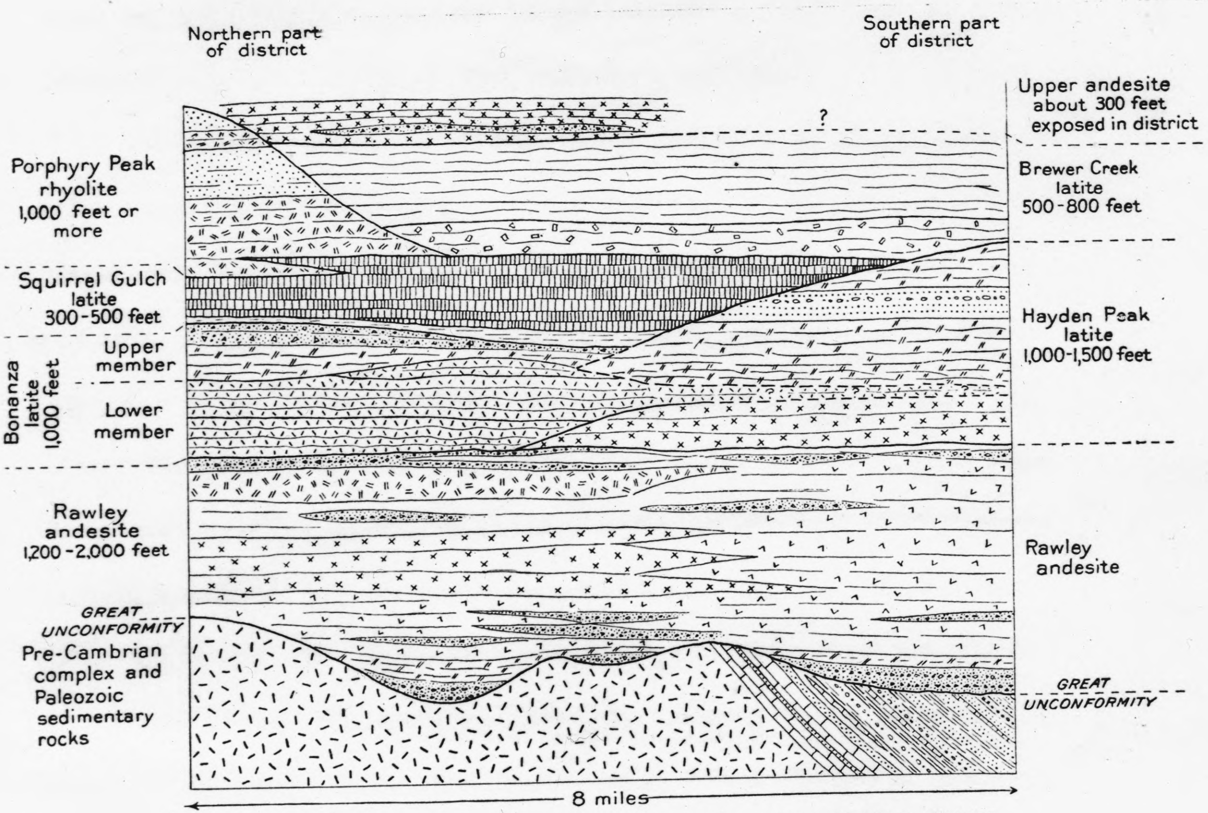


FIGURE 11 Columnar section of the Tertiary lavas of the Bonanza district

Burbank 1932, p.16

period of extensive erosion during Eocene time. A great thickness of sedimentary formations was eroded off, and there resulted a hilly surface on which were exposed remnants of the Paleozoic formations and the underlying pre-Cambrian basement. Because of the great extent of this erosion only synclinal bodies of the Paleozoics were preserved. The average topographic relief developed on this erosion surface is estimated to have been at least 500 feet in the region of the Bonanza district.

Tertiary volcanism subsequently resulted in the formation of a high volcanic plateau. The structure in the Tertiary volcanic rocks as it now exists can be explained most simply by a moderate local doming of the plateau formations during a deep-seated migration of molten magma, followed by a collapse of the dome about the intrusive mass when its close approach to the surface weakened the crust sufficiently to permit the extrusion of lava. Presumably this extrusion of lavas resulted in such a loss of volume and supporting force of the intrusive body that the crust failed and subsided locally under its own weight. The older lavas were broken into many small block faults which were thrown downward in successive steps towards a central area of collapse. The fault blocks were steeply tilted away from the central axis of the dome on at least its western, northern and southern flanks. The uniform and unusual character of the tilting is attributed in part to an initial tilt produced during doming but greatly increased locally by compressional stresses that became active during the subsidence.[1]

Most veins of the Bonanza mining district occupy fault fissures whose displacements range from 600 to 1000 feet. Variation

[1] Burbank and Henderson, 1932, pp. vii-viii.

in dip on these structures is from 15°to 90° but the average dip is 60°. Most of the faults are normal, but a few are high-angle reverse faults which have resulted from shearing of large fault blocks subjected to compressional stress during the subsidence. The walls of the low angle faults, less than 45°, have been subjected to great pressure and friction during faulting which formed a pre-mineral gouge. The ore bodies in these fault fissures are lenticular and not as extensive as those in the steeper fissures.

In the high angle fissures, more than 45°, the pre-mineral gouge is not so thick and the difficulties of controlling broken ground are obviously much less than along faults of low angle. Stresses in the walls of some faults during the period of faulting have caused the formation of hanging wall fractures and parallel fractures. A few of the hanging wall fractures are commercially mineralized.

The Bonanza mining district can be divided into two parts, the northern and southern, on the basis of consistant difference in the character of the veins and their metal content. The veins of the northern part are base-metal veins, characteristic of a low to intermediate temperature of formation. They are typically high in silica and moderately high in sulfide content. Some of them show a primary zoning of metal content, changing from lead-silver or lead-zinc veins near their outcrops to copper-silver or pyritic veins at depth. The mineral zones are in places telescoped within a vertical range of 500 to 1000 feet, so that complex ores are common. The principle sulfide ores contain pyrite, sphalerite, galena, silver-bearing tennantite and chalcopyrite with some enargite, bornite, stromeyerite and chalcocite. The gangue minerals are mainly quartz, barite, manganiferous calcite and rhodonite. Locally tellurides of silver and gold represent a very late stage of mineralization.

In the southern part of the Bonanza district the veins are of types generally assumed to have formed at comparatively low temperatures. Their sulfide content is very low, in many veins not exceeding two or three per cent. Quartz, rhodochrosite and fluorite are very common gangue minerals, and adularia is found in some veins. The sparse sulfides are commonly pyrite, chalcopyrite, sphalerite, galena, pyrargyrite, proustite and tennantite. The principle economic value of these veins is in the silver content of the primary sulfide shoots, or in the enriched sulfide zones, and to some extent in the manganese oxide content of the completely oxidized veins.

All parts of the Bonanza district had two main stages of mineralization. The first stage followed closely the development of faults and fissures. It was a barren silicification of the lavas near the fissure channels which converted them into tough jaspery rocks made up mainly of fine-grained quartz and a little chalcedony. The chemical decomposition of the rocks that were deposited with and which accompanied deformation of the early silica resulted in alteration characterized by hematite, diaspore, alunite, barite, zunyite, rutile and kaolin minerals. In places the silicified lavas contain much pyrite but seldom any other sulfides. The jaspers are commonly brecciated near strong veins, and the second stage of mineralization, consisting of the vein filling with gangue and metal sulfides, followed the brecciation.

In the second stage the alteration of the fissure walls was mainly a micaceous alteration. The minerals formed are sericite, chlorite, carbonates, quartz and pyrite. This intensely altered rock is soft and weak. The early stage of silicification was accomplished by either fumarolic activity or by acid hot spring waters. The later stage of alteration and vein filling was done by either alkaline or neutral solutions.

Ore Localization

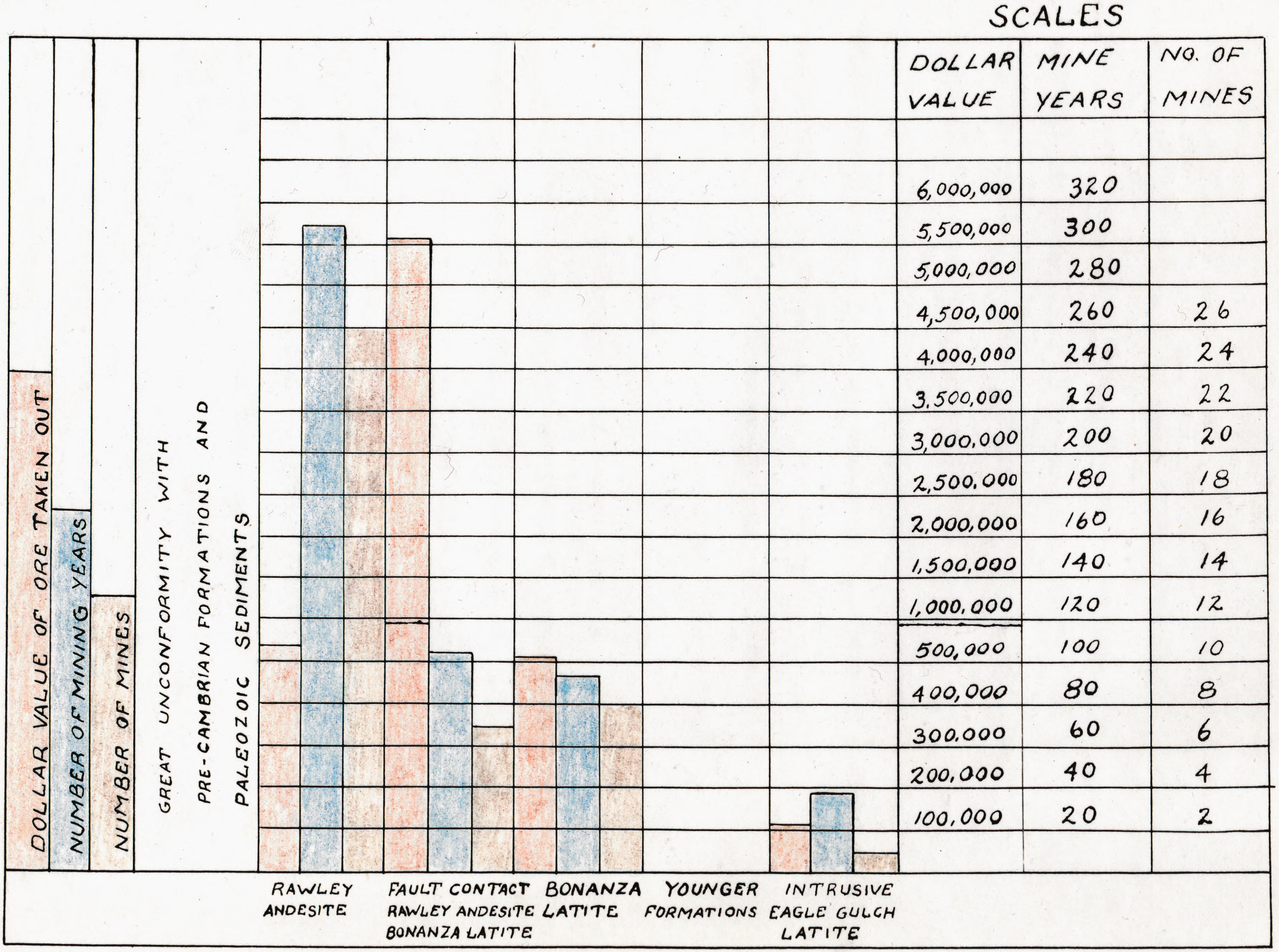
The production of ore from mines located on the fault contact between the Rawley andesite and the Bonanza latite is over 81 per cent of the total Bonanza district production. The second largest producing zone is the Rawley andesite which contributes nine per cent of the district total. The mines in the Bonanza latite produce 7.5 per cent of the total production for the district. These relationships are expressed graphically in plate 9.

No commercial ore deposits are found in the Squirrel Gulch latite, Porphyry Peak rhyolite, Hayden Peak latite or Brewer Creek latite. The last two formations probably are barren because of their relatively high position in the lava series and their distance from the center of mineralization rather than to unfavorable characteristics of the rocks. The only ore of commercial importance found in the intrusive rocks is in the Eagle Gulch latite. The other intrusives consist of granite porphyry, diorite and monzonite dikes, and rhyolite and latite bodies.

The different country rocks have had no differential influence on the chemical processes affecting ore deposition, for there has been essentially no replacement of wall rock fragments within the faults or of the fissure walls by ore minerals. The principle effect of the various formations appears to be the mechanical influence which these rocks have had on the nature of openings along faults. The character of these openings and the amount of

Plate 6

BONANZA DISTRICT
COMPARISON OF PRODUCING FORMATIONS



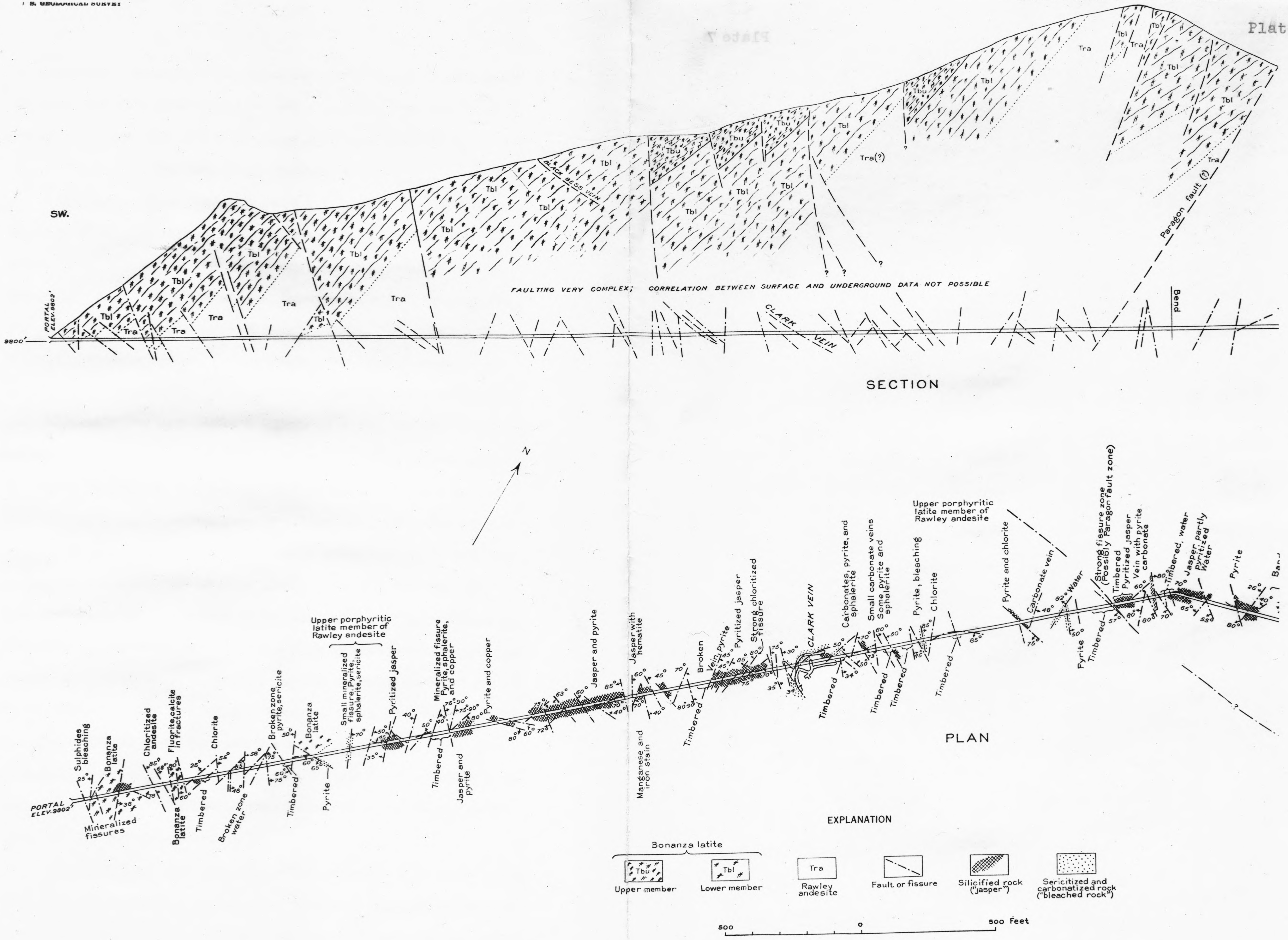
pre-mineral gouge which they contain have indirectly affected the processes of metallic mineral deposition. The andesitic lavas fracture most cleanly and have no flow planes or partings to influence the direction of fractures, so they were mechanically the most favorable rocks. The intense early silicification of the wall rocks favored the later formation of openings that were suitable for ore deposition; because the silicified rocks were very hard and brittle and fractures in them did not develop gouge but remained relatively permeable.

The veins occupy fault fissures produced in the rocks during their deformation, and the ore deposition has taken place largely as filling in the fissure zone. The ore bodies are often related to cross-faults and cross-fissures, but many appear to be fillings in open spaces formed by movement along a fissure of changing dip (see figure 4).

Evaluation of Lithologic Control

Data for the enclosed graph, plate 9, were obtained from Burbank and Henderson, 1932. The period covered is from 1880 to 1930. The figures for the total value of the district's production came from two sources: 1. Listed production values for various mines, 2. Approximated production values based on tonnage figures for several mines. Where sufficient information was not available no approximations were made.

In arriving at a figure for the length of mining activity or "mine years," it was necessary to divide the mines into three groups: 1. Mines with a record of mining years, 2. Mines without a record for either mining years or production. For each such mine described two years were added to the total, 3. Mines without a record of mining years but with a record of production. For



Burbank 1932, p.110

GEOLOGIC PLAN AND SECTION OF RAWLEY DRAINAGE TUNNEL each mine thus described two years were added to the total plus one year for each $5000 worth of ore produced. For the total number of mines, the number of mines described was taken.

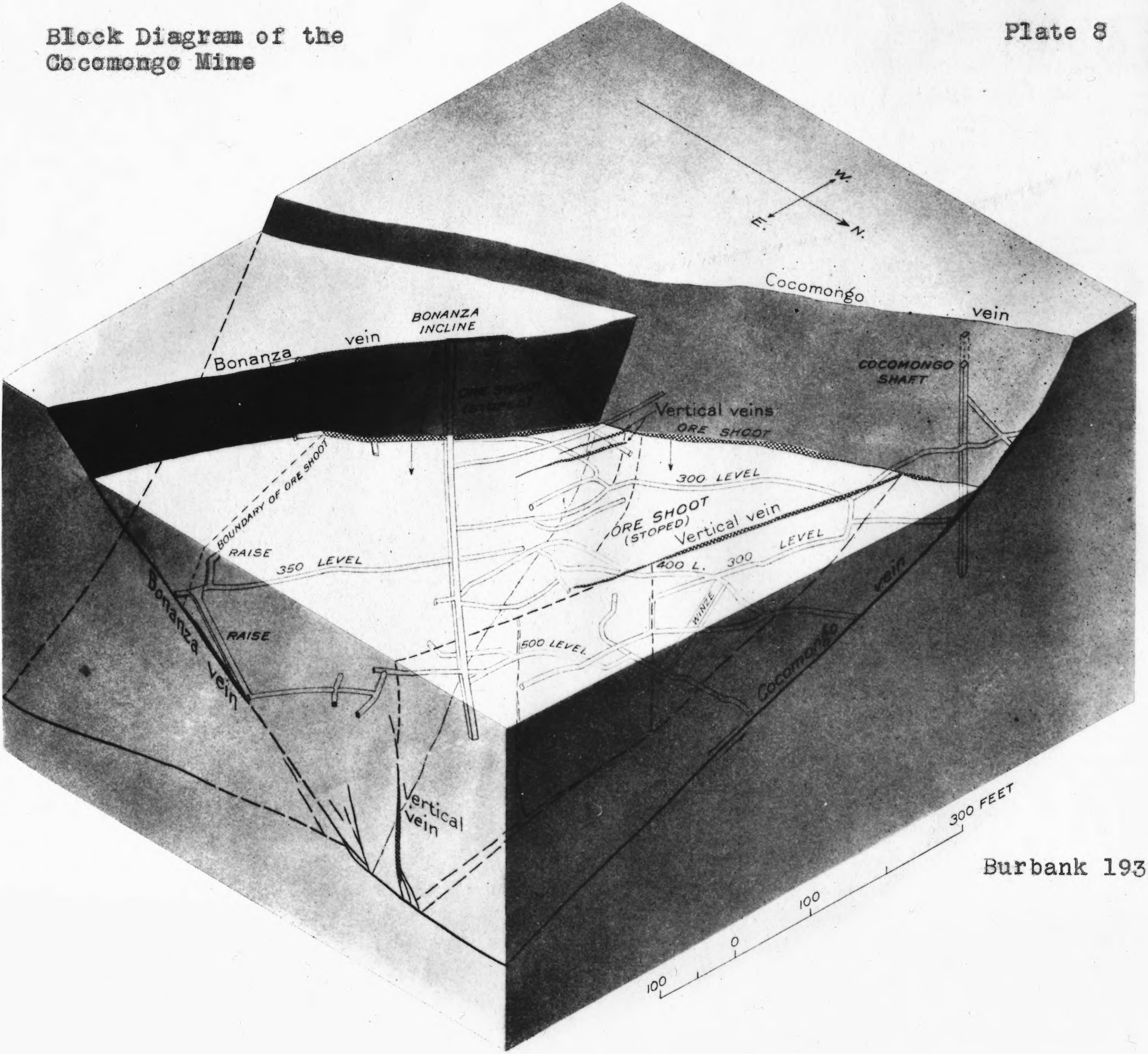
Ore Control in Typical Mines

The Rawley Mine 1880-1930.—The Rawley Mine has produced $5,500,000 of ore, representing 80 per cent of the Bonanza district total production (see plate 8). It is located on Rawley Gulch in the northern part of the Bonanza mining district. The ore minerals are pyrite, sphalerite, chalcopyrite, galena, bornite, enargite, tennantite and stromeyerite. The gangue consists of quartz, barite, calcite, rhodochrosite, manganiferous calcite and siderite. The vein shows a change in metal content from lead-silver-copper in the upper levels to predominately copper-silver at depth. Metals in descending order of value from the Rawley Mine production are: silver, copper, lead and gold. The mine is located on a north-south fault of small displacement in both the Rawley andesite and the Bonanza latite. The country rock is much broken up by two series of faults, one trending north-south, the other northeasterly. The ore bodies appear to be largely the result of filling of open spaces, for the ore bodies pinch out as the veins flatten and split. Movement along the Paragon fault has opened the Rawley vein, but the stresses were relieved progressively to the north away from the Paragon fault by minor fissures. The largest ore bodies, therefore, are found in the proximity of the Paragon fault.

The Cocomongo Mine 1910-1927.—The Cocomongo Mine is on Kerber Creek about one and a half miles north of the town of Bonanza. It has produced almost a half million dollars' worth of ore, repre-

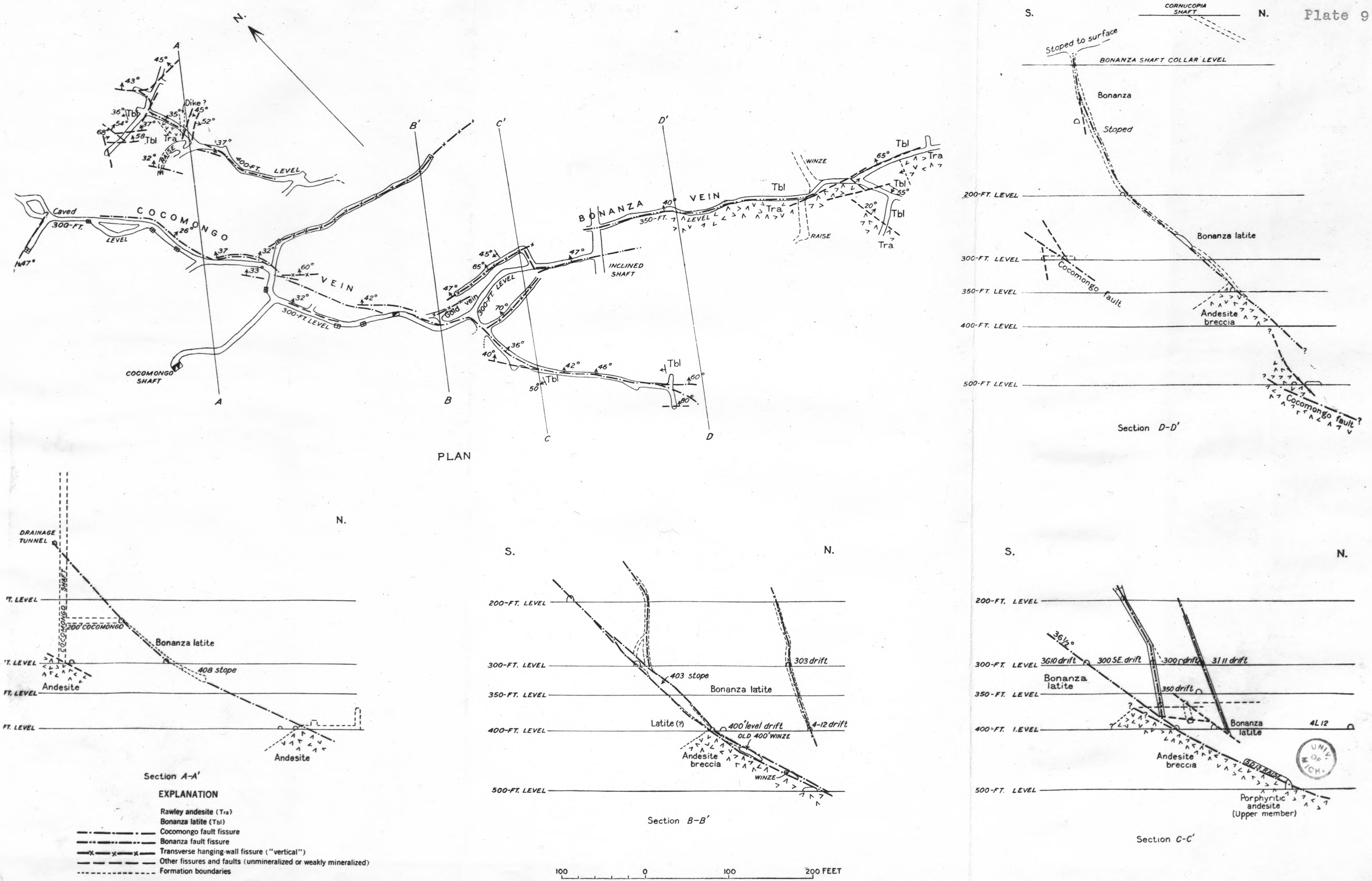
Block Diagram of the Cocomongo Mine

Plate 8



Burbank 1932, p.118

Plate 9



GEOLOGIC PLAN AND SECTIONS OF COCOMONGO AND BONANZA VEINS, COCOMONGO MINE

senting 7 per cent of Bonanza district production. The ore minerals are pyrite, sphalerite, galena, tennantite, chalcopyrite, stromeyerite and covellite. The gangue minerals are quartz, barite, rhodochrosite, manganocalcite, fluorite, rhodonite, and apatite. No consistant vertical zoning exists.
The Bonanza-Cocomongo vein system consists of two main mineralized faults and several related veins occupying fissures in the hanging walls of the main faults. The greater bulk of the ore that has been taken from these veins lay above the fourth level of the mine between walls of Bonanza latite. Below the fourth level the Rawley andesite has been cut in several places, and it forms at least one wall of the vein, usually the footwall. For the purpose of this report the Cocomongo Mine is considered to be entirely in the Bonanza latite.

The greatest amount of faulting appears to have occurred on the Cocomongo fault, which has an average strike of about N 30 W and an eastward dip which ranges from 47° in the upper levels to about 20° in the lowest. A wide high-grade lead-zinc ore body was found between the 300 and 400 foot levels just north of the Bonanza fissure (see figure 7, stope 403, cross-section B-B'). The differential movement between the hanging and the foot walls left an open space because the two adjacent walls were unconformable. However, the localization of this ore body may be due to the combined effect of change of dip and the intersection of the two fissures. However, other ore bodies of this vein system, like stope 408 in cross-section A-A', figure 7, appear to be definitely related to steepening of dip (see plate 7).

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